Establishing Data Governance Framework for Enhanced Decision Efficacy in Industry 4.0

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Abstract. This paper examines how Data Governance (DG) enhances data-driven decision-making in Industry 4.0 operations and supply chain management. Drawing on literature review and empirical case studies, the research identifies persistent challenges in data usability, such as human errors, regulatory gaps, technological constraints, and resource limitations. To address these, the study proposes a tailored governance framework that provides both theoretical insights and practical guidance for improving operational efficiency and decision accuracy.

1 Introduction

The onset of the Fourth Industrial Revolution, frequently referred to as Industry 4.0, has deeply transformed the worldwide production landscape by embedding digital technologies into every facet of production and supply networks. Enterprises are swiftly adopting cutting-edge solutions such as the Internet of Things (IoT), cyber-physical systems (CPS), cloud computing, and advanced analytics to enhance operational productivity, agility, and competitiveness. These digital enablers, integrated within organizational operations, generate extensive quantities of high-frequency, complex, and frequently unstructured datasets, giving rise to what is now termed as data-driven production ecosystems. While this unparalleled volume of data unlocks new routes for knowledgeable and educated decision-making and predictive abilities, it concurrently introduces no- table data management problems. Enterprises often struggle with fragmented and siloed data infrastructures, discrepancies in data formats, identical or re- dundant records, unfinished datasets, inadequate metadata documentation, and an absence of uniform taxonomies. These problems not exclusively degrade data quality but furthermore impede the effective deployment of advanced analytical techniques such as Artificial Intelligence (AI), Machine Learning (ML), and Big Data Analytics (BDA) within Operations and Supply Chains (O&SC).

The success of AI/ML-driven solutions in O&SC environments is basically dependent on the dependability, consistency, and integrity of underlying data resources. Without resilient systems to ensure these attributes, predictive models, optimization algorithms, and automation instruments yield suboptimal or even deceptive results. Consequently, organizations are increasingly identifying that data exclusively does not constitute a strategic asset unless it is correctly

A. Jain and S. Gupta (eds.), *Proceedings of the International Conference on Policies, Processes and Practices for Transforming Underdeveloped Economies into Developed Economies (PPP-UD 2025)*, Advances in Economics, Business and Management Research 357,
https://doi.org/10.2991/978-94-6463-894-3_23

governed. Data Governance (DG) has emerged as an essential organizational capability that guarantees data assets is managed effectively across their lifecycle. DG encompasses policies, operations, standards, functions, and technologies designed to ensure the availability, usability, integrity, privacy, and security of data. At its core, DG aligns data management practices with organizational objectives while balancing regulatory adherence and risk reduction necessities. Despite its vital value, existing literature and sector practices disclose a significant gap concerning the pragmatic application of DG in the explicit setting of Operations and Supply Chains. Most academic contributions address DG from a common and nonspecific information systems perspective, offering conceptual frameworks that is frequently abstract and disconnected from the operational realities faced by O&SC practitioners. Moreover, there remains limited empirical inquiry that explores how DG can be operationalized to support data quality improvement, integrated and uninterrupted system integration, and analytics adoption within complicated, worldwide supply networks. In response to these obstacles, this study highlights the pressing and immediate need for domain-specific data management frameworks customized to the O&SC environment. It articulates the distinctive data-related complexities inherent to modern supply chains, inspects the implications of poor data management on organizational performance, and proposes a study agenda aimed at linking the theoretical and pragmatic separation. By methodically tackling data-centric obstacles through effective management, organizations can unlock the complete and entire potential of digital transformation initiatives, fostering resilience, transparency, and competitive benefit across interconnected supply ecosystems. The novelty of this study lies in building a domain-specific DG framework customized to Operations and Supply Chains. Unlike prior work that presents abstract or common and nonspecific models, this inquiry combines empirical case results with thematic analysis, producing a pragmatic pathway that directly addresses Industry 4.0 operational contexts.

2 Review of Related Work

2.1 Differentiating Data Governance and Data Management

The concepts of Data Governance (DG) and Data Management (DM) are often conflated in both academic discourse and industrial practice, yet they serve essentially dissimilar purposes. DM mainly concentrates on the technical and operational oversight of an organization‘s data assets. This encompasses activities such as data storage, data integration, database administration, upkeep of IT system, and the operational aspects of data processing. DM guarantees that data are collected, archived, and made available in a productive and consistent and stable manner, normally under the purview of IT departments. In contrast, DG introduces a strategic, organizational layer to data handling. It encompasses a set of procedures, policies, standards, functions, and duties that guarantee data is exact and true, accessible, uniform and unchanging, protected, and used in alignment with business objectives. DG offers the essential frameworks for defining

data possession, establishing responsibility structures, implementing adherence necessities, and aligning data practices with legal, moral, and strategic imperatives. Unlike the IT-centric extent of DM, DG is intrinsically cross-functional, involving stakeholders from mixed and assorted departments, comprising senior managers, adherence officers, legal teams, and operational leaders. DG initiatives seek to formalize data stewardship, execute admittance control processes, ensure regulatory adherence (for instance, GDPR, CCPA), and foster data-driven decision-making across the organization. Without DG, even the most technically sound DM practices risk failing to support enterprise-wide objectives, especially in complicated domains like Operations and Supply Chains (O&SC), where data heterogeneity and distributed decision-making are common and widespread.

2.2 Data Governance in IS and Industry Practice

Within the Information Systems (are) inquiry community, initial studies on DG mainly centered around technical subcomponents, incorporating metadata management, data integration, and quality assurance processes. These contributions laid the foundation for understanding the technical difficulties of managing data in huge and massive organizations. However, as data volumes and intricacy increased, the limitations of solely technical methods became evident, prompting a shift towards holistic, enterprise-wide DG models. A variety of DG frameworks have since emerged, highlighting systematized data possession, uniform and consistent taxonomies, quality control procedures, policy execution processes, and data stewardship functions. Examples contain frameworks established on CO- BIT (Control Objectives for Information and Related Technologies), DAMA- DMBOK (Data Management Body of Knowledge), and ISO 8000 standards for data quality. These models provide organized and systematic guidelines to align technical data practices with organizational management necessities, regulatory adherence, and risk management. Despite their theoretical rigor, a recurring criticism of these frameworks is their limited relevance in operational contexts, especially within O&SC environments. Many existing DG models were designed with generalized information systems in mind and fail to account for the domain- specific complexities associated with production systems, worldwide logistics, vendor networks, and real-time operational data. Consequently, practitioners frequently struggle to translate abstract management principles into actionable, domain-specific methods that address the mixed, dynamic, and distributed na- ture of O&SC data ecosystems. Furthermore, empirical inquiry examining DG implementation remains scant, with few studies offering insights into organizational enablers, hurdles, and success aspects for operationalizing DG within sector. The absence of pragmatic, evidence-based advice hinders organizations from achieving effective DG in real-world, high-stakes operational settings.

2.3 Data Governance in the OSCM Field

The Operations and Supply Chain Management (OSCM) literature has long identified the strategic role of data in driving productivity, responsiveness, and

competitiveness across supply networks. However, explicit examinations into thorough DG frameworks customized to the OSCM domain continue limited. Existing studies mainly address fragmented aspects of data obstacles instead than offering integrated management solutions. For instance, inquiry on real-time analytics has examined the value of sensor data, IoT devices, and predictive models for enhancing production planning, inventory management, and transportation logistics. Similarly, studies directing on data integration have highlighted the weight of consolidating information from disparate systems for upkeep scheduling, quality management, and provider collaboration. Other works highlight the significance of data quality for enhancing product development cycles, customer service levels, and regulatory adherence. While these contributions underscore the operational value of data, they frequently treat data-related problems in separation, lacking a cohesive, organization-wide management perspective. As a result, crucial aspects such as data stewardship, cross-enterprise data sharing protocols, data possession clearness, and policy execution persist underexplored within OSCM literature. Moreover, the extremely mixed and distributed nature of supply chain data; spanning several stakeholders, geographies, and information systems; exacerbates the management difficulty. Data originating from vendors, manufacturers, logistics providers, and customers frequently changes in format, detail, and dependability, making it tough and arduous to ensure consistency and quality without an organized management framework. Given the growing reliance on AI, ML, and advanced analytics in modern O&SC processes, the lack of resilient DG practices not exclusively undermines data quality but furthermore limits the effectiveness of predictive, prescriptive, and autonomous decision-making instruments. This creates an urging need for inquiry that develops DG frameworks specifically designed to address the unique complexities of OSCM environments. In summary, while substantial progress has been made in understanding DG from an IS perspective, the OSCM area still lacks thorough, actionable DG models that integrate technical, organizational, and operational dimensions. Bridging this gap is necessary and fundamental to permitting data-driven decision-making, enhancing supply chain resilience, and maximizing the value of digital transformation initiatives within O&SC contexts.

3 Methodology

3.1 Approach

To explore DG within genuine operational contexts, three case studies were implemented. The selected instances span upstream, midstream, and downstream segments of the supply chain, all involving large-scale production firms. The scale and intricacy of these enterprises provide a fertile ground for examining mixed and assorted data difficulties.

3.2 Data Collection and Analysis

Data were collected from October 2021 to March 2023 via semi-structured interviews and document analysis. Participants included IT specialists, mid-level

managers, and operational staff involved in data-driven initiatives. Thematic queries addressed business objectives, data flows, and encountered problems. Analysis followed three stages: mapping business workflows, documenting data interactions, and implementing root reason identification via the 5 WHY tech- nique. Workflow representations and problem logs were confirmed with partici- pants.

4 Case Study Findings

4.1 Case Descriptions

Case 1: A beverage manufacturer's bottling center in Denmark used sensor-generated data to boost productivity and support quality assurance.

Case 2: A Danish wind energy firm's supply chain planning unit aimed to optimize component logistics by applying integrated datasets.

Case 3: A consumer goods distribution center in Denmark utilized operational data for order packing and performance monitoring.

4.2 Identification of Data Problems

In table 1, using the DAMA Data Management Body of Knowledge framework, the follow- ing recurring issues were classified:

- **Data Quality:** Missing fields, duplicated entries, conflicting or contradictory labels.
- **Integration and Interoperability:** Redundant sources, hidden data, siloed systems.
- **Storage and Operations:** Local-only storage, obsolete systems, unarchived datasets.
- **Analytics:** Reliance on individual proficiency, unstandardized reports, irregular KPIs.

Table 1. Summary of Data Issues and Their Impacts

Data Issue	Consequences
Missing or wrong entries	Reduced decision accuracy
Inconsistent naming	Ambiguous interpretation
Multiple databases	Prolonged data retrieval
Manual data compilation	Increased labor cost
Shadow IT systems	Undocumented workflows

4.3 Root Cause Analysis

The 5 WHY analysis traced the origin of data flaws to systemic gaps, such as:

- Absence of enforced naming conventions.
- Limited training on data entry and management.
- Non-standardized maintenance of spreadsheets.
- Fragmented IT infrastructure lacking centralized oversight.

The overall impact of data defects was evaluated by considering both the seriousness of each concern and its repetition across instances. This qualitative assessment revealed that repeated errors, such as irregular labels or missing entries, amplified operational risks.

5 Keyword Analysis and Thematic Categorization

A thorough term analysis was undertaken on the 110 core and foundational clarifications associated with the 22 classified data problems. Initially, non-substantive conditions such as conjunctions, prepositions, and determiners were eliminated to improve the keyword dataset. Subsequently, conceptually rele- vant and substantial conditions indicating actions or corrective approaches were marked as keywords. For instance, from the phrase "... useless communication or instruction, or data entry criteria was ambiguously outlined...", the condi- tions "communication," "training," and "data entry criteria" was extracted as vital and crucial conditions. Topic modeling applied to the curated keyword list revealed four central thematic domains: (1) personnel-centric components,
(2) regulatory documentation and policy adherence, (3) digital system, and (4) organizational resourcing. Personnel-related aspects contain abilities, competencies, leadership dynamics, organizational learning, and cultural attributes. Policy-related themes encompass organized processes, recorded standards, and responsibility systems. Technological aspects relate to the sufficiency of platforms, applications, and systems. Resource-based elements include workforce, capital allocation, and investment approach.

6 Pathway for Data Governance in OSC

An integrated approach to Data Governance in OSC is formulated to address the thematic domains discussed above. The strategy comprises three synergistic layers: (1) managerial-level alignment, (2) operations-level engagement, and (3) technology-enabled support.

6.1 Strategic Alignment via Top-Down Initiatives

This managerial layer tackles problems tied to leadership, advocacy, policy development, and strategic investments. As shown in table 2, effective management requires senior lead- ership's commitment to promoting data-centric principles, instituting exhaus- tive and inclusive policies, and apportioning fitting resources. To support this,

Table 2. Keyword Themes and Illustrative Triggers

Theme	Illustrative Keywords and Examples
Personnel Elements	Communication, coordination, leadership, training, awareness, cultural orientation, technical literacy
Regulatory Policies	Protocols, documentation, accountability, policy design, ownership, standardization
Technological Systems	Databases, tools, systems, infrastructure, compatibility
Organizational Resources	Budget, workforce, competing priorities, investment constraints

executive-level data management boards should be established to synchronize business priorities with management objectives. Further, investment in capacity-building; through recruitment and training of DG experts; is vital and crucial for implementation.

6.2 Operational Involvement via Bottom-Up Practices

From the executional standpoint, management initiatives should originate at the level of business requirements. Personnel must be equipped with domain-specific knowledge and encouraged to engage in data-driven routines. This approach reverses the traditional decision pipeline: instead of "data precedes decision," the approach indicates "decision necessities ascertain data requirements." The workflow is started by identifying operational issues, followed by clarifying the data specifications and analysis instruments required, and concluding in joint problem-solving between business and technical actors.

6.3 Technological Enablement for Governance Execution

The technological layer highlights the design and deployment of sturdy and resilient, interoperable platforms. Solutions like the Data Middle Platform can bridge business-user necessities with backend systems by packaging data and analysis instruments around business domains. Unlike customary data warehousing solutions, the middle platform centralizes data utility while maintaining domain-level setting. It supports ongoing knowledge retention and adjustment to business dynamics.

7 Conclusion and Future Scope

The results of this inquiry underscore a persistent and crucial difficulty confronting modern enterprises; namely, the barriers to digital transformation efforts emerging from unresolved, systemic data management limitations. Despite

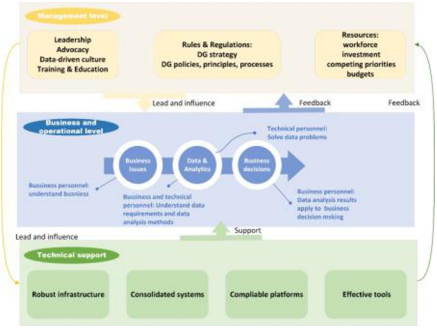

Fig. 1. Schematic of Three-Tier Governance Pathway

Table 3. Open Questions in Governance Pathways

Approach	Research Question
Top-down	Optimal executive involvement? Strategy alignment with corporate vision? Investment prioritization and metrics?
Bottom-up	How to formalize cross-role collaboration? How to reverse-engineer decisions to define data needs?
Technical	Platform standardization strategies? How to provide accessible tools to non-technical users?

notable investments in advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Big Data Analytics (BDA), organizations continue to struggle with fragmented, irregular, and low-quality data, which finally undermines their capability to extract actionable insights and achieve operational excellence. This study contributes to both academic discourse and pragmatic application by proposing an exhaustive and inclusive, multi-level Data Governance (DG) framework specifically customized to the complexities of Operations and Supply Chains (O&SC). As shown in table 3, the proposed management model combines three core and foundational dimensions: managerial commitment, operational alignment, and technological enablement. Collectively, these dimensions address not solely the technical necessities for data integrity and accessibility but furthermore the organizational and cultural requirements for fostering data-driven decision- making at scale. In figure 1, first, managerial commitment is crucial to ensure that data management is identified as a strategic imperative instead than merely a technical exercise. Executive leadership must prioritize DG initiatives, allocate sufficient and acceptable resources, and establish obvious and evident responsibility structures for data stewardship across all organizational levels. Second, operational alignment requires embedding DG principles into the day-to-day activi-

ties of O&SC operations. This necessitates collaboration among cross-functional teams to ensure that data standards, possession protocols, and quality controls are consistently applied throughout the supply network, from procurement and production to distribution and customer service. Third, technological enablement concentrates on leveraging modern data platforms, integration instruments, and automation solutions to enforce management policies, enhance data compatibility, and support real-time analytics. The convergence of these dimensions assists the transition from fragmented data silos to cohesive, trusted information ecosystems capable of supporting predictive, prescriptive, and autonomous decision-making. However, this inquiry furthermore identifies that building and operationalizing effective DG frameworks within O&SC remains a developing effort. Several limitations warrant further exploration. First, while the proposed model provides conceptual clearness, its pragmatic implementation across varied and distinct industries, organizational structures, and regulatory environments necessitates exhaustive and stringent empirical validation. Context-specific aspects such as supply chain intricacy, technological maturity, and organizational culture can considerably affect the effectiveness of DG plans. Second, existing study mainly concentrates on reactive data management measures; remediation of data quality problems, compliance-driven data management, and post-hoc integration efforts. Future work should advance toward proactive data man- agement, stressing predictive data quality observation, automated data descent monitoring, and strategic data valuation methodologies. Such a shift can allow organizations to not exclusively mitigate risks but furthermore unlock new value streams through enhanced data use, improved transparency, and supply chain re- silience. Furthermore, cross-sector collaborations, involving sector practitioners, academic researchers, and policymakers, are vital and crucial to develop uni- form DG best practices, reference architectures, and benchmarking instruments that transcend organizational boundaries. These initiatives can help harmonize data management methods across worldwide supply networks, enabling data sharing, compatibility, and coordinated decision-making among stakeholders. Lastly, the swiftly developing technological landscape, comprising advancements in blockchain, IoT, edge computing, and federated learning, presents both oppor-tunities and obstacles for data management. Future inquiry should examine how these emerging technologies can be effectively integrated into DG frameworks to address problems of data provenance, security, privacy, and distributed data possession within complicated, multi-tiered supply chains. In conclusion, sturdy and resilient and domain-specific data management is not merely a technical need but a strategic enabler for digital transformation in O&SC. As organiza- tions continue to navigate the complexities of globalized processes, regulatory stresses, and technological interruption, the capability to govern data effectively will increasingly differentiate market leaders from laggards. This study offers a necessary and fundamental foundation for advancing DG practices within O&SC, while moreover identifying essential paths for future inquiry and pragmatic in-novation.

References

1. Lai, M.B., Vergamini, D., Brunori, G.: Food supply chain: A framework for the governance of digital traceability. Foods 14(12), 2032 (2025)
2. Ghode, D.J., Yadav, V., Jain, R., Soni, G.: Integrated framework for supply chain with blockchain technology: A manufacturers' perspective. Journal of Innovation and Entrepreneurship 14, 62 (2025)
3. Sun, L.: Construction of supply chain management information system based on networked web service composition technology. Insights into Distributed Technologies (2024)
4. Panigrahi, R.R., Singh, N., Muduli, K.: Digital technologies and food supply chain: A scoping view from 2010 to 2024. International Journal of Industrial Engineering and Operations Management (2024)
5. Zhang, Y., Li, X., Wang, M.: Data governance in smart manufacturing: A comprehensive review. Computers in Industry 150, 103605 (2023)
6. Khan, A., Ali, S., Hussain, F.: AI-driven decision-making in supply chains: Governance and ethical considerations. IEEE Transactions on Systems, Man, and Cybernetics 54(2), 345–356 (2024)
7. Meyer, T., Schmidt, P.: Digital governance frameworks for cross-border logistics under Industry 4.0. International Journal of Production Research 63(6), 1023–1042 (2025)
8. Cheng, W., Li, H., Xu, J.: Enhancing data quality in IoT-based supply chains: An empirical study. Sensors 23(9), 4502 (2023)
9. Davis, R., Ng, E.: Hybrid big data platforms for real-time supply chain analytics. Journal of Big Data 11, 47 (2024)
10. Singh, P., Gupta, A., Verma, L.: Operational resilience via data governance in manufacturing ecosystems. International Journal of Logistics Management 35(3), 621–641 (2024)
11. Zhou, L., Chen, Y.: A platform-based approach to intra-enterprise data governance. IEEE Access 13, 10845–10860 (2025)
12. Rossi, M., Marques, F., Pereira, D.: Data middle platform adoption in manufacturing: Case evidence from Europe. Journal of Manufacturing Systems 68, 112–127 (2023)
13. Tan, J., Lim, S.: Data-driven culture in supply chains: A structural equation model. European Journal of Operational Research 298(1), 200–213 (2024)
14. Kim, S., Lee, J.: Automating metadata management in supply chain analytics environments. International Journal of Information Management 65, 102682 (2025)
15. Fernandez, L., Garcia, M., Lopez, C.: Policy-driven data governance in hybrid supply chains. International Journal of Production Economics 253, 108–120 (2023)
16. Martinez, E., Sanchez, R.: Data quality assurance in Industry 4.0 ecosystems: A mixed-methods study. IFAC-PapersOnLine 57(3), 1125–1130 (2024)
17. Lopez, F., Martinez, J., Gonzalez, A.: Governance mechanisms for real-time data sharing across tiers. IEEE Transactions on Engineering Management 72(1), 58–70 (2025)
18. Verma, S., Sharma, P.: Towards comprehensive frameworks for data governance in supply chain operations. Journal of Supply Chain Management Science 12(2), 33–52 (2024)