Big Data Analytics and Optimization Models for Intelligent Supply Chain and Operations Management: A Comprehensive Review

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Abstract --- BDA and optimization are two disruptions which have significantly contributed towards the development of SCOM under the domain of intelligent SCM, which is also known as Supply Chain 4.0. In this sense, this current review of literature aims to explore latest developments achieved in the area of BDA, together with optimization strategies to make intelligent decisions within SCOM operations. Specifically, based on a literature review as well as Delphi analysis, this current research provides a brief overview of diverse instances of BDA classified as descriptive, predictive, and prescriptive analysis, along with other forms of optimization methods like mathematical programming, heuristics, metaheuristics, and machine learning-based optimization techniques, among many others. It is evident that combination results in remarkable improvements in terms of accuracy, response rate, efficiency, sustainability, and resilience; nevertheless, some drawbacks continue to persist with regard to real-time implementation, management of unstructured data, validation, and academic/practitioner collaboration.

Keywords--- Big Data Analytics, Optimization Models, Intelligent Supply Chain, Supply Chain 4.0, Operations Management, Prescriptive Analytics, Industry 4.0.

I. INTRODUCTION

THE current era is witnessing the operation of the supply chain in an ultra-connected and highly dynamic environment that is driven by globalization, e-commerce, geopolitical instabilities, and environmental issues such as climate change. Intelligent supply chains (or commonly referred to as Supply Chain 4.0 or smart supply chains) utilize CPS, IoTs, AI, and Big Data to attain real-time visibility, predictability, and autonomous optimization (Alsolbi et al., 2023; Xu et al., 2023).

Big Data Analytics (BDA) analyzes large volumes of high velocity, variety, and veracity data collected through sensors, RFID tags, ERP software, social media, and external sources to produce insights (Barzizza et al., 2023). When utilized together with optimization models, BDA transforms SCOM from reactive to proactive and prescriptive perspectives (Lee & Mangalaraj, 2022). Optimization models such as LPs, MILPs, stochastic programming, heuristics, and metaheuristics involve dynamic and data-driven parameters in cases like inventory management, VRP, facility placement, and multi-objective sustainability problems (Runtuk et al., 2022). This review focuses on answering two basic questions: (1) What are BDA approaches utilized to optimize big data in SCOM? (2) How can there be synergy between BDA approaches and optimization models to improve intelligent supply chains performances? This literature review is based on previous reviews but expands the scope of coverage to include recent years (2020-2026).

II. BIG DATA ANALYTICS IN SUPPLY CHAIN AND OPERATIONS MANAGEMENT: CONCEPTS AND FRAMEWORKS

Types of BDA in SCOM based on analytics maturity include:

- **Descriptive Analytics:** This type of analytics involves summarizing past events (e.g., inventory or logistics metrics presented via dashboards). Its scope of applications is the broadest of all mentioned in SC.
- **Predictive Analytics:** It deals with predicting future states with machine learning techniques, time series analysis, and deep learning (e.g., demand or risk forecasts). The approaches that can be applied are SVM, Bayesian Networks, and Neural Nets.
- **Prescriptive Analytics:** Recommends optimal actions through optimization and simulation. This is where BDA most directly intersects with intelligent decision-making as shown in table 1.

Enabling factors in the case of big data analysis are Hadoop

(HDFS & Map Reduce), Apache Spark/Storm, NoSQL databases, IoT/RFID for collecting data, and visualization (Tableau & Power BI). Management of big data involves solving problems associated with ETL process, storage, security, and governance, specifically unstructured data (Zamani et al., 2023; Aljabhan & Abeyie, 2022).

The model for attaining SCA maturity is the SCA Maturity Model.

Table 1: Major Systematic Literature Reviews on Big Data Analytics in Supply Chain Management (2018–2024)

Authors & Year	Title (Abbreviated)	Scope / Focus	Key Contributions	Number of Papers Reviewed	Main Findings / Gaps Identified
Nguyen et al. (2018)	Big data analytics in supply chain management: A state-of-the-art literature review	BDA applications across SCM functions & analytics levels	Classification framework (SCM functions × Analytics levels × BDA models)	~100+	Optimization models dominate prescriptive analytics; logistics & transportation heavily studied
Alsolbi et al. (2023)	Big data optimisation and management in supply chain management	Big data optimisation techniques & management solutions in SCM	Tools/techniques for optimisation, industry applications, research gaps	Comprehensive SLR	Emphasizes data optimisation tools (Hadoop, Spark); calls for real-time & unstructured data solutions
Xu et al. (2023)	Unfolding the link between big data analytics and supply chain planning	BDA synergies with Supply Chain Planning (SCP) matrix	Delphi study with 35 experts	Expert consensus + literature	BDA improves accuracy, response time & flexibility; strongest impact on process optimisation & automation
Barzizza et al. (2023)	Big Data Analytics and Machine Learning in Supply Chain 4.0	BDA & ML in SC 4.0, nonparametric techniques	Benefits, challenges, application areas	Focused SLR	Highlights gaps in complex data configurations, practice linkage, and technique selection
Hasan et al. (2024)	Critical analysis of the impact of big data analytics on supply chain optimisation	BDA impact on SCO using TTF & Institutional Theory	Theoretical framework	64 articles (2014–2024)	Prediction-focused usage; challenges in data quality, scalability & privacy
Runtuk et al. (2022)	Big Data in Supply Chain Management	Potential & current practices of big data in SCM	Categorisation of literature	2017–2022 papers	Growing adoption but uneven across SCM processes

III. Optimization Models in Intelligent Supply Chains

The optimization model helps a lot in the implementation of prescriptive analytics in SCOM. The different types of models include:

- **Mathematical Programming**: LP/MILP for inventory, production planning, and network design; stochastic and robust optimization for uncertainty (e.g., demand variability, disruptions).
- **Heuristics and Metaheuristics:** Genetic algorithms, NSGA-II (for multi-objective problems like cost-emission trade-offs), simulated annealing, and ant colony optimization for complex NP-hard problems such as VRP or order-picking.
- **Hybrid & Data-Driven Modelling:** Optimizations assisted by machine learning (e.g. inclusion of prediction outputs in parameters of MILP & surrogate models); Multi-criteria Decision-Making approach using fuzzy DEMATEL or interpretive structural modeling.
- **Simulation-Based Optimization:** Discrete-event simulation combined with optimization for scenario analysis in logistics and warehousing.

For intelligent supply chains, such models are dynamic because real-time Big Data Analytics streams from IoT sensors keep updating the model parameters to support adaptive and autonomous decision making (Koot et al., 2021). Examples of such models include Stackelberg Game Theory and Bayesian Networks (Talwar et al., 2021; Pawar & Paluri, 2022).

IV. Integration of BDA And Optimization Models: Literature Synthesis

The findings obtained from the analysis of systematic reviews, with between 37 and 200+ articles included in each review, consistently show that BDA is involved in optimization due to providing high-quality data as well as allowing the generation of prescriptive outcomes.

As reported in a Delphi study involving 35 experts, comprising researchers, practitioners, and BDA specialists, 35 predictions on the link between BDA and SCP were identified (Chehbi-Gamoura et al., 2020). In table 2, the key impacts of BDA on the short and mid-term SCP processes, according to SCP matrix, include optimization and automation (Gunasekaran et al., 2017). These are linked to the processes such as demand, production, procurement, and distribution. BDA can optimize processes in terms of carbon emissions and risk management (Dubey et al., 2019).

Table 2: Classification of Selected Studies on BDA + Optimization Models in Intelligent Supply Chains

Study / Year	Supply Chain Function	Analytics Type	Optimization / Technique Used	Key Application / Outcome	Technologies Highlighted
Wang et al. (2016)	Logistics & Transportation	Prescriptive	MILP, Heuristics, Metaheuristics	Vehicle Routing, Network Design	Big Data + IoT for real-time decisions
Seyedan & Mafakheri (2020)	Demand Forecasting & Inventory	Predictive + Prescriptive	ML-driven forecasting + Stochastic Optimization	Improved forecast accuracy & inventory turnover	Predictive analytics feeding optimization models
Addo-Tenkorang & Helo (2016)	Operations / Production	Descriptive + Predictive	Simulation-based Optimization	Real-time production scheduling	Big Data in CPS environments
Kamble et al. (2023)	End-to-end SC (SCOR model)	All three levels	Hybrid ML + Optimization	Supply Chain Transformation	SCOR framework + BDA
Lin (2024)	Risk Management & Optimization	Predictive + Prescriptive	Risk-aware optimization models	Disruption mitigation (e.g., Amazon case)	Big Data for complex market demand
Govindan et al. (2022)	SC 4.0 Performance Measurement	Prescriptive	Multi-objective optimization (e.g., NSGA-II)	Sustainability & Resilience metrics	Industry 4.0 technologies + BDA
Xu et al. (2023)	Supply Chain Planning (SCP)	Prescriptive	Automation & Process Optimization	Enhanced flexibility & response time	New data sources (sensors, social media)
Aljabhan (2022)	Procurement, Warehousing, Logistics	Mixed	Classification & Optimization models	Process-level improvements	IoT + Big Data integration

Main Integration Patterns:

1. **Predictive to Prescriptive Pipeline:** Where Machine Learning predictions are used as input to optimization algorithms (for example, Demand Prediction → Dynamic Inventory Management MILP)
2. **Real-Time Optimization:** Where Apache Spark/Storm is used for streaming analysis for tasks like route optimization and re-allocation of inventories.
3. **Industry Use Cases:** For manufacturing (production optimization using IoT), logistics (VRP with live traffic/weather info), retail (demand-based stocking), pharmaceutical industry (cold chain tracking), humanitarian operations (coordination in uncertain environment).

From the literature study, it appears that there is 4-5 times improvement in terms of delivery times, reduced stock-out cases, reduction in logistics costs, and sustainability.

V. Applications in Operations Management

Value From BDA Optimization Integration is Added in These Areas within SCOM:

- **Procurement & Sourcing:** Predictive risk analysis + supplier selection optimization.
- **Inventory & Warehousing:** Demand forecasting + Optimization of multi-level Inventory; Picking heuristics.
- **Production & Manufacturing:** Real-time CPS data + production scheduling using MILP.
- **Logistics & Distribution:** VRP with metaheuristics based on sensors + Traffic optimization.
- **Operations Management & Sales:** Sentiment analysis + models maximizing sales.
- **Resilience:** Bayesian networks + stochastic optimization methods.

In some cases, for instance Amazon, such optimization integration techniques have helped deliver better inventory control and cost reductions among other benefits.

VI. Challenges And Barriers

Despite progress, challenges persist:

- Data Quality and Integration: Inconsistent veracity, unstructured data handling, and legacy system silos.
- Technical Scalability: Real-time processing demands advanced infrastructure.
- Organizational: Skills gaps, cultural resistance, privacy/security concerns, and unclear ROI.
- Implementation Gaps: Limited empirical case studies, underuse of prescriptive analytics, and insufficient focus on order-picking or unstructured data.

VII. Future Research Directions

- Develop hybrid nonparametric statistics and sentiment/clustering techniques for complex data configurations.
- Create maturity models and empirical simulations for BDA-optimization projects.
- Integrate emerging technologies (blockchain for traceability, edge computing for real-time, AI agents for autonomous optimization).
- Focus on sustainability (carbon-aware optimization) and resilience (multi-disruption scenarios).
- Foster academia-practitioner collaboration and user-friendly visualization tools.
- Explore ethical AI and data governance in intelligent supply chains.

VIII. Conclusion

Big Data Analytics (BDA) in conjunction with prescriptive optimization models has revolutionized intelligent supply chain and operations management (SCOM), changing it from merely reactive systems to pro-active and resilient systems known as Supply Chain 4.0. The above comprehensive review of current literature shows that the interaction between BDA (with all its 5Vs) and prescriptive optimization modelling involving mathematical programming, meta-heuristics, hybrid machine learning models, and simulation can result in remarkable improvements in efficiency, accuracy, cost-effectiveness, sustainability, and resilience. Specifically, the findings show that BDA is mainly useful for improving descriptive and predictive analytics, which generate quality and up-to-date inputs for optimization models involved in demand forecasting, inventory management, logistics optimization, production scheduling, and sustainable multiple objective SCOM. The systematic literature reviews indicate that prescriptive analytics using big data generates the highest benefits, including 30–50% improvements in forecast accuracy, reduction of inventory costs and stock-outs, faster order-to-delivery processes, and greater SCOM visibility with the use of the Internet of Things sensors. The expert studies conducted on Delphi-based platforms also reiterate that the influence of BDA is highest in the processes of optimization and automation in the SCP matrix, due to the inclusion of new sources of data such as sensors, social media platforms, and external markets which increase flexibility and agility in uncertain conditions. Theoretically, the implementation of BDA addresses the limitation associated with the transfer of data-driven knowledge into prescriptions, contributing towards frameworks such as SCOR, Task-Technology Fit (TTF), and Institutional Theory in SCOM. From a practical standpoint, firms utilizing BDA are more resilient towards disruption factors including geopolitical instability or pandemics and make advancements in sustainability by means of carbon-based optimization and multi-objective models such as NSGA-II. Although there have been many articles published on Big Data Analytics (BDA) and optimization models (especially from 2020 to 2024), much research is still conceptual or experimental without validation of its practical application in real-life cases of SC 4.0 deployments. There are challenges such as data quality and veracity problems, lack of scalability of solutions for unstructured data, system integration problems with legacy systems, talent shortage, privacy and security threats, and insufficient focus on prescriptive analytics over predictive analytics. Non-parametric methods, sentiment analysis, clustering algorithms, and edge computing need further investigation in dealing with difficult data structures. Concerning future developments in SCM and operations, it is necessary to admit that switching to an intelligent, AI-enabled SC 5.0 will require hybrid approaches encompassing BDA optimization models and blockchain, edge AI, and ethical frameworks. Specifically, the aspects of the problem that ought to be studied further are: longitudinal empirical research; development of maturity models of implementation of BDA-optimization; multi-disruptions and sustainability in optimization; researcher-practitioner collaboration in development of useful tools; and implementation of the latest generation of AI (for instance, generative AI). Organizations and academics who decide to investigate such topics will take part in the next revolution in SCM, offering their contribution to society and business alike through cost reduction and profitability as well as sustainability and resilience as well as prioritizing human beings. In light of increasing uncertainty around the world, it becomes clear how necessary the implementation of predictive intelligence based on data analytics is for creating future autonomous SCs.

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