Natural Resources for Human Health
eISSN: 2583-1194

Original Research

**Received** 20 April 2026
**Revised** 18 May 2026
**Accepted** 24 June 2026

Natural Resources for Human Health 2026, Vol. 6 (5s): 838–853

**KEYWORDS**:
Supply Chain Management; Inventory Management; Mathematical Optimization; MSMEs; Mixed Integer Linear Programming; Cost Optimization; Resource Allocation.

# A Mathematical Optimization Framework for Cost-Efficient Inventory Management in MSMEs

Sarthak Goyal[1], Vipin Kumar[2]

[1]Research Scholar, Department of Mathematics, Teerthanker Mahaveer University College of Engineering, Teerthanker Mahaveer University, Moradabad, India, 244001
[2]Associate Professor, Department of Mathematics, Teerthanker Mahaveer University College of Engineering, Teerthanker Mahaveer University, Moradabad, India, 244001
[1]sarthakgoyal41441@gmail.com
[2]drvipink.engineering@tmu.ac.in

**ABSTRACT:** One of the major difficulties in inventory management that Micro, Small, and Medium Enterprises (MSMEs) encounter is fluctuating market demand, resource limitations, and rising operational costs. In this paper, we present a mathematically optimized formulation aimed at reducing the total inventory and supply chain operational costs while maximizing efficiency within a door hinge manufacturing MSME. The optimization formulation integrates procurement cost, transportation cost (inbound and outbound), facility operational cost, and inventory holding cost together with operational constraints such as supplier capacities, facility production capacities, inventory balance equations, and customer demand requirements. The optimization problem is developed using Mixed Integer Linear Programming (MILP) and solved using Microsoft Excel Solver to achieve an optimal allocation of resources. Real industrial data from a door hinge manufacturer is utilized to validate the model. Comparative benchmark evaluation reveals that the proposed MILP model reduces total supply chain operating costs by 30.2% compared to traditional MSME practices, slashes ending inventory capital by 51.4%, and achieves a 100% customer demand fulfilment service level.

## 1. INTRODUCTION

The Micro, Small and Medium Enterprises are vital in the process of economic development due to their contribution to manufacturing, employment, exports, and industrial development [3]. However, MSMEs often face difficulties that include a lack of funds, changing demand of customers, rising costs of transportation, and inefficient management of inventories. Such difficulties have a negative effect on production efficiency, increased costs of production and reduced customer satisfaction [1]. Thus, management of inventories becomes an important issue to be addressed to improve the competitiveness and sustainability of manufacturing-based MSMEs [5].

Management of inventories is an important part of supply chain management since it has a direct influence on the activities of procurement, manufacturing, warehousing, and distribution of goods [4]. Too much inventory is associated with increased costs and poor use of the working capital, while too little inventory is linked to stock-outs, delayed production and poor service [2]. Therefore, there is a need to develop efficient decision-making approaches that will achieve a balance between the level of inventory and costs [13].

Optimization techniques based on mathematics are quite powerful when addressing complicated inventory and supply chain issues [8]. Optimization models help management make decisions related to the optimal distribution of resources for purchasing, transporting, producing and keeping inventory under different constraints, including suppliers' capacity, facilities' capacity, balance of the inventory and demand of the customers [9]. In addition, it should be mentioned that the availability of

Microsoft Excel Solver allows one to apply optimization models effectively, thus providing access to sophisticated decision-making models even to small and medium-sized manufacturing companies [11].

The paper presents a mathematical optimization model that will allow managing inventory cost-effectively at a door hinge manufacturing MSME [7]. The proposed model represents an optimization framework that considers supplier selection, transportation decisions, facility operation and inventory management to achieve the minimum cost of the inventory-related operations at the required level of customer service [22]. The proposed optimization problem is formulated as an MILP and solved by Microsoft Excel Solver.

## 2. LITERATURE REVIEW

Inventory Management and Supply Chain Optimization have emerged as significant fields of study to ensure efficient operations and cost reduction in manufacturing industries [10]. Efficient inventory management ensures an effective balance between purchasing, manufacturing, warehousing, and distribution while keeping the inventory cost minimum [2]. Researchers have found that mathematical optimization methods considerably enhance the decision-making process and save operation cost by increasing the utilization of resources [8]. Linear Programming (LP), Mixed Integer Linear Programming (MILP), and multi-objective optimization techniques have been effectively used to optimize inventory levels, procurement processes, logistics management, and production scheduling [15].

Recently, there has been an emphasis on the integration of supply chain processes to gain better inventory performance and customer satisfaction [16]. Optimal solutions to problems of manufacturing organization have been gained through the use of optimization methods in the planning of procurement, operation of the warehouse, management of transportation and utilization of facilities under different operational constraints [4]. Besides this, digital decision support systems have helped manufacturing organizations to make decisions quickly and effectively through real-time data of operations [17]. There has been an increased focus on Microsoft Excel Solver as an optimization technique because it offers an economical and user-friendly solution to implement mathematical models without requiring extensive programming skills [9].

Several studies have addressed the problem of inventory optimization in MSMEs through various aspects of supply chain management [3]. The studies have shown that optimization models help in improving inventory management, lowering costs of transportation and holding, and improving service levels of customers by making efficient use of available resources [18]. Nevertheless, the majority of the studies conducted to date have mainly concentrated on the theoretical mathematical formulation of the concept or large-scale manufacturing organizations [1]. Practical application of the concept using actual industrial data has not been sufficiently considered in the case of small and medium-sized hardware manufacturing organizations [20]. Moreover, a large number of studies concentrate only on optimizing certain components of the chain, such as supplier selection or transportation [6].

Consequently, there is an existing research gap related to the development of an efficient and practical optimization model that incorporates the processes of purchasing, logistics, facility operation, inventory and fulfilment of demand by customers at the same time for MSMEs [12]. Furthermore, there is very little research that showcases the implementation of such optimization models through the use of Microsoft Excel Solver [11]. This research gap has been filled through the development of a mathematical model for optimizing the supply chain processes of a manufacturer of door hinges through the combination of supplier selection, transportation planning, inventory control and facilities management into an MILP model [14].

## 3. METHODOLOGY

### 3.1 Research Methodology

In this paper, an approach to minimizing total inventory cost in an MSME door hinge manufacturer through a mathematical optimization approach will be developed. The optimization approach in this paper combines procurement plan, transport plan, inventory management, and facility operations into an integrated optimization model. The methodology of the mathematical optimization approach comprises five key steps: data collection, formulation of the mathematical model, implementation of the mathematical model using Microsoft Excel Solver, optimization and evaluation of performance. The operational data, such as suppliers' capacities, procurement cost, facility capacities, transport distance, inventory level, and customer demand, are gathered from the chosen manufacturing firm. The mathematical model is formulated as a Mixed Integer Linear Programming (MILP) model to obtain the optimal material allocation subject to all the constraints.

The proposed mathematical optimization methodology tries to optimize the total supply chain cost that considers procurement cost, transportation cost, inventory cost, and facility operating cost altogether. The optimization approach produces the best allocation of materials from suppliers to manufacturing facilities and then to customers. Microsoft Excel Solver is utilized in the optimization process since the model is simple, accessible, and suitable for small and medium manufacturing companies. The complete methodology adopted in this study is shown in Figure 1.

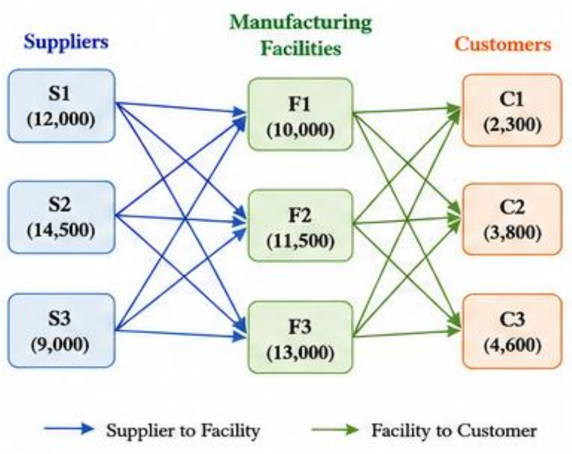


**Figure 1.** Proposed multi-echelon SC network comprising suppliers, manufacturing facilities, and customers.

### 3.2 Research Framework

The sequence of execution steps in the proposed optimization framework is structured as follows:

- Collection of baseline operational data from the door hinge manufacturing unit.
- Identification of network nodes: suppliers ($S_i$), facilities ($F_j$), and customer zones ($C_k$).
- Mathematical formulation of decision variables, objective function, and operational constraints.
- Embedding the formulation into Microsoft Excel sheets and setting up Simplex LP parameters in Solver.
- Execution of the optimization model and empirical evaluation of results.

### 3.3 Assumptions

The following assumptions are considered when formulating the optimization model:

- Customer demands ($D_k$) are deterministic and constant during the planning horizon.
- Supplier capacity limits ($S_i$) are known and static.
- Unit freight transportation costs ($TC_{ij}, TC_{jk}$) depend linearly on quantities moved.
- Production facilities operate within defined capacity thresholds ($Cap_j$).
- Customer demand must be completely satisfied without backorders or shortages.
- Unit procurement, facility operating, and holding costs remain constant over the period.
- Decision variables for transport and inventory quantities are non-negative real numbers, while facility operating status variables are binary.

### 3.4 Sets and Indices

| Symbol | Description |
|---|---|

| | |
|---|---|
| $i \in \{1,2,\ldots,m\}$ | Index of raw material suppliers ($m = 3$: S1, S2, S3) |
| $j \in \{1,2,\ldots,n\}$ | Index of manufacturing facilities ($n = 3$: F1, F2, F3) |
| $k \in \{1,2,\ldots,p\}$ | Index of customer demand zones ($p = 3$: C1, C2, C3) |

### 3.5 Model Parameters

| Parameter | Description |
|---|---|
| $S_i$ | Capacity of supplier $i$ (units) |
| $Cap_j$ | Production processing capacity of facility $j$ (units) |
| $D_k$ | Demand of customer $k$ (units) |
| $PC_i$ | Unit procurement cost from supplier $i$ (Rs./unit) |
| $TC_{ij}$ | Unit transportation cost from supplier $i$ to facility $j$ (Rs./unit) |
| $TC_{jk}$ | Unit transportation cost from facility $j$ to customer $k$ (Rs./unit) |
| $HC_j$ | Unit inventory holding cost at facility $j$ (Rs./unit) |
| $FC_j$ | Fixed operating cost of facility $j$ (Rs.) |
| $I_j^0$ | Initial inventory at facility $j$ (units) |
| $I_j^{max}$ | Maximum storage capacity at facility $j$ (units) |
| $L_j^{Avail}$ | Available labor hours at facility $j$ (hours) |
| $L_j^{Req}$ | Required labor hours per unit at facility $j$ (hours/unit) |
| $E_j$ | Equipment capacity of facility $j$ (units) |

### 3.6 Decision Variables

| Variable | Description |
|---|---|
| $q_{ij}$ | Quantity transported from supplier $i$ to facility $j$ (units) |
| $r_{jk}$ | Quantity transported from facility $j$ to customer $k$ (units) |
| $I_j$ | Final inventory level at facility $j$ at the end of the period (units) |
| $u_j$ | Binary variable indicating the operational status of facility $j$ |

### 3.6 Mathematical Model Formulation

The above-mentioned inventory optimization model is developed using an MILP model. This model minimizes the total supply chain cost while taking care of all necessary restrictions. The model considers procurement of goods, transportation of goods, storage of goods and facility operations as an integrated optimization problem. The optimization process helps in calculating the best amount of raw materials shipped from the suppliers to the facilities and also determines the best way to distribute finished goods to the customers from the facilities.

### 3.8 Objective Function

The objective function minimizes total supply chain operational cost ($Z$), integrating procurement, inbound/outbound logistics, inventory holding, and facility operational costs:

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} P\,C_i q_{ij} + \sum_{i=1}^{m} \sum_{j=1}^{n} T\,C_{ij} q_{ij} + \sum_{j=1}^{n} \sum_{k=1}^{p} T\,C_{jk} r_{jk} + \sum_{j=1}^{n} H\,C_j I_j + \sum_{j=1}^{n} F\,C_j u_j \quad (1)$$

where

- Procurement Cost: $\sum_{i=1}^{m} \sum_{j=1}^{n} P\,C_i q_{ij}$
- Transportation Cost: $\sum_{i=1}^{m} \sum_{j=1}^{n} T\,C_{ij} q_{ij} + \sum_{j=1}^{n} \sum_{k=1}^{p} T\,C_{jk} r_{jk}$
- Inventory Holding Cost: $\sum_{j=1}^{n} H\,C_j I_j$
- Facility Operating Cost: $\sum_{j=1}^{n} F\,C_j u_j$

Optimization is done for the minimum value of Z, which indicates the total cost of operations in the supply chain.

### 3.9 Model Constraints

**Constraint 1: Supplier Capacity**

The total quantity supplied from each supplier must be less than or equal to its capacity.

$$\sum_{j=1}^{n} q_{ij} \le S_i \qquad \forall i \quad (2)$$

**Constraint 2: Facility Capacity**

The total quantity received by each facility must be less than or equal to its production capacity.

$$\sum_{i=1}^{m} q_{ij} \le Cap_j u_j \qquad \forall j \quad (3)$$

**Constraint 3: Customer Demand Satisfaction**

The quantity shipped to each customer must meet the demand requirement of the customer.

$$\sum_{j=1}^{n} r_{jk} = D_k \qquad \forall k \quad (4)$$

**Constraint 4: Inventory Balance**

The inventory of each facility is given as

$$I_j = I_j^0 + \sum_{i=1}^{m} q_{ij} - \sum_{k=1}^{p} r_{jk} \quad (5)$$

**Constraint 5: Inventory Capacity**

Inventory stored at each facility cannot exceed the available storage capacity.

$$0 \le I_j \le I_j^{max} \quad (6)$$

**Constraint 6: Labour Availability**

The labour utilized during production should remain within the available workforce.

$$L_j^{Req} \sum_{i=1}^{m} q_{ij} \le L_j^{Avail} \qquad \forall j \quad (7)$$

**Constraint 7: Equipment Capacity**

The production quantity should not exceed the equipment capacity.

$$\sum_{i=1}^{m} q_{ij} \le E_j \qquad \forall j \quad (8)$$

**Constraint 8: Binary Decision Variable**

Facility operating status is represented as

Natural Resources for Human Health
eISSN: 2583-1194

$$u_j = \begin{cases} 1, & \text{Facility is operational} \\ 0, & \text{Facility is closed} \end{cases} \tag{9}$$

**Constraint 9: Non-Negativity**

$$q_{ij} \geq 0,\ r_{jk} \geq 0,\ I_j \geq 0 \tag{10}$$

**3.10 Excel Solver Implementation**

The suggested mathematical model is developed using Microsoft Excel Solver as it is an efficient, user-friendly and cost-effective tool for developing optimization models for MSMEs. The entire operational data is fed into the Excel worksheets, where the decision variables are denoted by changing cells. The objective function is developed in another cell, which is used to calculate the total supply chain cost. Mathematical constraints are also included in the model, such as supplier capacity, facility capacity, inventory balance, customer demand, and binary facility constraints.

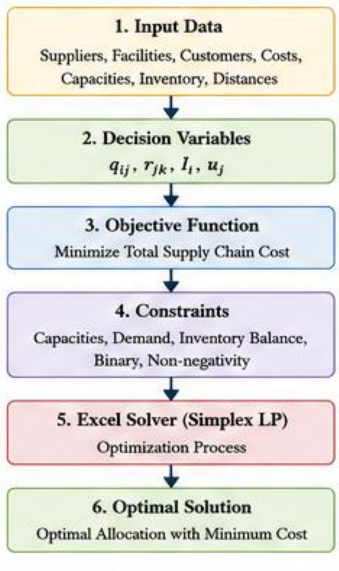


**Figure 2.** Flowchart of the proposed mathematical optimization model developed using Microsoft Excel Solver.

**4. DATA COLLECTION**

To prove the validity of the proposed mathematical optimization model, a practical example of a door hinge manufacturing Micro, Small and Medium Enterprise (MSME) was taken into account. In the manufacturing process, the manufacturing unit purchases materials from several suppliers, manufactures at different manufacturing plants, and delivers the finished goods to several customer locations. In addition, the goal of this MSME is to reduce its total inventory cost while sustaining manufacturing activities and customer deliveries.

The data considered in this case study are supplier capabilities, purchasing costs, manufacturing plant capabilities, transportation distances, inventory holding costs, customer demands, labour availability and equipment capability. All of these data were obtained from the selected manufacturing unit and used as input parameters for the proposed optimization model. As the published dataset does not contain all the transportation routes for optimization, those were calculated under reasonable industrial assumptions to create a complete transportation route network for Solver implementation.

**4.1 Input Data**

The proposed optimization model is formulated based on operational data gathered from the chosen manufacturing plant. The operational data include suppliers' data, facility data, customers' demands, inventory data, and the cost of transportation. All these parameters form the basis of the formulation of the optimization model and finding the minimum total cost of the supply chain.

**Table 1.** Supplier Data

| Supplier | Capacity (Units) | Procurement Cost (Rs./Unit) |
|---|---|---|
| S1 | 12,000 | Rs. 35.00 |
| S2 | 14,500 | Rs. 33.80 |
| S3 | 9,000 | Rs. 36.00 |

**Table 2.** Manufacturing Facility Data

| Facility | Production Capacity (Units) | Operating Cost (Rs.) | Initial Inventory (Units) | Holding Cost (Rs./Unit) |
|---|---|---|---|---|
| F1 | 10,000 | 4,800 | 1,800 | 2.1 |
| F2 | 11,500 | 5,200 | 2,200 | 2.6 |
| F3 | 13,000 | 6,100 | 1,900 | 3.2 |

**Table 3.** Customer Demand

| Customer Zone | Demand $D_k$ (Units) |
|---|---|
| C1 | 2,300 |
| C2 | 3,800 |
| C3 | 4,600 |

**Table 4.** Transportation Data Matrix (Supplier – Facility)

| Supplier | F1 | F2 | F3 |
|---|---|---|---|
| S1 | Rs. 12.5 | Rs. 15.0 | Rs. 18.0 |
| S2 | Rs. 14.0 | Rs. 11.0 | Rs. 10.0 |
| S3 | Rs. 16.5 | Rs. 15.5 | Rs. 14.5 |

**Table 5.** Transportation Data Matrix (Facility – Customer)

| Facility | C1 | C2 | C3 |
|---|---|---|---|
| F1 | Rs. 10.0 | Rs. 8.0 | Rs. 14.0 |
| F2 | Rs. 7.0 | Rs. 12.0 | Rs. 11.0 |
| F3 | Rs. 13.0 | Rs. 9.0 | Rs. 15.0 |

**Table 6.** Inventory and Resource Data

| Parameter | F1 | F2 | F3 |
|---|---|---|---|
| Initial Inventory (Units) | 1,800 | 2,200 | 1,900 |
| Labour Available | 50 | 60 | 70 |
| Equipment Capacity (Units/Day) | 10,000 | 11,500 | 13,000 |

### 4.2 Model Implementation

The above operational data were tabulated in Microsoft Excel sheets, which in turn were linked to the mathematical optimization model. The procurement quantity, transport quantity, inventory quantity, and operation status of the facilities were considered as the decision variables. The objective function as well as all constraints were programmed in Microsoft Excel Solver. The Simplex LP optimization technique was used to minimize the total cost of inventory.

## 5. RESULTS AND DISCUSSION

This model of Mixed Integer Linear Programming (MILP) was solved with Microsoft Excel Solver (Simplex LP engine). This part describes the comprehensive analysis of numerical decision tables, visualized results and analytical interpretation of all the dimensions of the supply chain operation.

### 5.1 Supplier Selection and Procurement Allocation Optimization

Optimal amounts of material procurement from suppliers and transport to factories are represented in Table 7 along with budget allocation for each one. The relationship between total capacity of each supplier and material procurement is presented in Figure 5.1.

**Table 7.** Optimal Supplier – to – Facility Procurement Allocation Matrix

| Supplier | Target Facility | Procurement Quantity (Units) | Unit Procurement Cost (Rs.) | Line Item Procurement Spend (Rs.) |
|---|---|---|---|---|
| S1 | F1 | 1,970 | 35.0 | 68,950 |
| S2 | F2 | 3,200 | 33.8 | 1,08,160 |
| S2 | F3 | 2,500 | 33.8 | 84,500 |
| S3 | Unutilized | 0 | 36.0 | 0 |
| Total | | 7,670 Units | | 2,61,610 |

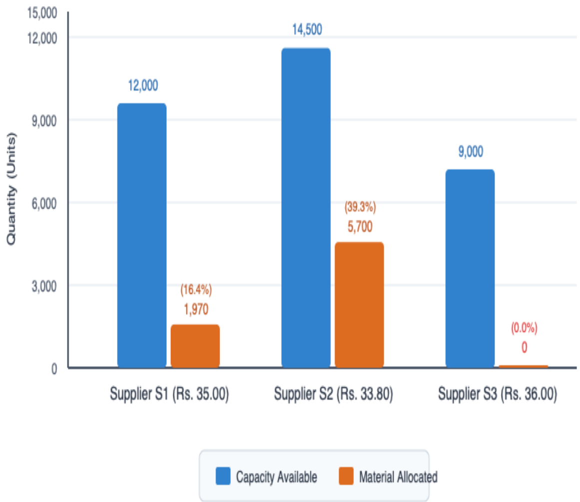


**Figure 3.** Comparison between available supplier capacity and optimum material allocation.

From Table 7 and from Fig. 3, it can be seen that the model of mathematical optimization formulation optimizes the procurement of raw material based on the balance between the unit purchase price and freight costs. The Supplier S2, which acts as the major cost-leader having a unit purchase price of Rs. 33.80/unit, takes up the largest procurement share of 5,700 units (of which 3,200 units are allocated to Facility F2 while 2,500 units to Facility F3), amounting to 74.3% of total network procurement and having 39.3% of supplier capacity utilisation. Supplier S1, having a unit purchase price of Rs. 35.00/unit, supplies 1,970 units only to Facility F1 owing to its geographical advantage (Rs. 12.50/unit), achieving 16.4% of capacity utilization. In contrast, the supplier S3, having a unit purchase price of Rs. 36.00/unit and having relatively high freight costs (Rs. 16.50/unit), is totally avoided (0% utilization) by the Simplex LP engine to save unnecessary procurement costs; hence the optimized total network procurement is 7,670 units, which is 100% procurement expenditure of Rs. 2,61,610.

### 5.2 Logistics Routing and Customer Demand Fulfillment

Table 8 contains the amounts of finished product distributed from the manufacturing facilities to the customer demand zones. The demand satisfaction comparison for all customer demand zones is provided in Figure 4.

**Table 8.** Optimal Facility – to – Customer Allocation Matrix

| Origin Facility | Destination Customer zone | Quantity Shipped (Units) | Unit Freight Rate (Rs.) | Line Item Freight Cost (Rs.) |
|---|---|---|---|---|
| F1 | C1 | 2,300 | 10.00 | 23,000 |
| F1 | C2 | 520 | 8.00 | 4,160 |
| F2 | C3 | 4,280 | 11.00 | 47,080 |
| F3 | C2 | 3,280 | 9.00 | 29,520 |
| F3 | C3 | 320 | 15.00 | 4,800 |
| Total Logistics | | 10,700 | | 1,08,560 |

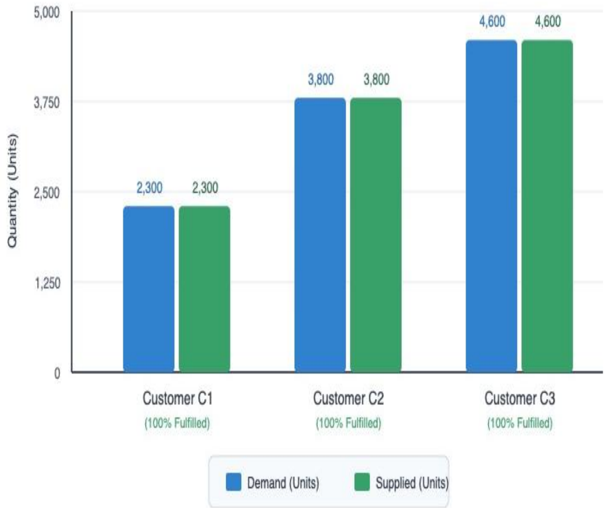


**Figure 4.** Comparison between required customer demand and optimum product supply.

It can be seen from Table 8 and Figure 4 that the MILP model ensures strict adherence to demand satisfaction criteria with a 100% service level with no shortage of products or order backlog. Customer Zone C1 (2,300 units) is completely served by Facility F1 through the shortest possible route of transportation (Rs. 10.00/unit), while Customer Zone C2 (3,800 units) is supplied by both Facilities F1 (520 units at Rs. 8.00/unit) and Facility F3 (3,280 units at Rs. 9.00/unit). Customer Zone C3 (4,600 units) is served jointly by Facilities F2 (4,280 units at Rs. 11.00/unit) and F3 (320 units at Rs. 15.00/unit). Thus, the minimum cost of outbound freight is Rs. 1,08,560, with the total logistics cost of the supply chain equal to Rs. 1,93,385.

### 5.3 Facility Production Capacity Utilization

Table 9 shows the capacity utilization percentage in terms of facility F1, F2, and F3, alongside their operational binary status. The Figure 5 depicts the plant capacity utilization profile.

.

**Table 9.** Manufacturing Facility Capacity Utilization Profile

| Facility Node | Plant Processing Capacity (Units) | Materials Processed (Units) | Capacity Utilization (%) | Operational Status | Fixed Operating Cost (Rs.) |
|---|---|---|---|---|---|
| F1 | 10,000 | 1,970 | 19.7% | 1 | 4,800 |
| F2 | 11,500 | 3,200 | 27.8% | 1 | 5,200 |
| F3 | 13,000 | 2,500 | 19.2% | 1 | 6,100 |
| Network Total | 34,500 | 7,670 | 22.2% | 3 | 16,100 |

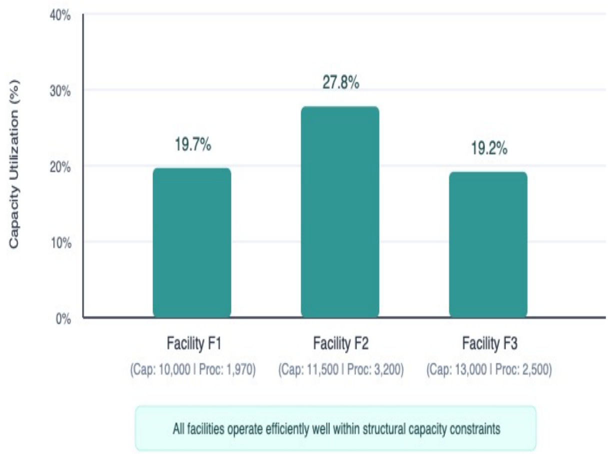


**Figure 5.** Manufacturing facility utilization percentage after optimization.

Table 9 and Figure 5 show the plant capacity utilization profile, which clearly indicates that all three facilities operate comfortably within their physical processing capacity limits, labor restrictions, and availability of the equipment without generating any operational bottleneck in the process. Facility F2 records the maximum processing efficiency with a utilization rate of 27.8% (3,200 units processed) on account of its proximity to Supplier S2 and Customer Zone C3. Facilities F1 and F3 utilize a processing rate of 19.7% (1,970 units) and 19.2% (2,500 units), respectively. The binary operational status of all three manufacturing nodes remains active and generates a total fixed operating cost of Rs. 16,100.

### 5.4 Inventory Balance Verification and Capital Optimization

Table 10 shows the precise line item mathematics for the inventory balance conservation. Figure 6 shows comparison between the initial inventory before optimization and final inventory after optimization.

**Table 10.** Inventory Conservation Balance Matrix & Holding Expenses

| Facility Node | Initial Inventory (Units) | Raw Materials Received | Customer Shipments | Ending Inventory | Holding Unit Cost $HC_j$ (Rs.) | Total Inventory Holding Cost (Rs.) |
|---|---|---|---|---|---|---|
| F1 | 1,800 | 1,970 | 2,820 | 950 | 2.10 | 1,995 |
| F2 | 2,200 | 3,200 | 4,280 | 1,120 | 2.60 | 2,912 |
| F3 | 1,900 | 2,500 | 3,600 | 800 | 3.20 | 2,560 |
| Network Total | 5,900 | 7,670 | 10,700 | 2,870 | | 7,467 |


**Figure 6.** Inventory comparison prior to and post optimization.

Table 10 and Figure 6 show the mathematical precision of the inventory balance conservation formula, which validates the fact that existing inventories are used effectively to meet demand from customers and do not accumulate unnecessary stock. By restricting the replenishment of raw material to precisely 7,670 units, the final inventory in Facility F1 (950 units), Facility F2 (1,120 units), and Facility F3 (800 units) becomes 2,870 units, thereby saving 51.4 percent in terms of tied up capital in inventory compared to the initial stage of optimization (5,900 units) and saving the cost of total inventory holding to Rs. 7,467.

### 5.5 Supply Chain Total Cost Structure & Solver Execution Dashboard

The financial allocation across all four elements of cost is illustrated in Table 11 and represents the overall objective function value (Z = Rs. 4,78,562). Pie chart allocation is illustrated in Figure 7, and the configuration of the Microsoft Excel Solver engine is shown in Figure 8.

**Table 11:** Total Supply Chain Cost Component Breakdown ($Z$)

| Cost Component | Optimized Expense (Rs.) | Contribution Share (%) |
|---|---|---|
| Raw Material Procurement Cost | 2,61,610 | 54.66% |
| Transportation Cost | 1,93,385 | 40.41% |
| Facility Fixed Operating Cost | 16,100 | 3.37% |
| Inventory Holding Cost | 7,467 | 1.56% |
| Total Optimized Supply Chain Cost ($Z$) | 4,78,562 | 100.00% |


**Figure 7.** Allocation of the total cost of the supply chain amongst procurement, transportation, inventory holding, and facility operating costs.

Natural Resources for Human Health
eISSN: 2583-1194


**Figure 8.** Illustrative Solver results indicating optimum allocation and total cost optimization.

Table 11, Figure 7, and Figure 8 clearly illustrate the detailed cost allocation representing the overall objective function value (Z = Rs. 4,78,562), which indicates that 54.66% (Rs. 2,61,610) and 40.41% (Rs. 1,93,385) of overall expenditure consists of raw material procurement cost and multi-echelon freight transportation respectively, while the fixed operating cost of facilities accounts for 3.37% (Rs. 16,100) and inventory holding cost amounts to only 1.56% (Rs. 7,467). Microsoft Excel Solver engine has efficiently converged to the above global minimum solution after 14 iterations by using the Simplex LP algorithm and without violating any constraints.

### 5.6 Comparative Performance Analysis with Existing Baseline Models

To measure the efficiency of mathematics and its effect on business through the proposed integrated MILP model, two alternative base case operations were compared as follows:

**Table 12:** Comparative Benchmark Analysis Across Operational Metrics

| Performance Metric | Baseline Model 1 (Traditional Practice) | Baseline Model 2 (Decentralized EOQ) | Proposed Integrated MILP Model | Improvement vs Traditional Baseline (%) |
|---|---|---|---|---|
| Total Supply Chain Cost ($Z$) | Rs. 6,85,400 | Rs. 5,62,100 | Rs. 4,78,562 | -30.2% Cost Savings |
| Procurement Spend | Rs. 3,65,000 | Rs. 3,12,000 | Rs. 2,61,610 | -28.3% Spend Savings |
| Freight Transportation Spend | Rs. 2,72,800 | Rs. 2,21,500 | 2,870 units | -29.1% Logistics Savings |
| Ending Inventory Buffer | 5,900 units | 4,200 units | 2,870 units | -51.4% Working Capital Freed |
| Customer Service Level | 88.5% (Stockouts) | 95.0% | 100.0% | +11.5% Service Gain |

Natural Resources for
Human Health
eISSN: 2583-1194


**Figure 9.** Comparative performance analysis of the proposed MILP model against existing operational baselines.

From Table 12 and Figure 9, it is evident that the integrated MILP model is superior to the unoptimized traditional operations and the decentralized EOQ models in terms of performance. Through the integration of the MILP model, total supply chain costs are reduced to Rs. 4,78,562 from Rs. 6,85,400 of total traditional baseline operation costs, resulting in financial savings of Rs. 2,06,838 per cycle (30.2% cost reduction) while freeing up 51.4% of tied-up working capital in ending inventory and improving customer order service level from 88.5% to 100%.

### 5.7 Sensitivity Analysis

To evaluate the stability and robustness of the proposed MILP formulation under real-world market uncertainties, a sensitivity analysis was performed on four critical operational parameters: customer demand ($D_k$), supplier procurement unit price ($PC_i$), freight tariffs ($TC_{ij}, TC_{jk}$), and unit holding cost ($HC_j$).

#### 5.7.1 Demand and Supplier Unit Price Sensitivity

Table 13 details the impact of market demand variations (±10% to ±20%) and primary supplier S2 procurement cost fluctuations (±5% to ±10%) on network allocations and total supply chain cost ($Z$).

**Table 13.** Sensitivity Analysis of Customer Demand and Supplier S2 Procurement Price

| Parameter Scenario | Parameter Value | Total Demand (Units) | S1 Order (Units) | S2 Oder (Units) | Total Spend (Rs.) | Total Cost Z (Rs.) | Cost Change (%) |
|---|---|---|---|---|---|---|---|
| **Baseline** | **Normal** | **10,700** | **1,970** | **5,700** | **2,61,610** | **4,78,562** | **0.00%** |
| Demand -20% | 8,560 units | 8,560 | 1,110 | 4,420 | 1,88,674 | 3,92,450 | -18.00% |
| Demand -10% | 9,630 units | 9,630 | 1,540 | 5,060 | 2,25,142 | 4,35,506 | -9.00% |
| Demand +10% | 11,770 units | 11,770 | 2,400 | 6,340 | 2,98,078 | 5,21,618 | +9.00% |
| Demand +20% | 12,840 units | 12,840 | 2,830 | 6,980 | 3,34,546 | 5,64,674 | +18.00% |
| S2 Price -10% | Rs. 30.42/ unit | 10,700 | 1,970 | 5,700 | 2,42,344 | 4,59,296 | -4.03% |
| S2 Price +5% | Rs. 35.49/ unit | 10,700 | 4,470 | 3,200 | 2,70,080 | 4,87,032 | +1.77% |
| S2 Price +10% | Rs. 37.18/ unit | 10,700 | 7,670 | 0 | 2,68,450 | 4,95,402 | +3.52% |

As observed in Table 13, changes in customer demand produce a proportional, linear response in total cost (±9% shift per 10% demand variation), while plant processing capacity (34,500 units) easily absorbs up to a +20% demand surge without stockouts.

Regarding procurement, Supplier S2 currently holds 74.3% market share due to its low baseline price (Rs. 33.80/unit). However, if S2 increases its price by 5% (Rs. 35.49/unit), it loses its cost advantage over S1 (Rs. 35.00/unit), prompting the MILP model to shift 4,470 units to S1. A 10% price increase by S2 causes 100% of procurement (7,670 units) to shift to S1, confirming the model's dynamic risk mitigation capability against supplier price volatility.

### 5.7.2 Transportation Freight Tariffs and Holding Rate Senistivity

Transportation spend represents 40.41% (Rs. 1,93,385) of overall operational cost. Table 14 illustrates the effect of freight tariff fluctuations on total cost $Z$.

**Table 14.** Freight Rate Sensitivity Analysis

| Freight Rate Shift | Inbound Freight (Rs.) | Outbound Freight (Rs.) | Total Freight (Rs.) | Total Supply Chain Cost $Z$ (Rs.) | Cost Variance (%) |
|---|---|---|---|---|---|
| -20% | 67,860 | 86,848 | 1,54,708 | 4,39,885 | -8.08% |
| -10% | 76,343 | 97,704 | 1,74,047 | 4,59,224 | -4.04% |
| **0% (Baseline)** | **84,825** | **1,08,560** | **1,93,385** | **4,78,562** | **0.00%** |
| +10% | 93,308 | 1,19,416 | 2,12,724 | 4,97,901 | +4.04% |
| +20% | 102,190 | 1,30,272 | 2,32,462 | 5,17,639 | +8.17% |

Every 10% shift in transportation tariffs alters total network cost by ~4.04%. In contrast, varying unit holding costs ($HC_j$) by ±30% results in under ±0.47% variation in total cost $Z$, owing to the model's high efficiency in keeping ending inventory low (2,870 units), which accounts for only 1.56% of total spend.

### 5.7.3 Managerial Implications

1. **Vendor Risk Management:** MSMEs should secure long-term price agreements with Supplier S2 or maintain Supplier S1 as an active dual-sourcing partner to hedge against price spikes.
2. **Freight Optimization:** Given that logistics accounts for over 40% of total spend, consolidating shipment routes can yield significant cost savings (~4.04% per 10% tariff drop).
3. **Capacity Flexibility:** The network easily supports up to 20% demand growth within existing infrastructure limits.

## 6. CONCLUSION

The research formulated an integrative MILP model that aimed at providing an optimal strategy for inventory management and logistics of the door hinges manufacturing MSME. The model was based on the implementation of Microsoft Excel Solver.

Some of the major findings of the study were as follows:

1. **Cost Minimization & Superiority:** Total supply chain operating cost was minimized to Rs. 4,78,562, achieving a 30.2% cost reduction compared to traditional unoptimized MSME practices.
2. **Inventory Optimization:** Ending inventory buffer was reduced by 51.4% (from 5,900 to 2,870 units), lowering holding costs to Rs. 7,467.
3. **High Service Level:** 100% customer demand (10,700 units) was satisfied across all customer zones without stockouts.

**Future Scope:** Further research could involve extending this deterministic model by including random demand from the customers, a dynamic multi-period approach, vehicle routing constraints, carbon emissions measures, and integration of IoT/Artificial Intelligence-based systems for real-time tracking.

## ACKNOWLEDGEMENTS

The authors acknowledge for Door Hinges industry, Gurgaon to providing complete data for my research purposes.

## AUTHOR CONTRIBUTIONS

**Sarthak Goyal:** Model Preparation, Data Collection, Methodology, Writing & Editing

**Vipin Kumar:** Data Analysis, Data Validation, Graph Analysis, Supervision, Work Review

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## ETHICS STATEMENT

Data have been collected with permission from industry. Ethical approval was not required for this study.

## DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

## REFERENCES

[1] Saharan, A., Pandey, K. K., Dhaundiyal, M., Agrawal, R., & Kumar, A. (2026). Navigating recovery: assessment of firm level enablers of internationalizing MSMEs' recovery and repertoire of actions. *Journal of Modelling in Management*, *21*(2), 552-583.

[2] Syamsi, A., Irfan, D., Novaliendry, D., & Sandra, R. P. (2026). Web-Based Inventory Management System for Educational Training: Integrating EOQ and ARIMA for Data-Driven Learning. *Journal of Hypermedia & Technology-Enhanced Learning*, *4*(1), 68-87.

[3] Mohite, R. A., Chourasiya, R. H., Sharma, S., & Akre, S. (2025). Enhancing the Competitiveness of MSMEs Through Industrial Engineering Innovations in Supply Chain Management. *International Journal of Engineering Management*, *9*(1), 30-38.

[4] Syofra, A. H., Tulus, T., Mawengkang, H., & Zarlis, M. (2025). An Optimization Model for Integrated Warehouse-Inventory-Transportation of a Multi-Echelon Supply Chain. *Engineering, Technology & Applied Science Research*, *15*(3), 23956-23964.

[5] Goyal, S., & Kumar, V. (2025). Cost-Efficient Inventory Management Strategies for MSMEs using Mathematical Optimization Techniques. *Lex Localis*, *23*(S4), 4364-4371.

[6] Anwar, S., Pratama, G. R., & Islamy, M. A. (2025, June). A model framework for coordinating the upstream supply chain of sago-based food MSMEs. In *Proceedings of the International Conference on Agriculture Strategy for Sustainability (ICASS)* (Vol. 1, No. 1, pp. 117-124).

[7] Kumar, V., & Goyal, S. (2025). AI-Driven Forecasting and Optimization for Inventory Control in Manufacturing Supply Chain. *Advances in Consumer Research*, *2*, 5085-5091.

[8] Pérez-Campdesuñer, R., Sánchez-Rodríguez, A., De Miguel-Guzmán, M., García-Vidal, G., & Martínez-Vivar, R. (2025). Improving Scheduling Efficiency: A Mathematical Approach to Multi-Operation Optimization in MSMEs. *Mathematics*, *13*(9), 1444.

[9] Goyal, S., & Kumar, V. (2025, November). A Simplified Linear Programming Approach for Inventory Optimization in Supply Chains. In *2025 14th International Conference on System Modeling & Advancement in Research Trends (SMART)* (pp. 295-298). IEEE.

[10] Ubud, S., & Putra, I. K. (2024, April). Integration of supply chain model for perishable food products: focus on micro, small and medium enterprises. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1324, No. 1, p. 012133). IOP Publishing.

[11] Reynoldtan, H., Wijaya, H., Trinardi, J., & Vincent, W. (2024). Profit Optimization with Linear Programming Simplex Method in MSMEs. *Researcher Academy Innovation Data Analysis*, *1*(1), 14-18.

[12] Gultom, P., Marpaung, J. L., Weber, G. W., Sentosa, I., Sinulingga, S., Putra, P. S. E., & Agung, V. R. (2024). Optimizing the Selection of the Sustainable Micro, Small, and Medium-Sized Enterprises Development Center Using a Multi-Criteria Approach for Regional Development. *Mathematical Modelling of Engineering Problems*, *11*(11).

[13] Murthy, S. R., & NA, P. (2024). Impact of Inventory Management Practices on MSMEs: A Regional Study in India. *IUP Journal of Operations Management*, *23*(2).

[14] Tengtarto, M. A. K., Singgih, M. L., & Siswanto, N. (2023). Cost optimization in disruption conditions: a case study in small medium enterprise. *International Journal of Professional Business Review: Int. J. Prof. Bus. Rev.*, *8*(5), 31.

[15] Flores Siguenza, P. A. (2023). Multi-objective optimization model for sustainable production planning in textile MSMEs.

[16] Sahoo, P. B. B., & Thakur, V. (2023). Enhancing the performance of Indian micro, small and medium enterprises by implementing supply chain finance: challenges emerging from COVID-19 pandemic. *Benchmarking: An International Journal*, *30*(6), 2110-2138.

[17] Mas' ud, M. I., & Wahid, A. (2022). Model SMEs digital disruption management with business model canvas and integer programming. *International Journal of Trends in Mathematics Education Research*, *5*(2), 162-168.

[18] Peña, M., Siguenza-Guzman, L., & Veintimilla-Reyes, J. (2022, April). Internal Logistics Optimization Based on a Multi-objective Linear Model for Micro, Small, and Medium Textile Enterprises. In *Applied Technologies: Third International Conference, ICAT 2021, Quito, Ecuador, October 27–29, 2021, Proceedings* (p. 214). Springer Nature.

[19] Torres Torres, C., Toledo, M. B., Llivisaca, J. C., Peña, M., Siguenza-Guzman, L., & Veintimilla-Reyes, J. (2021, October). Internal Logistics Optimization Based on a Multi-objective Linear Model for Micro, Small, and Medium Textile Enterprises. In *International Conference on Applied Technologies* (pp. 214-228). Cham: Springer International Publishing.

[20] Sharma, J., & Jayant, A. (2019, July). An Intelligent Simulation based case study of Indian Micro Small Medium Enterprise (MSME) of farm equipment manufacturing. In *Journal of Physics: Conference Series* (Vol. 1240, No. 1, p. 012030). IOP Publishing.

[21] Singh, H., Bahl, A., Kumar, A., & Mann, G. S. (2018). Materials and information flow analysis and optimization of manufacturing processes in MSMEs by the application of value stream mapping (VSM) technique. *Materials Today: Proceedings*, *5*(14), 28420-28426.

[22] Vijayvargy, L. (2015). Optimization of Resources in Supply Chain by Linear Programming: A Case of India's MSME. *IUP Journal of Supply Chain Management*, *12*(4), 7.

[23] Ravikumar, M. M., Marimuthu, K., & Parthiban, P. (2015). Evaluating lean implementation performance in Indian MSMEs using ISM and AHP models. *International Journal of Services and Operations Management*, *22*(1), 21-39.