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Multi-Agent Supply Chain Optimization System

Saniya Ramesh Satkar
Dept. of CSE
School of Computing,
MIT ADT University, Pune, India

Sanika Ramesh Satkar
Dept. of CSE
School of Computing,
MIT ADT University, Pune, India

Harshada Kiran Kate
Dept. of CSE
School of Computing,
MIT ADT University, Pune, India

Lakshya Dutt Purohit
Dept. of CSE
School of Computing,
School of Computing,
MIT ADT University, Pune, India

Prof. Kiran Shinde
Dept. of CSE
School of Computing,
School of Computing,
MIT ADT University, Pune, India

Abstract **- This paper presents an approach to the Multi-Agent Supply Chain Optimization System (MASOS), an intelligent, decentralized solution for optimizing complex supply chains. MASOS employs a collection of autonomous, AI-driven agents each responsible for tasks such as demand forecasting, inventory management, logistics routing, supplier evaluation, and disruption handling. These agents collaborate dynamically through a shared decision- making framework to simulate, predict, and optimize supply chain operations in real time. The project highlights the potential of multi-agent architectures to transform traditional supply chain management into an intelligent, self-optimizing ecosystem capable of learning and evolving continuously.**

Keywords **- Multi-Agent Systems, Supply Chain Optimization, Artificial Intelligence, Machine Learning, Automation, Logistics**

I. INTRODUCTION

In today's globalized economy, supply chain management plays a pivotal role in ensuring that goods and services are delivered efficiently, cost-effectively, and on time. Traditional supply chain systems, including Enterprise Resource Planning (ERP) and Material Requirements Planning (MRP), often operate in centralized and rigid frameworks. These systems struggle to adapt to dynamic market fluctuations, unexpected supplier delays, and disruptions such as transport failures or demand surges. The increasing complexity of modern supply chains necessitates intelligent, autonomous, and adaptive systems capable of real-time decision-making. Recent advancements in Artificial Intelligence (AI) and Multi-Agent Systems (MAS) have enabled decentralized and collaborative decision architectures. In such systems, multiple autonomous agents work together—each focusing on specialized tasks such as demand forecasting, inventory management, logistics optimization, and supplier evaluation. This agent-based paradigm introduces scalability, adaptability, and resilience to the overall supply chain.

The proposed **Multi-Agent Supply Chain Optimization System (MASOS)** integrates AI-driven predictive analytics and cooperative agent interactions to create a dynamic and self-optimizing supply chain framework. By simulating and managing interactions among multiple entities, MASOS enhances forecasting accuracy, reduces operational costs, and minimizes delays. This research highlights the potential of multi- agent technologies to revolutionize traditional supply chain management, transforming it into an intelligent, data-driven, and adaptive ecosystem capable of responding to real-time challenges.

II. LITERATURE SURVEY

SNo	Authors	Year	Title	Key Findings
1	Khanna A., Jain S.,	2025	Generative AI & Blockchain -Integrated	Demonstrates a MAS + generative AI + blockchain

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	Sah A. et al.		Multi-Agent Framework for Resilient and Sustainable Fruit Cold-Chain Logistics	framework improving resilience and traceability in cold-chain logistics.
2	Anantha Mukherjee, Peeyush Kumar, Boling Yang et al.	2023	Privacy Preserving Multi-Agent Reinforcement Learning in Supply Chains	Introduces a privacy-preserving MARL mechanism for supply chain agents, improving revenue and reducing waste.
3	Zhang B., Tan W.J., Cai W., Zhang A.N.	2024	Leveraging Multi-Agent Reinforcement Learning for Digital Transformation in Supply Chain Inventory Optimization	Shows how multi-agent RL can enhance inventory optimization in digital supply chains.
4	Maciej Bielecki et al.	2024	Supply Chain 4.0: What the Supply Chains of the Future Might Look Like	Explores agent-based modelling in future supply chains under industry 4.0 paradigms.
5	E. Sahin and P. Robinson	2020	Dynamic Supply Chain Management Using Reinforcement Learning in Multi-Agent Systems	Implemented reinforcement learning for real-time dynamic optimization in SCM.
6	J. Gjerdrum, N. Shah, and L. G. Papageorgiou	2019	A Combined Optimization and Agent-Based Approach to Supply Chain Management	Integrated optimization algorithms with agent communication for better production-distribution balance.
7	R. Kumar, S. Gupta, and V. Sharma	2023	AI-Based Predictive Analytics for Supply Chain Optimization	Improved forecasting accuracy using machine learning and AI-based data analytics.
8	S. Chopra and P. Meindl	2019	Supply Chain Management: Strategy, Planning, and Operation	Provided foundational strategies for supply chain design and performance evaluation.
9	T. Wang, C. Zhang, and Y. Zhang	2022	Blockchain-Enabled Multi-Agent Supply Chains	Combined MAS with blockchain for transparency, traceability, and trust in logistics operations.
10	H. Hindy, D. Brosset, and N. Moustafa	2020	A Survey of AI and Multi-Agent Techniques for Smart Industrial Systems	Reviewed modern AI and MAS applications in cyber-physical and industrial management systems.

Fig. 1. Literature Survey Table

SYNTHESIS AND RESEARCH GAPS

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The surveyed literature demonstrates a clear progression: early agent-oriented conceptual frameworks evolved into hybrid optimization + agent solutions , and more recently to learning-based multi-agent reinforcement learning and privacy-preserving MARL. Contemporary research also explores domain-specific integrations (e.g., blockchain + agents for traceability) and policy design for fairness/scalability. Major strengths across studies include improved modularity, responsiveness to local conditions, and potential for cost and service improvements.

However, persistent gaps remain:
Real-world integration and scalability: Many studies rely on simulation or small pilots; end-to-end deployment with live IoT/ERP data is limited.
Learning stability & explainability: MARL and deep RL approaches show promise but suffer from training instability, poor interpretability, and sample inefficiency.
Privacy and data sharing constraints: Collaborative optimization often requires data sharing; privacy-preserving methods exist but add communication overhead and complexity.
Interoperability between optimization and agent layers: Hybrid approaches sometimes face integration and computational overhead challenges.
Domain generalization: Several solutions are domain-specific (cold-chain, retail) and may not generalize across different supply chain topologies.

How MASOS Addresses These Gaps

The Multi-Agent Supply Chain Optimization System (MASOS) is designed to synthesize the strengths and directly address the gaps found in the literature: Hybrid architecture: MASOS combines predictive ML models for forecasting with reinforcement learning for adaptive disruption handling and classical optimization for logistics—mirroring the effective hybrid strategy of while focusing on tighter integration and lower overhead.

Scalability & modularity: Agent modularity inherits the scalable benefits of foundational MAS work, but MASOS emphasizes asynchronous, message-based communication and stateless service endpoints (FastAPI) to support large agent fleets.

Robust training & interpretability: MASOS adopts stabilized training regimes (centralized critiquing, replay buffers) and embeds surrogate explainers for decisions to improve RL transparency—mitigating key practical issues highlighted in MARL studies.
Privacy-aware coordination: Building on privacy-preserving concepts, MASOS supports selective data sharing and aggregated summary exchanges for cross-organizational decisions to reduce privacy risk while preserving coordination benefits.
Realistic evaluation: MASOS validates performance using mixed real and synthetic datasets and modular simulation scenarios (demand surges, supplier failures), aiming for closer-to-production assessment than purely academic studies

METHEDOLOGY

The proposed Multi-Agent Supply Chain Optimization System (MASOS) adopts a decentralized, AI-driven approach to managing the dynamic operations of supply chains. The system architecture is composed of multiple intelligent agents, each assigned a specific role such as demand forecasting, inventory management, logistics coordination, supplier evaluation, and disruption handling. These agents operate autonomously yet collaboratively, exchanging real-time data through a shared communication framework to ensure optimal decision-making across the entire supply chain.

The research utilized both simulated and publicly available datasets to represent various supply chain activities, including demand patterns, supplier performance, and transportation metrics. Data preprocessing involved cleaning, normalization, and feature selection to ensure consistency and accuracy. Each agent was designed using machine learning techniques suited to its role — for instance, regression based models for forecasting, optimization algorithms for logistics, and reinforcement learning for handling disruptions. The system was implemented using **Python, FastAPI while a HTML+CSS dashboard** visualized real-time agent interactions and system performance.

Evaluation of MASOS was conducted through multiple simulation experiments to assess accuracy, responsiveness, and cost efficiency. Performance metrics such as prediction accuracy, response time, and cost optimization were used to measure each agent's contribution. The results demonstrated that MASOS significantly enhances coordination, reduces operational costs, and adapts effectively to real-time fluctuations. This methodology establishes MASOS as a scalable and intelligent framework for modern, data driven supply chain management.

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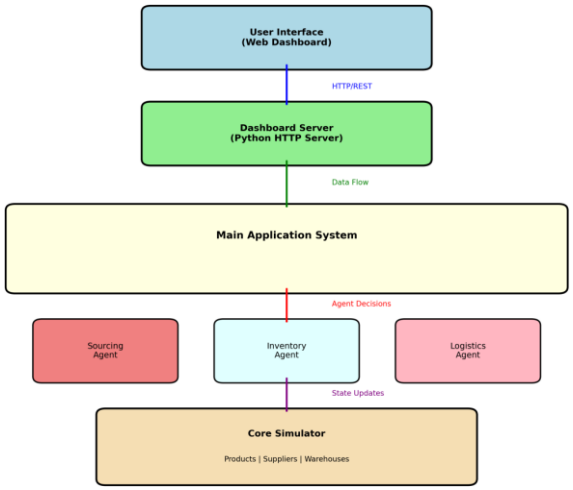
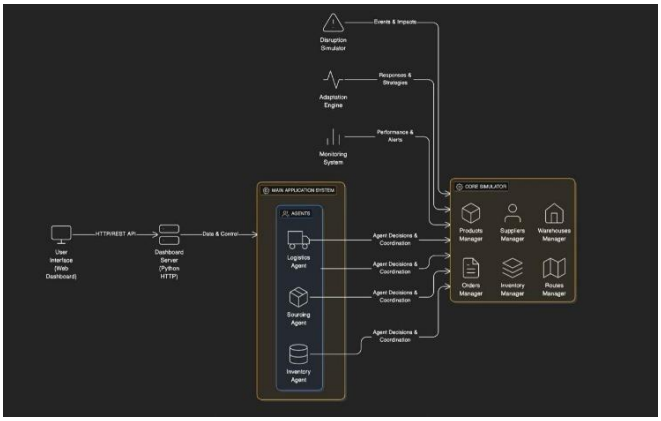
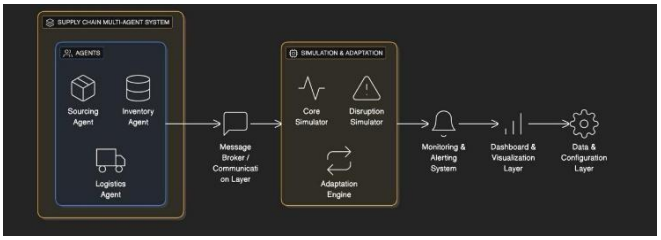


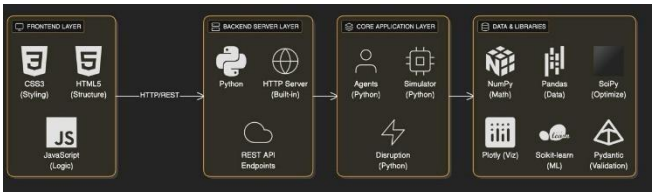
Fig. 2 Proposed Data Flow Diagram of Working Methodology



A. Proposed Component Flow Diagram of Working Methodology



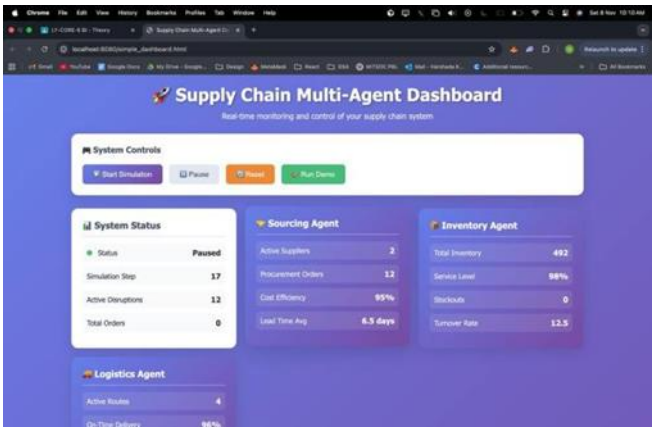
B. Proposed Block Diagram

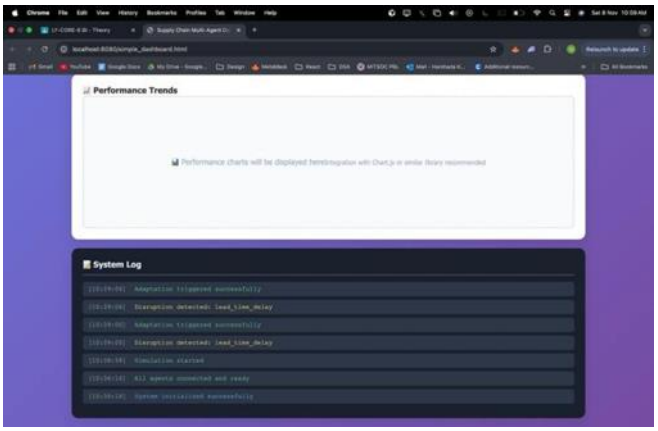


C. Track Stack

OUTPUT

The dashboard looks like this:





CONCLUSION

The Multi-Agent Supply Chain Optimization System (MASOS) enhances supply chain efficiency through intelligent, autonomous agent collaboration. It improves forecasting accuracy, logistics optimization, and decision-making in dynamic environments. Future work includes implementing real-time data integration, reinforcement learning for self-adaptation, and deployment on large-scale distributed environments.

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