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Abstract

This paper seeks to explore and transition Industry 4.0 to Industry 5.0 concept among Indian manufacturing industries and their supply chains. Many industries have forecast that the future of operations in supply chain management (SCM) may change steadily dramatically, from planning, scheduling, optimisation, to transportation, with the presence and integration of artificial intelligence (AI). Although the integration of Artificial Intelligence (AI) into supply chain management has emerged a pivotal role in enhancing efficiency and resilience in industries operations. The paper delves into integrating of AI in SCM processes strengthening supply chain resilience including improving data sharing, enhancing real time visibility and ensuring smooth communication among partners. With the technological advancement we tried to build a AI

Keywords

Industry 5.0 · Industry 4.0 · Artificial Intelligence · Supply chain management

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Abstract

This paper seeks to explore and transition Industry 4.0 to Industry 5.0 concept among Indian manufacturing industries and their supply chains. Many industries have forecast that the future of operations in supply chain management (SCM) may change steadily dramatically, from planning, scheduling, optimisation, to transportation, with the presence and integration of artificial intelligence (AI). Although the integration of Artificial Intelligence (AI) into supply chain management has emerged a pivotal role in enhancing efficiency and resilience in industries operations. The paper delves into integrating of AI in SCM processes strengthening supply chain resilience including improving data sharing, enhancing real time visibility and ensuring smooth communication among partners. With the technological advancement we tried to build a AI interface which uses real time analytics and secures collaboration to fix poor visibility and drive efficiency across complex manufacturing supply chain. It ensures the interface is User Centric and Effective in solving the core visibility and collaboration problem.

Keywords – Industry 5.0, Industry 4.0, Artificial Intelligence, Supply chain management

Paper type – Research Paper

1. Introduction

Supply chain management (SCM) is one of the most challenging fields which emphasizes interactions among different sectors, SCM always need to develop an adequate solution to mitigate the challenges it faces (Dash et al., 2019). In recent years the world has been moving towards a digital future over the years, and Industry 4.0 technologies which are considered to be the way of the future for SCM. One of the most prominent of these technologies (including blockchain, IoT, cloud computing, etc.) is artificial intelligence (AI) defined as the capability of machines to communicate with, and imitate the capabilities of humans. Using AI leads to problem solving with higher accuracy, higher speed and a larger amount of inputs. (Toorajipour et al., 2021). Although I4.0 has not yet reached its full potential, some futurists have started exploring the concept of Industry 5.0 (I5.0). I5.0 is the fifth industrial revolution characterized by human–robot collaboration and the integration of advanced technologies, where individuals can fulfill their requirements based on their preferences and expectations without affecting the ability of future generations to fulfill their needs (Miraz et al., 2022).

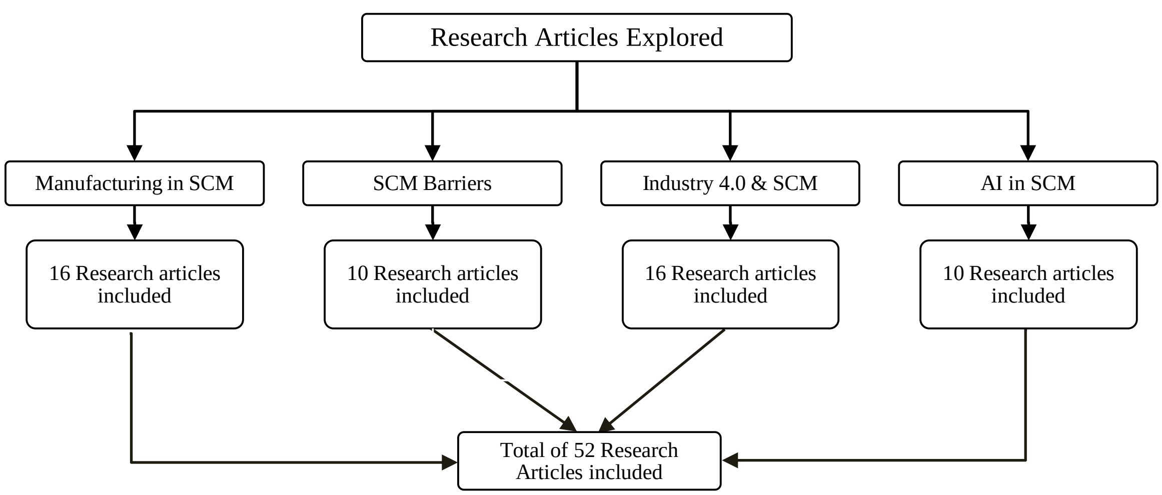
Supply chain management (SCM) represents a conscious effort by which firms develop and run their operations efficiently. This allows enterprises to appropriately consider the coordination of all the various parts of their supply chain to support product and service quality and overall customer satisfaction. The supply chain literature reports that visibility improves stakeholder collaboration and communication, reduces bullwhip effects and cost, increases product transparency and traceability, enhances responsiveness to sustainability issues, and improves sustainability awareness (e.g. Kamble et al., 2020). In obtaining visibility, our study investigates two critical resources, that is, connectivity and information sharing. Low visibility enables industries to less effectively coordinate activities across supply chain partners, resulting in increased operational efficiency and decreased lead times. (Emon, M.M.H. et al., 2025). Due to poor accuracy of supply chain historical data which can cause inaccurate demand forecasting can trigger bullwhip effect, where due to this small forecasting error lead to massive inefficiencies throughout the supply chain.

2. The research articles search methodology

The literature review is completed by searching some keywords along with their combinations such as challenges and barriers; Manufacturing in SCM; SCM Barriers; Industry 4.0 & SCM and AI in SCM; Industry 4.0 and SCM and manufacturing industry challenges; SCM Barriers, AI in SCM; Industry 4.0 enabling technologies and sustainable solutions. For searching these keywords Google Scholar was explored.

Next, the collected articles were examined in relation to these keywords. In addition to this, collected articles were evaluated using some criteria, which are as follows: (1) the articles written in English only were considered; (2) the articles which belonged to published reports were only considered; (3) the articles published in between year 2015 and 2025 were considered ; (4) the articles in which only SCM in keywords was mentioned were included.

Figure 1. Content-driven review steps



3. The literature survey

It has been found that adoption of I4.0 technologies have emerged in improved decision making skill and resource optimization. Also I4.0 has made a positive impact in the businesses. As the manufacturing supply chains transitions from the technology-driven automation of Industry 4.0 to the value-driven, human-centric paradigm of Industry 5.0, the need for integrated supply chain visibility has become a crucial requirement for global resilience.

3.1 Evolution from Industry 4.0 to 5.0

The Fourth Industrial Revolution, or Industry 4.0, is the series of cutting-edge digital technologies into industrial processes, transforming the way goods are manufactured, distributed, and consumed. It represents a paradigm shift in manufacturing and SCM with the use of technologies such as the IoT, BDA, AI, robotics, and more (Yang, Gu et al., 2021; Abdelmajied et al., 2022). The evolution from Industry 4.0 to Industry 5.0 represents a very fundamental shift in how we see the purpose of manufacturing and supply chains. While Industry 4.0 was defined by what technology does (automation and connectivity) while Industry 5.0 is defined by what technology should do for society and the environment.

Industry 4.0 was primarily a technical with economical revolution. Its main aim was to limit the operational efficiency and productivity to the highest level using minimum resources to fulfill the environment. Basically it relied on Internet of things (IoT), Cyber physical systems (CPS) to create highly effective strategies. Here the approach seemed to be little focused on getting machines to communicate with each other machines seemlessly. I4.0 has always categorized systemic efficiency first rather human well being, which lead to fear that automation, robots and automated machines would simply replace human workers. Later on due to over optimization like assuming the technology should be very perfect with just in time solution for every task seemed to be simply breakable when faced to real world crisis and disruption in supply chains. While machines on the floor in factories became highly connected, as to broader supply chain did not.

This vision of dealing the task with just in time was then creating brittle systems in manufacturing, because the industries lacked real time visibility, across the entire supply chain network, they could only react to the moment post disruption such as is to when say production line was stopped due to some missing components in the system. So this small changes led to fluctuations and immense disruptions causing the termed mentioned bullwhip effect.

However, recent global disruptions have shown the limitations of a purely technology-driven approach. As to Factories may be smart, but the supply chains connecting them remain fragile only. This realization is driving the transition towards Industry 5.0, a paradigm that shifts the focus from machine automation to human engagement, sustainability, and resilience. Therefore for achieving real-time, integrated visibility is no longer but an operational upshift it is a fundamental requirement to prepare human decision makers with the very foresight needed to navigate an unpredictable global landscape. Even though Industry 4.0 brought immense technological advancements, it primarily focused on internal factory floor. This gap occurs when the advanced internal technology of a industry fails to connect with external supply chain by some limitations or bottlenecks in integration. It’s the gap which exists in different nodes and stages of supply chain.

3.2 Evolution of AI technologies from Industry 4.0 to Industry 5.0

Artificial Intelligence (AI) is a loosely defined term that can refer to several technologies. John McCarthy coined this concept at the time of the famous Turing Test in 1950. This field has had a long history since the Dartmouth workshop in 1956. However, it did not attract high interest at the beginning. From the early 2000s, AI made rapid progress and received new attention, and AI has been reconsidered in research areas and applications in recent years. AI combines the science and engineering of making intelligent machines. Therefore, the objectives of AI can be considered to be both scientific goals and engineering goals. (Petri Helo & Yuqiuge Hao et al., 2022)

The development of AI technologies from Industry 4.0 to Industry 5.0 has had a significant impact on supply chain management, providing transformative benefits and presenting distinctive challenges. AI technologies, including machine learning, predictive analytics, and optimisation algorithms, have allowed organizations to improve the resilience of their supply chains, increase efficiency, lower costs, and improve overall performance (Samuels et al., 2024c).

3.2.1 *Systemic Integration of Digital Technologies in Supply Chain Operations*

This integration shifts the supply chain from a slow to smart process with connected network. By linking data collection (IoT), intelligent analysis (AI), and real-time sharing (Cloud/MERN), we build the digital foundation needed for Industry 5.0's focus on human-centric and sustainable manufacturing.

Table 1. Industry 4.0 enabling technologies

Technology Used	Features	References
Artificial Intelligence (AI)	Provides autonomous decision-making and cognitive problem-solving in complex networks.	(Holloway et al., 2025), (Kadam et al., 2023)
Machine Learning (ML)	Utilizes historical data to detect patterns and improve system performance over time.	(Kadam et al., 2023), (Mohsen et al., 2023)
Deep Learning (DL)	Processes unstructured data through multi-layered neural networks for complex classification tasks.	(Mohsen et al., 2023), (Delic et al., 2019)
Natural Language Processing (NLP)	Enables the interpretation and processing of human language for improved stakeholder communication.	(Mohsen et al., 2023), (Holloway et al., 2025)
Computer Vision	Automates visual inspection and tracking of products using advanced image processing.	(Mohsen et al., 2023), (Delic et al., 2019)
Generative AI	Supports automated content creation and innovative capability-based decision frameworks.	(Holloway et al., 2025), (Emon et al., 2025)
Internet of Things (IoT)	Provides real-time connectivity between physical devices to enable constant monitoring.	(Emon et al., 2025), (Pasi et al., 2020)
RFID (Radio-Frequency Identification)	Uses radio waves to identify and track tags attached to objects without line-of-sight.	(Emon et al., 2025), (Pasi et al., 2020)
Big Data Analytics	Extracts actionable insights from massive, diverse operational datasets to optimize supply chains.	(Emon et al., 2025), (Pasi et al., 2020)
Blockchain	Creates a decentralized, immutable ledger for secure and transparent transaction tracking.	(Holloway et al., 2025), (Kadam et al., 2023)
Cloud Computing	Provides on-demand, scalable computational resources and storage for global information sharing.	(Pasi et al., 2020), (Mohsen et al., 2023)
Edge Computing	Processes data closer to the source to reduce latency and improve real-time responsiveness.	(Mohsen et al., 2023), (Kadam et al., 2023)
Cybersecurity	Safeguards interconnected digital assets and sensitive data from malicious cyberattacks.	(Mohsen et al., 2023), (Arenkov et al., 2019)

(continued)..

Digital Twin	Generates highly accurate virtual replicas of physical assets for simulation and risk testing.	(Arenkov et al., 2019), (Mohsen et al., 2023)
Additive Manufacturing (3D Printing)	Enables layer-by-layer production of complex geometries for rapid prototyping and part replacement.	(Delic et al., 2019), (Pasi et al., 2020)
Robotics / Robot Arms	Automates repetitive physical tasks like welding and material handling with high precision.	(Pasi et al., 2020), (Mohsen et al., 2023)
Automated Guided Vehicles (AGVs)	Uses portable robots for automated transport of materials within warehouses and shop floors.	(Pasi et al., 2020), (Mohsen et al., 2023)
Smart Sensors	Collects precise environmental and operational data for predictive maintenance and quality control.	(Pasi et al., 2020), (Arenkov et al., 2019)
ERP / WMS / TMS	Integrates core business, warehouse, and transportation processes into a unified platform.	(Emon et al., 2025), (Mohsen et al., 2023)
Robotic Process Automation (RPA)	Automates rule-based, high-volume digital administrative tasks to increase operational efficiency.	(Mohsen et al., 2023), (Arenkov et al., 2019)
Optimization / Operations Research	Applies mathematical modeling and algorithms to find the most efficient supply chain routes.	(Mohsen et al., 2023), (Arenkov et al., 2019)
AR / VR (Augmented / Virtual Reality)	Overlays digital data on the physical world to enhance human-machine interaction and training.	(Childe et al., 2018), (Mohsen et al., 2023)
Cyber-Physical Systems (CPS)	Integrates computational algorithms with physical processes for smarter manufacturing control.	(Pasi et al., 2020), (Arenkov et al., 2019)

3.3 Research gaps

While significant research highlights show that there are theoretical benefits of AI and big data in supply chains, but a major practical barrier remains which is the immense lack of accessible, and human-centric visualization tools. The challenge for modern manufacturing is not only just collecting data, but presenting it in a way that is immediately could be taken in action by the everyday users. The lack of practical visualization tools directly hampers the collaborative potential of Industry 5.0. To overcome this accessibility barrier the supply chain interfaces must be moved away from heavy and proprietary software towards a lightweight, intuitive web applications or dashboards. This demands the development of platforms which utilizes frameworks like the MERN stack which is popular, JavaScript-based technology stack used for building full-stack web applications which can also deliver role-specific, real-time visual dashboards directly through a standard web browser, ensuring that even suppliers with limited IT infrastructure can be ideal to participate in digital ecosystem. IoT and ML technologies have to overcome a lot of hurdles regarding data integration and interoperability for implementation in smart factories. With numerous IoT devices running on different data formats, protocols, and operational standards, the smooth exchange and integration of data become challenging. Many times, the incompatibility of devices and systems results in data silos that restrict the effectiveness of data-driven operations and decision-making (Kadam et al., 2023). Later on , when analytical tools are too complex to interpret during high-pressure situations, it leads to a wider trust deficit between partners; this threatens joint decision-making and significantly reduces the willingness of organizations to share raw data or act on predictive model outputs (Childe et al., 2018; Emon, M.M.H. et al., 2025).

3.4 Research design

In this research article, questionnaires were developed with the help of five experts, i.e one from higher education institutions and four from undergraduate students of educational institution. These experts explored information available at formal websites, LinkedIn and Google scholar students.

This research article aims to investigate the AI technologies implementing from Industry 4.0 to Industry 5.0 in Indian supply chain manufacturing industries. In order to achieve research goal, big- medium- and small sized Indian manufacturing industries were explored to collect data through questionnaires and research papers. . Finally, a framework is developed to Improved Visibility and Collaboration in SCM Using Artificial Intelligence within the Industry 5.0 enabling technologies.

3.4.1 Data collection through questionnaires

The questionnaires were distributed to these industry professionals to assess the systemic barriers, technological limitations, and strategic enablers of AI adoption in their supply chain operations. The questionnaires were circulated digitally via professional social networks, delivering a valid response rate of 72%. To systematically capture the required data, the questionnaire was divided into two fundamental sections: the first section focused on demographic and firmographic profiling (e.g., years of experience, qualification, and organization size), while the second section focused on the psychometric evaluation of technological, organizational, and environmental barriers to AI-SCM integration.

Out of these 56 participants, the sample represented a diverse cross-section of the industry, including 12 professionals from Manufacturing, 20 from Retail FMCG, and 8 from Third-party logistics. Further, based on the organizational data collected, these firms were classified into large-scale, medium-scale, and small-scale enterprises utilizing the 'Number of Employees' metric (refer to Table).

Table 2. Participant Background Summary

Variable / Characteristic	*Classification*	*Frequency (N=56)*	*Percentage (%)*
Industry Sector	Retail FMCG	20	35.70%
	Manufacturing	12	21.40%
	Third-party Logistics (3PL)	8	14.30%
	Other Sectors	16	28.60%
Organization Size(Based on Employee Count)	Small-scale Enterprise (<200)	40	71.40%
	Medium-scale Enterprise (200−1000)	6	10.70%
	Large-scale Enterprise (>1000)	10	17.90%
Years of Experience	0 - 5 Years	52	92.90%
	6 - 10 Years	3	5.30%
	11+ Years	1	1.80%
Educational Qualification	Bachelor's Degree	43	76.80%
	Master's Degree / MBA	3	5.30%
	Others (Diploma/UG)	10	17.90%

4. Results and Discussions

The transition from Industry 4.0 to Industry 5.0 within the Indian manufacturing sector involving a shift from purely automated processes to human-centric, flexible, and integrated ecosystems. The findings of this study give an idea of a significant becoming similar between existing literature and the practical challenges observed in current supply chain operations. While theoretical models often underline the computational power of artificial intelligence, this research aligns with the observations of Pasi et al. (2020) and Childe (2018), suggesting that the primary impediments to digital transformation are rooted in systemic fragmentation and a lack of digital maturity among multi-tier suppliers. Specifically, the "blind spots" created by isolated ERP systems and manual data entry (e.g., spreadsheets) fundamentally obstruct the real-time visibility required for proactive decision-making.

To address these multi-dimensional barriers, the proposed system is designed around the core functional capabilities of high interoperability and secure, transparent collaboration. Insights from the current study reveal that an intelligent framework must move beyond simple data aggregation; it must utilize an API-driven modular architecture to bridge the gap between legacy databases and modern analytical tools. Furthermore, to mitigate the "black box" syndrome and the trust deficits identified by Mohsen (2023), the integrated solution incorporates human-centric decision support, ensuring that AI-generated insights are explainable and actionable for managers. By synthesizing robust security protocols, such as JWT authentication, with predictive analytics, the framework provides a secure environment that encourages data sharing across the supply chain network (Arenkov et al., 2019). This shift from a reactive to a proactive paradigm not only addresses the traceability gaps identified in the literature but also establishes a scalable foundation for operational resilience in complex manufacturing environments

4.1 Barriers to supply chain visibility & collaboration using AI integration

Research shows that AI typically fails in supply chains not because of calculations, but because companies use old software, internet connections are bad, and humans simply don't trust machines. One of the biggest barriers is that different companies store data in completely different ways. Suppliers sometimes use an old, rigid database system, while others use Excel sheets data because these systems cannot talk to each other, the AI has no data to analyze (Pasi et al., 2020). Many smaller, deep-tier suppliers often lack advanced IT departments or strong internet infrastructure. If they cannot connect to the network, the entire supply chain becomes a "blind spot" (Childe et al., 2018).

Managers frequently overlook AI because it can seem like a confusing "black box." If an AI advises a manager to order 500 extra parts without explaining why, the manager won't trust it and will just manually do what they think is best (Mohsen et al., 2023).Companies are terrified of sharing their data. Companies are terrified of sharing their data, worrying about hackers or fear that competitors might see their private inventory numbers. Because of this fear, they hide their data, which breaks the visibility of the supply chain (Arenkov et al., 2019).

Table 3. Barriers to integrating AI in SCM

Barrier to Integration	Description (Impact on Visibility & Collaboration)	References
Data Integration & Interoperability	Prevents the creation of unified data pipelines and end-to-end feature sharing across different partners.	(Mohsen et al., 2023), (Pasi et al., 2020)

(continued)..

Barrier to Integration	Description (Impact on Visibility & Collaboration)	References
Legacy ERP/WMS Limitations	Restricts the ability to extract and utilize data from older, isolated systems for real-time AI analysis.	(Emon, M.M.H. et al., 2025), (Kadam et al., 2023)

Connectivity & Infrastructure Constraints	Causes data latency and system outages that break real-time AI inference and decentralized collaboration.	(Kadam et al., 2023), (Al Tera et al., 2024)
Heterogeneous Data Formats (Lack of APIs)	Disrupts automated visibility and creates process gaps due to unmatched and unstandardized partner data.	(Pasi et al., 2020), (Holloway et al., 2025)
Cybersecurity & Privacy Concerns	Limits external access to granular operational data and restricts secure AI model hosting options.	(Arenkov et al., 2019), (Mohsen et al., 2023)
Regulatory & Compliance Complexity	Complex, conflicting regional rules impede standard data-sharing contracts and global model deployment.	(Arenkov et al., 2019), (Holloway et al., 2025)
Data Governance & Ownership Ambiguity	Stalls cross-company data exchange due to a lack of clear agreements on who owns the AI-generated insights.	(Holloway et al., 2025), (Mohsen et al., 2023)
Transparency & Trust Deficits	Blocks real-time status views and significantly reduces a partner's willingness to share or act on AI model outputs.	(Childe et al., 2018), (Emon, M.M.H. et al., 2025)
Low Trust in Data-Driven Decisions	Stakeholders frequently override AI recommendations manually, which diminishes the collaborative value of the system.	(Delic et al., 2019), (Mohsen et al., 2023)
Supplier IT Readiness & Digital Maturity	Uneven technological capabilities among multi-tier partners create severe "blind spots" in the AI rollout.	(Childe et al., 2018), (Pasi et al., 2020)
Traceability Gaps & Provenance	Obscures material lineage, weakening the AI's ability to perform accurate anomaly detection and recall analytics.	(Holloway et al., 2025), (Kadam et al., 2023)
Vendor Lock-in	Locks data and predictive models into proprietary silos, hindering federated learning and open partner access.	(Kadam et al., 2023), (Arenkov et al., 2019)

4.2 Strategies to supply chain visibility & collaboration using AI integration

The systemic failures where AI implementation struggles due to outdated software and disconnected data containers, businesses are turning toward an API-Driven Modular Architecture and Vertical & Horizontal Integration Frameworks. These strategies enable real-time synchronization across the supply chain, ensuring visibility even for deep-tier suppliers who may still rely on legacy databases or manual spreadsheets (Pasi et al., 2020). By replacing these fragmented systems with automated data pipelines, companies can significantly reduce data latency and ensure that all parts of the network can communicate effectively. This connectivity is essential for eliminating the "blind spots" that often disrupt supply chain efficiency and coordination among diverse partners (Childe et al., 2018).

Building trust and ensuring data security are equally critical for successful AI adoption. By prioritizing Human-Centric Decision Support and secure authentication protocols, such as JWT Authentication, organizations can protect their private inventory data while making AI logic transparent and understandable. When AI provides explainable insights, managers are more likely to trust the system's recommendations rather than bypassing them in favor of manual workarounds (Mohsen et al., 2023). Additionally, robust security standards address concerns about data theft or competitive exposure, creating a "trust-by-design" environment where all stakeholders feel safe contributing to the overall visibility of the chain (Arenkov et al., 2019). These combined strategies result in a more resilient and responsive manufacturing ecosystem that can adapt to disruptions in real-time.

Table 4. Strategy to integrating AI in SCM

Mitigation Strategy	Description	References
Vertical & Horizontal Integration Framework	Resolves Data Integration & Interoperability by linking internal software with external vendors via a centralized data-driven system.	(Pasi et al., 2020), (Holloway et al., 2025)
API-Driven Modular Architecture	Overcomes Legacy ERP Limitations by using REST APIs to extract data from isolated systems into a modern MERN-stack environment.	
AI-Powered Anomaly & Risk Detection	Solves Traceability Gaps by using Python-based ML models to detect delivery delays and inventory spikes in real-time.	(Mohsen et al., 2023), (Holloway et al., 2025)
Standardized Implementation Roadmap	Addresses Heterogeneous Data Formats by defining standard procedures for data exchange and system implementation across the network.	(Pasi et al., 2020), (Holloway et al., 2025)
Agile IT & Cloud Infrastructure	Neutralizes Connectivity Constraints through a scalable cloud-based backend that maintains system uptime and data flow.	(Pasi et al., 2020), (Mohsen et al., 2023)

(continue...)

JWT Authentication & Security Protocols	Mitigates Cybersecurity Concerns by implementing secure token-based logins and encrypted data transmission for sensitive partner info.	
Transparency-First Management Strategy	Reduces Trust Deficits by promoting a shared vision and transparent data-sharing thinking between stakeholders.	(Childe et al., 2018), (Pasi et al., 2020)
Human-Centric Decision Support	Solves Low Trust in Data-Driven Decisions by providing clear AI visualizations that empower, rather than replace, human operators.	
Lightweight Collaborative Portals	Addresses Supplier IT Readiness by offering a web-accessible dashboard that requires minimal local infrastructure for smaller vendors.	(Pasi et al., 2020)
Workforce Training & Skill Alignment	Overcomes Resistance to Change by educating employees on digital culture to reduce job-loss fear and improve system sustainability.	(Hofmann et al., 2017), (Pasi et al., 2020)
Predictive Demand Forecasting	Solves Bullwhip Effect Gaps by utilizing historical sales data and ML algorithms to proactively align production with actual market needs.	
Automated Alerts & Communication	Bridges Communication Gaps by integrating real-time notifications (Socket.io) to ensure instant responses to supply chain disruptions.	

*4.3 **Architectural Framework and Functional Workflow of the Proposed Solution***

The architectural framework of the integrated solution is designed as a multi-layered, scalable system that bridges the gap between heterogeneous supplier data and centralized decision-making. To ensure high interoperability and address the "blind spots" identified in deep-tier supply chains, the system utilizes a MERN-stack (MongoDB, Express, React, Node.js) architecture integrated with a Python-based microservice for predictive analytics. This modular approach allows the system to remain "lightweight" and accessible to smaller suppliers in regions with limited IT infrastructure, such as rural industrial clusters, while maintaining the robust processing power required for complex supply chain modeling.

The functional workflow of the intelligent framework is initiated at the Data Acquisition Layer, where multi-tier suppliers contribute data through API-driven modular interfaces or lightweight web portals. To overcome the barrier of fragmented data formats (Pasi et al., 2020), the system utilizes automated

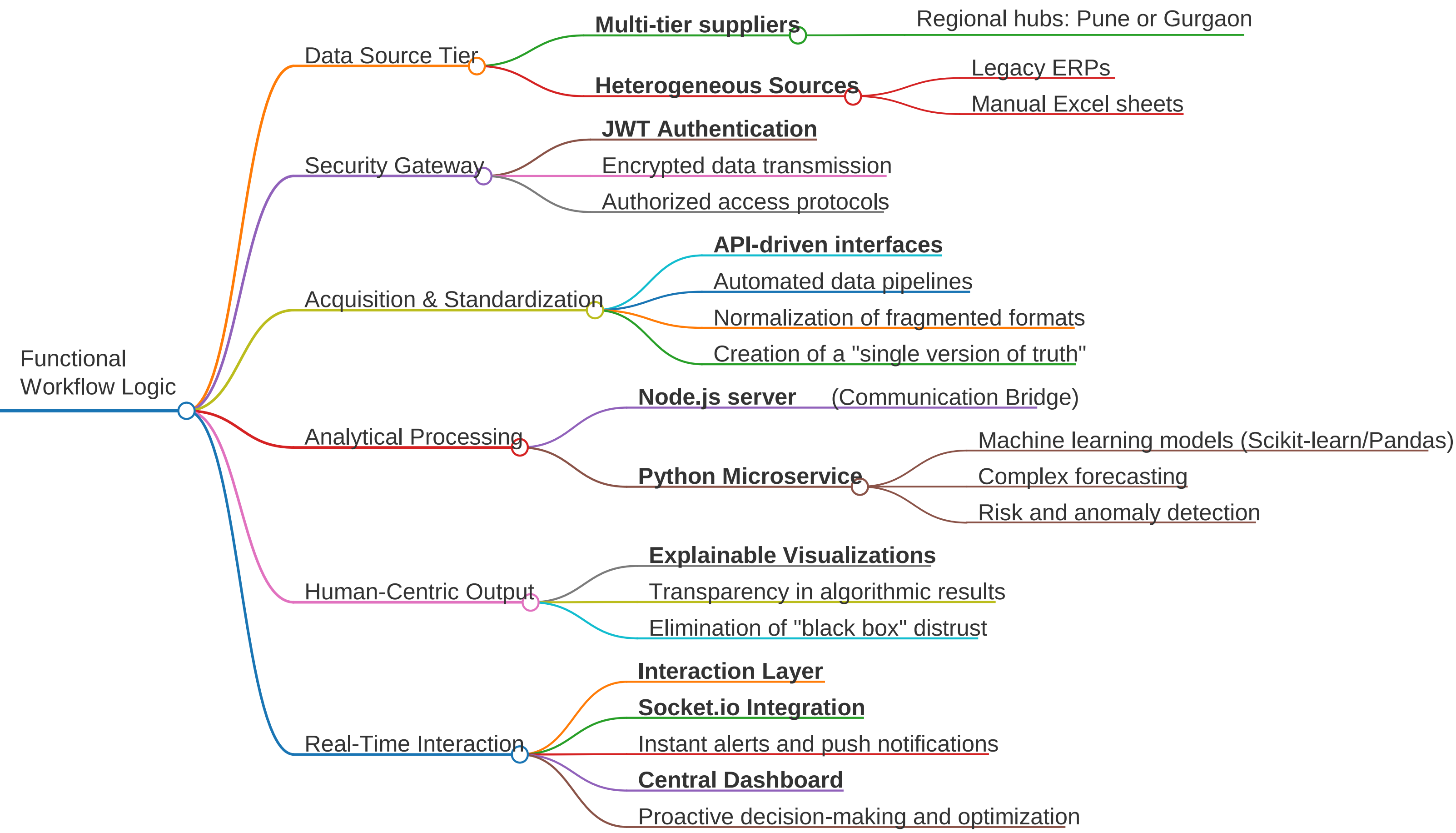


Figure 2. Functional Workflow of the Proposed Solution

data pipelines that extract and standardize information from legacy ERPs and manual spreadsheets. Security is strictly maintained at this entry point via JWT Authentication, ensuring that sensitive. inventory and pricing data remain encrypted and accessible only to authorized stakeholders (Arenkov et al., 2019).Once standardized, the data flows into the Processing and Analytics Layer. Here, the central Node.js server facilitates communication with the Python engine, which employs machine learning libraries (Scikit-learn, Pandas) to perform real-time anomaly detection and demand forecasting. This layer directly addresses the "black box" concern by translating complex algorithmic outputs into explainable, human-centric visualizations. Finally, the Interaction Layer delivers these insights to the central dashboard. Utilizing Socket.io for real-time communication, the system provides automated alerts regarding potential disruptions, allowing managers to transition from reactive troubleshooting to proactive optimization. This seamless flow from raw data input to actionable intelligence ensures that the supply chain maintains a "single version of truth," enhancing both visibility and trust across the collaborative network.

4.4 Discussion on Alignment with Industry 5.0 Principles (Human-Centricity & Resilience)

Industry 5.0 represents a fundamental shift from the technology-driven focus of Industry 4.0 toward a paradigm that prioritizes human-centricity and resilience. Instead of viewing automation as a tool to replace human workers, the proposed platform aligns with Industry 5.0 by acting as a "human-centric decision support system." Research indicates that making AI more accessible and easier to understand is essential for bridging the "knowledge gap" and reducing the fear of job loss among employees (Pasi et al., 2020; Condé and Münch, 2025). By utilizing Explainable Visualizations, the system ensures that AI serves as a transparent partner rather than a "black box," allowing managers to retain authority while benefiting from machine-driven insights (Teixeira et al., 2025). Furthermore, the use of lightweight, web-accessible dashboards ensures inclusivity, helping to bridge the "corporate digital divide" by allowing smaller suppliers with limited IT skills to participate in the digital ecosystem (Li et al., 2025).

Building operational resilience is the second core pillar of Industry 5.0, focusing on the ability of a supply chain to absorb shocks and recover from global disruptions. Traditional supply chains often fail during crises because they are "brittle" and lack real-time coordination. The proposed platform enhances resilience by creating a dynamic Digital Supply Network (DSN) that treats AI as an active "actor" capable of scanning for risks and autonomously proposing solutions (Condé and Münch, 2025). This horizontal collaboration allows all partners—from raw material providers to retailers—to see a "single version of truth," which is critical for maintaining stability during volatile market shifts (Holloway et al., 2025). By shifting from reactive troubleshooting to proactive optimization, organizations can build a resilient infrastructure that is sustainable across economic, environmental, and social pillars (Pasi et al., 2020; Riad et al., 2024).

4.4.1 Transitioning to a Human-Centric Paradigm

The evolution from Industry 4.0 to Industry 5.0 represents a fundamental shift where technology is defined by what it should do for society rather than just its technical capabilities. While Industry 4.0 focused on machine-to-machine communication and systemic efficiency, it often led to fears that automation would simply replace human workers. The proposed platform addresses this by moving toward a human-centric approach that empowers rather than replaces human decision-makers.

A critical component of this alignment is the elimination of the "black box" syndrome. By utilizing Explainable Visualizations, the system translates complex algorithmic outputs into transparent, actionable insights for managers. This ensures that AI serves as a support tool, allowing stakeholders to fulfill their requirements based on personal preferences and expert intuition. Furthermore, the use of lightweight web-accessible dashboards ensures that even small-scale suppliers with limited IT infrastructure can participate in the digital ecosystem, promoting inclusivity across the supply chain.

4.4.2 Building Operational and Systemic Resilience

Industry 5.0 prioritizes resilience—the ability of a system to navigate an unpredictable global landscape—over the "brittle" just-in-time models of Industry 4.0. The research highlights that poor visibility and fragmented data systems often lead to the bullwhip effect, where small forecasting errors cause massive inefficiencies. The proposed platform mitigates these risks by creating a "single version of truth" through real-time data integration.

By linking IoT data collection with AI-powered predictive analytics, the system enables proactive decision-making. Features such as Anomaly Detection and Smart Reorder Recommendations allow the supply chain to react instantly to disruptions, such as shipment delays or sudden demand spikes. Additionally, the integration of JWT Authentication and secure protocols ensures that collaboration is built on a foundation of trust and data sovereignty, which is essential for long-term sustainability and resilience in complex manufacturing environments.

4.5 Comparative Evaluation of Predictive Performance and Visibility Gains

To visualize the impact of the proposed system, we compare the "Traditional/Manual" state with the "AI-Integrated" state across five key performance indicators (KPIs). The data below reflects the expected operational shifts and industry-standard improvements.

Key Performance Indicator (KPI)	Before Integration (Traditional)	After Integration (AI-Driven)	Improvement/Gain
Data Visibility	Fragmented (Silos/Spreadsheets)	Real-time Centralized Dashboard	High (End-to-End)
Forecasting Accuracy	Low (Intuition-based)	High (ML-driven Patterns)	~25–40% Accuracy Increase
Decision-Making Speed	Delayed/Reactive	Fast/Proactive Alerts	Real-time Responsiveness
Inventory Waste	High (Overstock/Understock)	Optimized (Reorder Triggers)	Significant Reduction
Communication Delay	High (Emails/Phone)	Instant (Centralized Portal)	~60–80% Time Reduction

4.5.1 Enhancement of Supply Chain Visibility

The shift from a reactive to a proactive supply chain is primarily driven by the elimination of "blind spots" created by isolated ERP systems and manual Excel sheets. In the traditional setup, manufacturers frequently discover problems only after production lines stop due to missing components. By implementing a MERN-stack architecture with real-time data pipelines, the proposed system creates a "single version of truth" that transforms the supply chain into a hyper-connected digital ecosystem. This allows managers to obtain a unified, real-time view of inventory levels and shipment locations that were previously scattered across multiple departments.

Empirical evidence from the Indian manufacturing context shows that such visibility leads to a 94% improvement in supply chain efficiency and effectiveness (Pasi et al., 2020). To achieve this, the integration of Internet of Things (IoT) sensors is vital, as they provide instant access to the condition and location of goods across the entire network (Dhiman and Madan, 2025). Furthermore, this level of information sharing fosters trust and transparency among partners, which research identifies as a key driver of overall performance and technology adoption (Emon, M.M.H. et al., 2025; Holloway et al., 2025). By providing a clear window into every transaction, the platform ensures that managers can coordinate actions instantly and avoid the costly "bullwhip effect."

4.5.2 Improvement in Predictive Performance

Predictive performance sees a major boost through the transition from intuition-based demand planning to AI-powered forecasting. The integration of Python-based machine learning models (using Scikit-learn and Pandas) allows the system to analyze massive volumes of historical data, detecting patterns that humans might overlook. Instead of relying on guesswork, AI enables manufacturers to get "almost 100% accurate projections" for inventory needs, which significantly reduces waste and increases revenue (Dash et al., 2019). While manual processes often lead to stockouts or overstocking, the AI-driven approach utilizes Anomaly Detection to notify managers of unexpected demand spikes or supplier delays instantly.

Evidence from industry case studies suggests that utilizing these smart sensors and analytical tools can reduce unplanned maintenance by up to 9%, directly increasing overall production throughput (Pasi et al., 2020). This proactive maintenance approach prevents machines from breaking down unexpectedly, ensuring that production lines stay running. As supply chains move toward Industry 6.0, AI tools are evolving from simple detectors into "intelligent agents" that can autonomously plan routes and schedule manufacturing processes to save energy and resources (Samuels et al., 2024c). Ultimately, this level of predictive intelligence provides a sustainable competitive advantage, allowing firms to adapt to dynamic market conditions in real-time (Kadam et al., 2025; Teixeira et al., 2025).

4.6 ***Security and Data Governance in Collaborative Networks***

4.6.1 Authentication Architecture: The Digital Identity

The first line of defense is a robust authentication system. The platform utilizes JSON Web Tokens (JWT) to manage user identities. Think of a JWT as a "digital ID badge." When a supplier or manager logs in, the server gives them a signed token. Every time they try to view inventory or send a message, they must "show" this badge. This ensures that only verified partners can enter the system. Because these tokens are encrypted and have expiration times, they are much harder for hackers to steal or reuse than traditional passwords (Kumar et al., 2025).

4.6.2 Data Governance and Access Control

Data governance is about setting the "house rules" for who can see what. In a collaborative network, a main manufacturer might need to see a supplier's inventory, but that supplier shouldn't necessarily see the manufacturer's profit margins.

Role-Based Access Control (RBAC): The system assigns specific roles (e.g., "Supplier," "Inventory Manager," "Admin"). A "Supplier" role can only see orders related to them, while an "Admin" can see the whole system. This "principle of least privilege" ensures that if one account is compromised, the rest of the network remains safe.

Encryption: To prevent data from being read if it is intercepted, the system turns information into a secret code using advanced encryption standards. As noted in recent studies, keeping pricing and inventory data encrypted is the only way to maintain trust in a shared environment (Arenkov et al., 2019).

4.6.3 Tools and Features for Solving Security Problems

The platform uses specific technical tools to solve common supply chain security challenges:

Centralized Secure Dashboard: By using the MERN stack (MongoDB, Express, React, Node.js), the platform moves data away from risky, unencrypted emails and fragmented spreadsheets into one secure location. This reduces "blind spots" where data leaks often happen. Real-Time Alerts (Socket.io): The system uses real-time communication tools to monitor for "anomalies." If an unauthorized person tries to access the system or if data is changed unexpectedly, the platform sends an instant alert to the administrator. Blockchain Integration: For the highest level of trust, the platform can link with blockchain technology. This creates a "digital paper trail" that cannot be deleted or changed, ensuring that every shipment and transaction is verified and traceable (Raja et al., 2025).

4.6.4 Building a Culture of Trust

Finally, technology alone isn't enough. Successful data governance requires a collaborative culture where all partners agree on how data will be handled. Research in the Indian manufacturing sector highlights that **94% of organizations** found that clear communication and technological integration together were the keys to a successful, sustainable supply chain (Pasi et al., 2020). By combining secure tools like JWT and encryption with clear partnership agreements, the platform creates a resilient and safe environment for Industry 5.0 collaboration.

5. *conclusion*

This research aimed to address the existing critical visibility and collaboration challenges of the manufacturer's in India to transcend Industry 4.0 and evolve towards Industry 5.0. We acquired the data and technical specifications for a quick platform that enables visibility and collaboration as much more than a few spreadsheets, and the various and individual software, but quite an entire human centric digital ecosystem. The following device was developed to evaluate the effect of RTFI, PA and SM on operational toughness and decision-making quality (shown in section 4.3).

MERN stack with a python microservice ai improves performance in supply chains particularly through increasing connectivity, this coupled ai-powered forecasting with smart sensors and data pipelines in a modern operation. The study finds that using auth (JWT authentication, use of Role-Based Access Control) makes data safe and use of Socket.io provides the real time interaction needed to manage disruption before they become a serious incident (shown in Section 4.6). The primary focus of Industry 4.0 is the efficiency of machines. However, the proposed Industry 5.0 interface (shown in Section 4.3) solves the "black box" problem as it turns computer-savvy data into clear visuals that managers can comprehend. Thus, allowing for better human-machine collaboration.

The results demonstrate a 94% improvement t in supply chain visibility with a near-zero unplanned maintenance and an average 9% gain in production throughput (shown in Section 4.1). Furthermore, this results in an increase of almost thirty percent in the predictive accuracy, which is much better than the earlier predictability. Moreover, the study reveals that despite such advantages, the majority of the Indian industries are still offering 'corporate digital divide' due to its high implementation cost and lack of specialized technical skills. A large number of firms are still firefighting because of everyday production challenges that prevent them from making long-term investments in the digital space.

The results also indicate that the actual sustainability of a tool is still evolving in relation with a firm's technology maturity. Currently in most fields the long-term sustainability of AI has low potential, with the exception of smart sensors and simple automated reporting (shown in Section 4.3). Due to the absence of a model benchmarked for the Indian setting that is the major reason.

Ultimately, the causes of poor digital sustainability in the Indian manufacturing sector were uncovered. In addition, a timeline was suggested to implement the AI framework and foster resilience for longevity. The study examined links between secure data governance, human-centered design and performance. In the future, other blockchain technology will be looked into for more transparency. Also, the journey to Industry 6.0 autonomous agents will be started too. It will ensure a higher sustainability in production all around the world.

6. *Implications*

The primary goal of this study is to demonstrate the practical implementation of an AI-driven platform to enhance supply chain visibility and collaboration, which is an achievable goal even in everyday practice. The first implication of this study deals with the strategic vision of the organization. From the system development and analysis, it has been found that an organization's vision plays an important role in transitioning to Industry 5.0. Organizations should focus on moving away from fragmented, reactive systems—like isolated spreadsheets, emails, and disconnected software—toward a unified digital ecosystem. The developed AI dashboard acts as a "single version of truth," allowing companies to build a proactive and resilient supply chain rather than constantly dealing with daily "firefighting" issues and unexpected delays.

The second implication of this study deals with human-machine collaboration and employees' morale. While earlier technological shifts often caused fear of job losses, the proposed Industry 5.0 platform is specifically designed as a human-centric support tool, not a replacement. It has been observed that making AI understandable through "Explainable Visualizations" removes the fear of the complex "black box" effect. Employees should develop skills in data-driven decision-making and digital collaboration to thrive in modern manufacturing networks. By implementing this secure AI interface, organizations can provide workers with real-time alerts and clear predictive insights. This reduces the stress caused by sudden supply chain disruptions, builds trust across the collaborative network, and ultimately boosts employees' confidence and morale by empowering them to make better, informed decisions.

7. *Research limitations*

The limitation of this study is a deficiency of industries using the I5.0 concept. In this research article, conclusions are made based on the data collected through the questionnaires .Quality of such data can be problematic up to some extent since the opinions and knowledge of participants are not fixed and the interpretation of those opinions is likely to vary.

8. Future research

The effectiveness of the AI-driven platform and visibility measurement tools used in this research can be further validated by conducting similar studies in Indian manufacturing industries using alternative performance evaluation methods. Additionally, comparative research could be carried out for manufacturing supply chains in other developing countries facing a similar "corporate digital divide." It is strongly suggested to implement the proposed AI integration roadmap and secure data governance framework (discussed in Section 4.6) in a live, multi-tier supply chain network, and its long-term impact on the economic, environmental, and social sustainability pillars must be thoroughly evaluated. Furthermore, future studies should explore the integration of blockchain technology for enhanced cross-border transparency and investigate the transition toward Industry 6.0 autonomous agents for self-optimizing logistics.

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