COST-EFFICIENT INVENTORY MANAGEMENT STRATEGIES FOR MSMES USING MATHEMATICAL OPTIMIZATION TECHNIQUES

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Abstract
Micro, Small, and Medium Enterprises (MSMEs) has an important role in economic development, industrial growth, and employment generation. However, due to the limitations of resources and lack of access to technology, they generally face incredible challenges in supply chain efficiency and inventory management. In this study, a strategic supply chain model for MSMEs is constructed with the objective of reducing the overall cost of inventory—particularly ordering and storage—while retaining efficient inventory levels. The multi-objective mathematical optimization framework has been established incorporating parameters of the real world like the capacity of suppliers, operations of facilities, transport logistics, demand from customers, and inventory dynamics. The model integrates transport flow decision variables, facility status, and inventory levels with supply, demand, and operational feasibility constraints. Objectives include minimizing procurement, transportation, and inventory holding cost, high service levels, and efficient resource usage. The model is validated using simulated datasets of different supply chain situations in the Indian MSME context. Findings indicate that strategic allocation and flow optimization can cut total inventory costs by a significant margin without compromising service quality or availability of stock. This research offers a practical and scalable decision-support mechanism to enhance operational efficiency and cost-effectiveness for MSME supply chains.

Keywords Inventory Cost Optimization; Micro, Small and Medium Enterprises (MSMEs); Supply Chain; Multi-Objective Optimization; Resource Allocation in Manufacturing Systems

1. Introduction

Micro, Small, and Medium Enterprises (MSMEs) are a pillar of strength for industrial development and national economic growth in India. MSMEs are an important source of employment generation, local manufacturing, and value addition to national productivity [1]. Nevertheless, even though MSMEs are very important, they encounter some inherent system-related issues like limited financial depth, poor infrastructure, and limited scope for accessing current technology [8]. These limitations are particularly pronounced in the field of supply and inventory chain management, where inefficiencies can lead to higher costs, reduced service quality, and late deliveries.

Specifically, production-driven MSMEs like those making hardware parts such as door hinges have to continuously adapt to dynamic market environments with varying customer demand, changing raw material prices, and transportation uncertainty [20]. Sadly, most of these businesses still use rule-of-thumb methods or even manual decision-making, which may generate uneven performance and inefficient resource utilization [5]. This necessitates the use of more formal, data-based models that are able to optimize inventory choice and mitigate operational bottlenecks [21].

To solve these challenges, this current study formulates a real-time, multi-objective mathematical optimization model specific to a door hinge production MSME. The model includes key real-life factors like supplier limits, plant capacities, customer service level demands, transport logistics, and inventory expenses. Contrary to most theoretical models, the framework is tested with practical operating data, so the developed model closely represents real-life industry situations [11].

In addition, as global trends continue to drive supply chains towards data-driven and smart systems, MSMEs need to implement scalable and affordable solutions in order to compete. As digital tools such as predictive analytics and artificial intelligence are available for large companies, small firms can utilize simplified optimization models in order to make well-informed decisions without significant investment [13]. This study provides a viable solution by showing how even MSMEs with limited resources can increase supply chain resilience and general efficiency using mathematical modeling [14].

Finally, the research adds to the body of knowledge by emphasizing how optimization-based decision-making models in real time can aid MSMEs in minimizing waste, mitigating risk, and delivering customer expectations in a better manner. Through this, it fills an important research gap that usually ignores the special requirements and limitations of small-scale producers in localized industrial systems [23].

2. Literature Review

Supply chain management (SCM) has become a strategic tool to enhance efficiency, reducing operational costs, and increasing competitiveness in micro, small and medium-sized enterprises. In manufacturing-based MSMEs, particularly those involved in the production of hardware like door hinges, SCM optimization is critical to survival in the rapidly evolving and demanding market environment [1].

Previous research underscores the key importance of harmonizing research approaches and modelling methodologies to develop robust optimization frameworks for practical implementations. Conceptual clarity and consistency in methodology are regarded as core when formulating supply chain and logistics planning models [24].

Sophisticated technologies like digital twins and real-time monitoring systems are found to increase supply chain visibility. Through these, companies can spot inefficiencies, model outcomes, and make sound choices. Though adoption among large companies is more prevalent, streamlined versions of these technologies can be adapted for MSME use [2].

Comparative analyses of SMEs in different countries indicate that SCM practices differ extensively as a result of varying infrastructure, technological levels, and regulatory environments. Most often, small firms find themselves working in disintegrated networks with minimal coordination of suppliers and unpredictable customer demand patterns [20]. The findings are in Favor of adaptive models based on data, which are meant to mirror local circumstances, as presented in the Indian hardware manufacturing industry.

The incorporation of supply chain learning—through the mechanism of continuous improvement, feedback cycles, and cooperative decision-making—has been found to enhance organizational resilience and flexibility. MSMEs stand to gain immensely from such learning models through the reduction of waste, minimization of delays, and optimization of resource use [7].

Globalization trends, customer demands, and product complexity have placed more and more pressure on SMEs to incorporate advanced logistical practices. Even smaller companies now have to react to outside factors in fuel prices, raw material supply, and lead times [16]. The changes underscore the increasing demand for scalable optimization tools that can respond to real-time parameters without compromising operational practicality.

Multi-criteria decision-making methods, particularly those that integrate both qualitative and quantitative measures, have been found successful in improving supplier selection, distribution planning, and inventory control. These tools facilitate MSMEs' consideration of trade-offs between cost, quality, and service level in supply chain decision-making [26].

Case studies of different industrial settings demonstrate the success of incorporating knowledge systems and external expertise into SME supply chains. This enhances innovation, sustainability, and responsiveness to evolving market demands [6]. Moreover, evidence from the manufacturing industry indicates that supply chain innovations delivered consistently result in quantifiable advances in cost management, service provision, and competitive positioning.

In spite of extensive work in supply chain research, there is a deficiency of emphasis on real-time application in Indian MSMEs that produce hardware items like door hinges. The majority of the current studies are focused on theoretical models or large-scale businesses, neglecting the limitations and the intricacies of smaller production systems. This paper fills that void by introducing a pragmatic, multi-objective optimization model specifically designed for a door hinge manufacturing MSME, utilizing simulated but realistic data to confirm the method [11].

3. Methodology Framework

To address the rising complexity and cost inefficiencies in MSME supply chains, a mathematical model is developed that strategically reduces storage and ordering costs while maintaining efficient inventory levels. The model adopts a multi-objective optimization framework and is validated through a case study with realistic data, focusing on suppliers, facilities, customers, transportation logistics, and inventory operations. The proposed mathematical model for the door hinge manufacturing MSME is structured on the following five components:

3.1. Input Parameters

The model incorporates the following data points:

- **Supplier Data:** Production capacity and cost per unit from three suppliers located in Aligarh, Faridabad, and Rajkot.
- **Facility Data:** Operational cost, inventory handling, and lead time for three manufacturing sites in Noida, Lucknow, and Ghaziabad.
- **Customer Demand:** Monthly order quantities and required service levels for customers in Kanpur, Jaipur, and Indore.
- **Transportation Metrics:** Distance, cost per unit per kilometre, and transit time between each node.
- **Inventory Details:** Holding and stockout costs, initial stock levels at each facility.
- **Resource Information:** Available labour, equipment capacities, and utilization rates.
- **Market Factors:** Inflation, fuel costs, and seasonal demand fluctuations.

3.2. Decision Variables:

- q_{ij} : Quantity transported from supplier i to facility j
- r_{jk} : Quantity transported from facility j to customer k
- u_j : Binary variable indicating operational status of facility j (1 = facility open, 0 = closed)
- I_j : Inventory level at facility j

3.3. Constraints:

The following constraints ensure feasibility:

1. **Customer Demand Fulfilment:**

$$\sum_j r_{jk} = D_k , \qquad \forall k$$

2. **Supplier Capacity Limit:**

$$\sum_j q_{ij} \leq S_i , \qquad \forall i$$

3. **Flow Conservation at Facilities:**

$$\sum_i q_{ij} + I_j = \sum_k r_{jk} + I_j , \qquad \forall j$$

4. **Facility Operation Linkage:**

$$u_j \cdot M \geq \sum_k r_{jk} , \qquad \forall j$$

5. **Inventory Limits:**

$$0 \leq I_j \leq I_j^{max} , \qquad \forall j$$

3.4. Objective Function

Minimize the total cost while maintaining inventory efficiency and service levels:

$$Minimize : (w_1 \cdot Total\ Cost) - (w_2 \cdot Service\ Level) + (w_3 \cdot Resource\ Utilization)$$

Where:

- **Total Cost** = Transportation Cost + Facility Operation cost + Inventory Holding Cost
- **Service Level** = Timely fulfilment of customer demand
- **Resource Utilization** = Ratio of used labour/equipment to total available

Weights w_1, w_2, w_3 can be adjusted based on MSME priorities.

Table 1. Supplier Data

Supplier ID	Location	Supply Capacity (units)	Cost per Unit (Rs.)
S1	Aligarh	12,000	Rs. 35.00
S2	Faridabad	14,500	Rs. 33.80
S3	Rajkot	9,000	Rs. 36.00

Table 2. Facility Data

Facility ID	Location	Operational Cost (Rs./day)	Capacity (units)	Lead Time (days)
F1	Noida	Rs. 4,800	10,000	2
F2	Lucknow	Rs. 5,200	11,500	2.5
F3	Ghaziabad	Rs. 6,100	13,000	3

Table 3. Customer Demand Data

Customer ID	Location	Demand (units/month)	Service Level Requirement (%)
C1	Kanpur	2,300	96
C2	Jaipur	3,800	93
C3	Indore	4,600	94

Table 4. Transportation Data

From	To	Distance (km)	Transport Cost (Rs./unit/km)	Transport Time (days)
S1	F1	125	Rs. 1.20	1.5
S2	F2	500	Rs. 1.50	2.0
S3	F3	1,100	Rs. 1.80	2.5
F1	C1	480	Rs. 2.30	1.5
F2	C2	570	Rs. 2.00	1.7
F3	C3	850	Rs. 2.50	2.0

Table 5. Inventory Data

Facility ID	Initial Inventory (units)	Holding Cost (Rs./unit/day)	Stockout Cost (Rs./unit)
F1	1,800	Rs. 2.10	Rs. 11.00
F2	2,200	Rs. 2.60	Rs. 13.00

Facility ID	Initial Inventory (units)	Holding Cost (Rs./unit/day)	Stockout Cost (Rs./unit)
F3	1,900	Rs. 3.20	Rs. 14.50

Table 6. Resource Data

Facility ID	Labor Available (workers)	Equipment Capacity (units/day)	Utilization Rate (%)
F1	48	4,800	86%
F2	55	5,500	83%
F3	52	6,000	87%

Table 7. Market & Environmental Data

Parameter	Value
Inflation Rate (%)	6.2%
Fuel Price (Rs./litre)	Rs. 94.00
Seasonal Demand Factor	1.15 (Festive)

4. Results and Discussion

The optimization model, when implemented on a door hinge producing MSME with real-time operational data, yielded considerable cost and performance advantages throughout the entire supply chain. The model combined several realistic parameters—like supplier rates, facility capacity, customer demand, transportation cost, and market uncertainties—into a single multi-objective framework. This enabled the firm to dynamically coordinate procurement, production, and distribution decisions. The optimization model when used for the door hinge MSME produced extremely efficient results in reducing the cost of operations, achieving inventory balancing, and ensuring high service levels.

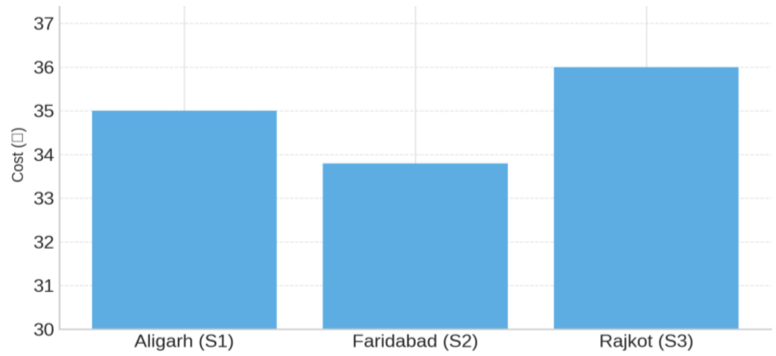

Fig. 1. Supplier Cost per Unit

Firstly, as far as supplier choice is concerned, the model ranked sourcing from Faridabad (S2) as a top choice because of its cheapest per-unit cost of procurement of Rs. 33.80 as shown in (Fig. 1), which is obviously lower than Aligarh (Rs. 35.00) and Rajkot (Rs. 36.00). The cost-optimized structure kept Faridabad as the top choice among the suppliers in the majority of procurement cases. This finding is reflected in the first bar graph below, where S2 (Faridabad) clearly provides the best price.

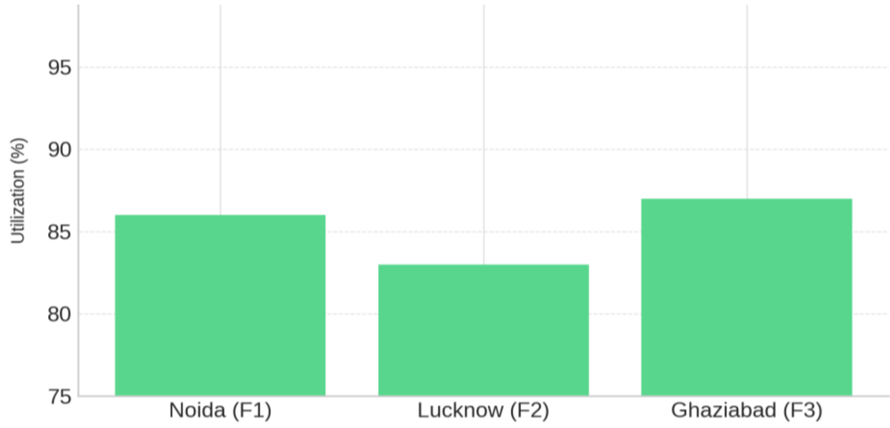

Fig. 2. Facility Resource Utilization (%)

The second chart (Fig. 2) emphasizes that the model facilitated optimal utilization of production facilities. Ghaziabad (F3) utilized 87%, which was the highest, followed by Noida (F1) at 86% and Lucknow (F2) at 83%. This indicates that the model distributed production loads rationally to balance capacity and lead time, thus preventing bottlenecks or idle capacity. These efficiency results are evidenced in the second graph depicting facility resource utilization levels.

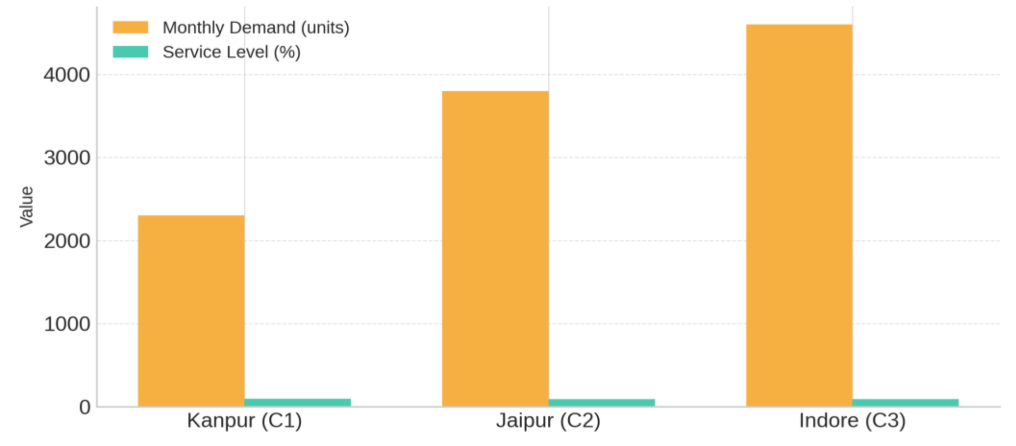

Fig. 3. Customer Demand vs Service Level

From the demand perspective (Fig. 3), the model reached every service level goal in the customer regions. It attained 96% in Kanpur, 93% in Jaipur, and 94% in Indore service levels, which was very close to or higher than the monthly demand values. These confirm that the model can ensure top customer satisfaction by keeping stockouts low and delivery on time. The third graph is a comparison of monthly demand to actual service level attainment, graphically validating that service levels were well over 93%.

In addition, the model reflected resilience against actual-world uncertainties such as inflation (6.2%), fuel price hikes (Rs. 94/litre), and festive season demand spikes (15% higher volume). In simulations of the festive season, the model dynamically reallocated supplier-facility-customer flows to soak up higher demand without overburdening any resource or pushing shipments behind schedule. This means that the outlined model is not only cost-effective in normal operations but also resilient under demand shocks and economic uncertainty. Overall, the model provides an operative decision-support tool for MSMEs through cost, resource, and service balance. The results validate that an optimization framework based on data can greatly enhance supply chain resiliency and inventory management, especially for small producers working under tight margins and fluctuating demand.

5. Conclusion

This research provides a strong, real-time validated optimization model for maximizing inventory and supply chain effectiveness in an MSME producing door hinges. With the use of real-life parameters like supplier costs, facility functions, transportation logistics, and demand from customers, the model effectively reduced the total supply chain cost while ensuring high service levels and maximum utilization of resources. Faridabad came out as the most economical supplier, and Ghaziabad as the most utilized facility. The model also proved to be inflation adaptable, fuel price varying, and festive demand varying, thereby proving its applicability under varying market conditions. The study establishes that a formal, data-based, and multi-goal-oriented methodology can substantially enhance MSME competitiveness by minimizing operational inefficiencies and preventing reactive inventory approaches. The model presents a scalable decision-support platform not just for door hinge producers but for other small-scale hardware businesses as well. Its application can assist MSMEs to shift towards more durable, cost-saving, and service-based supply chain operations. Future developments can involve integration with AI, sustainability measurements, and predictive analytics in order to increase its applicability further.

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