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Abstract: *This Paper presents an integrated supply chain optimization model designed to minimize total costs in supply chain management using a Mixed Integer Linear Programming (MILP). The primary objective is to reduce overall transportation costs within the supply chain, including costs at each stage and inventory costs at warehouses. The model also ensures customer demands are met while considering the capacity constraints of suppliers, manufacturers, warehouses and customer zones. The supply chain in this Paper includes four echelons: supplier, manufacturer, warehouse and customer. Specifically, it comprises six suppliers, two manufacturers, five warehouses and five customer locations. By integrating these elements into a cohesive optimization model, businesses can make data-driven decisions to enhance supply chain efficiency and lower overall costs.*

Key Words: *Supply Chain Management, Mixed Integer Linear Programming, Transportation Model.*

1. Introduction:

In modern supply chain management, minimizing transportation and inventory costs is critical for companies aiming to maintain competitiveness. Traditional supply chain operations often rely on fixed transportation routes and historical practices that do not account for optimal resource allocation. This can lead to inefficiencies, increased costs and challenges in meeting customer demand efficiently. To address this problem, we developed an integrated supply chain optimization model using Mixed Integer Linear Programming (MILP). The objective of the model is to minimize the total transportation and inventory holding costs across a multi-echelon supply chain, which consists of six suppliers, two manufacturers, five warehouses, and five customer zones. This research focuses on optimizing the flow of materials and goods across these echelons while ensuring that customer demand is met and all capacity constraints are respected. By employing LP and solving the model with LINDO software, we aim to demonstrate the potential for substantial cost reductions and improvements in overall supply chain efficiency. The paper also includes a comparative analysis of the optimized results with a traditional, non-optimized model.

Many researchers have studied supply chain network design (SCND) to optimize various aspects such as costs, logistics and sustainability. These studies range from simple deterministic models to complex stochastic and fuzzy frameworks. Vladova et al. [1] developed a sustainable multi-objective optimization model to address uncertainties in product demand and pricing, focusing on economic, environmental, and social aspects. Bhatia and Bhat [2]

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explored operational strategies for agricultural supply chains, particularly in managing perishable goods and enhancing profitability.Bas and Ozkok [3] introduced a fuzzy approach for multi-objective optimization in closed-loop supply chains, addressing cost minimization and environmental concerns in multi-product and multi-period systems. Similarly, Nayak et al. [4] designed a deterministic multi-stage and multi-product milk supply chain network for the coastal region of Odisha, optimizing distribution center locations and replenishment cycles. Pourrousta et al. [5] proposed a fuzzy mixed-integer linear programming model that integrates procurement, production, and distribution, enhancing coordination in uncertain conditions.

In terms of aggregate production planning, Mirzapour Al-E-Hashem et al. [6] developed a robust multi-objective optimization model for multi-site and multi-product systems, balancing cost efficiency and customer satisfaction. Kanna and Dandigi [7] applied linear programming to optimize cropping patterns for farmers in Karnataka, significantly improving profitability and resource allocation. Albornoz and Urrutia-Gutiérrez [8] focused on agribusiness supply chains, proposing a mixed-integer linear model to optimize profit and crop rotation. Mohamad and Said [9] addressed crop mix optimization using mathematical programming to maximize returns under resource constraints. Chetthamrongchai et al. [10] proposed a model for supply chain optimization that accounts for uncertainties like natural disasters and labor issues, enhancing reliability in distribution. Alrefaei et al. [11] applied fuzzy linear programming to manage uncertainties in the steel industry supply chain, offering greater flexibility in decision-making. Ge et al. [12] compared analytical and simulation models for agricultural supply chain optimization, focusing on quality control and logistical challenges. Raj et al. [13] minimized transportation costs in the dairy industry through vehicle route optimization, improving cost efficiency for perishable goods. Similarly, Scaria and Joseph [14] optimized transportation routes for milk distribution, achieving significant cost reductions. Verma et al. [15] explored the use of mathematical programming for improving operational efficiency in supply chain management.

Tabrizi and Razmi [16] introduced a mixed-integer non-linear fuzzy model for risk management in supply chain networks, considering uncertainties in demand and supplier reliability. Babagolzadeh et al. [17] developed a multi-objective fuzzy programming model for sustainable supply chain network design, incorporating disruptions and social considerations. Ardakani et al. [18] proposed a fuzzy multi-objective optimization model for sustainable supply chains in the ceramic tile industry, balancing economic, environmental, and social goals.Chang

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et al. [19] focused on supplier selection using a fuzzy optimization model that integrates qualitative and quantitative criteria. Sutthibutr and Chiadamrong [20] presented a fuzzy multi-objective optimization model for supply chain master planning, using α-cut analysis to address uncertainties in cost, demand, and service levels. Gupta et al. [21] highlighted the significance of multi-objective optimization for logistics in multi-product supply chains, addressing transportation and allocation inefficiencies. Sitek and Wikarek [22] proposed an integrated optimization model for supply chains using mixed-integer linear programming to manage strategic and operational decisions. Subbaiah et al. [23] studied production-distribution planning in dairy supply chains, emphasizing the importance of efficiency in multi-echelon networks. Feili and Khoshdoon [24] developed a fuzzy optimization model to integrate decision-making in supply chain production planning. Spitter et al. [25] proposed linear programming models with planned lead times for synchronized supply chain operations. Kabak and Ülengin [26] utilized possibilistic linear programming for supply chain network decisions, effectively managing uncertainty in demand and supply. Jindal and Sangwan [27] optimized closed-loop supply chain networks using fuzzy mixed-integer linear programming to address recycling and remanufacturing processes.

Douaioui et al. [28] presented a MILP model for procurement, production, and distribution under uncertainty, demonstrating cost efficiency improvements. Govindan et al. [29] comprehensively reviewed reverse logistics and closed-loop supply chains, identifying future research directions in sustainability. Fahimnia et al. [30] performed a bibliometric analysis of green supply chain management, highlighting environmental sustainability as a priority.Pishvaee and Torabi [31] used possibilistic programming for closed-loop supply chain design, addressing uncertainties in recycling and remanufacturing. Eskandarpour et al. [32] reviewed sustainable supply chain design, focusing on optimization techniques for environmental and social considerations. Melo et al. [33] explored facility location and supply chain management, offering insights into optimizing network performance.Mohammadi and Ghomi [34] proposed an integrated production-distribution model for multi-echelon supply chains, employing an improved Lagrangian relaxation approach to handle demand uncertainty. Sangaiah et al. [35] addressed LNG supply chain planning using robust optimization and mixed-integer linear programming, improving operational flexibility. Bidhandi et al. [36] developed a deterministic supply chain network design model using MILP and Benders' decomposition, integrating strategic and tactical planning. Lastly, Kaur and Kumar [37]

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introduced a fuzzy transportation problem-solving method, enhancing decision-making in uncertain supply chain environments.

The reviewed literature on supply chain network design (SCND) highlights significant advancements in deterministic, stochastic, and fuzzy optimization frameworks, yet notable research gaps persist. While multi-objective optimization, such as cost minimization and sustainability goals, is well explored [1], [3], [17], there is limited practical implementation in real-world, dynamic environments. Studies focusing on sustainability, such as Fahimnia et al. [30] and Govindan et al. [29], primarily address environmental concerns, with insufficient integration of economic and social dimensions. Moreover, the potential of emerging technologies like AI, Blockchain, and IoT to enhance SCND models remains underexplored, with reliance on traditional heuristics [13], [27]. Industry focus is skewed towards agriculture [2], [9], dairy [13], [14], and ceramics [18], while high-tech, pharmaceutical, and e-commerce sectors are largely overlooked. Existing models, predominantly static [1], [4], [36], fail to address dynamic market conditions, and adaptive models that evolve with supply chain fluctuations are scarce. Reverse logistics is explored in works like Jindal and Sangwan [27] and Pishvaee and Torabi [31], but comprehensive closed-loop integration is limited. Although stochastic and fuzzy approaches [6], [17], [31] handle uncertainties, they inadequately address extreme disruptions like pandemics or geopolitical crises. Furthermore, SCND research rarely incorporates interdisciplinary perspectives such as behavioral economics or policy frameworks, which could provide holistic solutions. Computational complexity also poses challenges, with methods like Benders' decomposition [36] requiring more scalable and efficient algorithms for large-scale networks. Lastly, service-based supply chains, such as healthcare or education, are underrepresented, as research predominantly focuses on manufacturing and distribution. Addressing these gaps requires dynamic and adaptive models, integration of emerging technologies, robust frameworks for high uncertainty, and interdisciplinary approaches to expand SCND's applicability across diverse industries.

2. Multi stage supply chain model:

2.1. Model formulation

This study presents a multi-echelon model aimed at minimizing total costs. A three-stage supply chain model, as illustrated in Figure 1, is considered.In this model there are six suppliers, two manufacture, five Warehouses and five Customer location.

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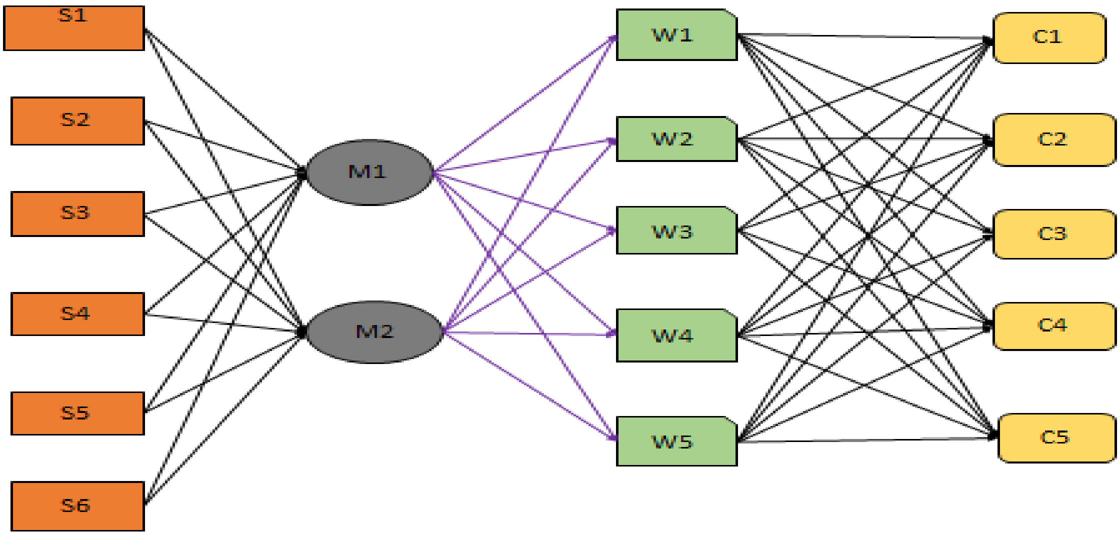
Figure. 5.1: Supply Chain Networks



2.2 Indices:

i: index for supplier

j: index for Manufacturer

k: index for Warehouses

r: index for customer location

t: index for time period

p: represent material

g: represent product

2.3 Decision variable:

AM_{ijpt}: -Quantity of raw material p which Supplier i transported to manufacturer j at time t

QM_{jkgt}: -Quantity of good g which manufacturer j transported to Warehouses k at time t

QM_{krgt}: -Amount of goods g which Warehouses k transported to Customer location r at time t

S_{pit}: - Quantity of material p in inventory at supplier i at the beginning of time period t

S_{gjt}: - Quantity of product g in inventory at manufacturer j at the beginning of time period t

S_{gkt}: - Quantity of product g in inventory at warehouse k at the beginning of time period t

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2.4 Parameter:

TC_{ijpt}: -Transportation cost per unit from Supplier i to manufacturer j at time t

TC_{jkgt}: -Transportation cost per unit from manufacturer j to Warehouse k at time t

TC_{krgt}: -Transportation cost per unit from Warehouse k to Customer location r time t

IHC_{it}:-Inventory Holding cost at supplier i at time t

IHC_{jt}: - Inventory Holding cost at manufacturer j at time t

IHC_{kt}: - Inventory Holding cost at Warehouse k at time t

LV_{ipt}: −Lower bound of the capacity of the supplier i for material p at time t

SC_{ip}: − Maximum capacity of supplier i to supply material p

MC_{jg}: − Maximum capacity of Manufacturer j to produce and transport product g

WC_{kg}: − Maximum storage capacity of warehouse k for product g

D_{rgt}: − Demand of product g at customer location r at time t

Y_{ij}: Binary Decision variable for selecting route from Supplier to Manufacturer

Y_{jk}: Binary Decision variable for selecting route from Manufacturer to Warehouse

Y_{kr}: Binary Decision variable for selecting route from Warehouse to Customer Location

2.5 Assumptions of the Model:

- The demands for goods at customer locations are deterministic.
- The capacities of suppliers, manufacturers, warehouses, and customers location are fixed
- There are no lead times.
- Inventory levels are non-negative and cannot exceed the maximum storage capacities.

2.6 Objective function:

min Z=transportation cost +Inventory holding cost

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$$\min Z = \left[\sum_{i}\sum_{j}\sum_{p}(TC_{ijpt} * AM_{ijpt}) + \sum_{j}\sum_{k}\sum_{g}(TC_{jkgt} * QM_{jkgt}) + \sum_{k}\sum_{r}\sum_{g}(TC_{krgt} * QM_{krgt})\right] + + \sum_{i,p,t} IHC_{it} * S_{pit} + \sum_{j,g,t} IHC_{jt} * S_{gjt} + \sum_{k,g,t} IHC_{kt} * S_{gkt} \quad (1)$$

2.7 Subjected to constraint:

Upper Lower bound restriction

$$0 \le AM_{ijpt} \le AM_{ijpt}\_upbound$$

$$0 \le QM_{jkgt} \le QM_{jkgt}\_upbound$$

$$0 \le QM_{krgt} \le QM_{krgt}\_upbound$$

Capacity Constraint

For supplier

$$\Sigma AM_{ijpt} \le SC_{ip}$$

For Manufacturer

$$\Sigma QM_{jkgt} \le MC_{jg}$$

For Warehouse

$$\Sigma QM_{krgt} \le WC_{kg}\_\text{upbound}$$

$$\Sigma QM_{krgt} \ge WC_{kg}\_\text{lowerbound}$$

For customer Demand constraint

$$S_{gkt} \le D_{rgt}\_\text{up bound}$$

$$S_{gkt} \ge D_{rgt}\_\text{lower bound}$$

Flow Conservative restrictions

$$S_{pit} + \Sigma AM_{ijp(t-1)} = \Sigma QM_{jkgt} + S_{gj(t+1)}$$

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$$S_{gkt}+\Sigma QM_{jkg(t-1)} = \Sigma QM_{krgt}+ S_{gk(t+1)}$$

$$\Sigma \, AM_{ijpt} \geq LV_{ipt}$$

$$Y_{ij} = 1, Y_{jk} = 1, Y_{kr}= 1$$

Non –Negativity Constraint

All Decision Variable must be Non-Negative

3. Numerical Example:

In this study, a computational experiment is conducted on a hypothetically designed supply chain network comprising six suppliers, two manufacturers, five warehouses, and five customer locations. The research develops a multi-echelon supply chain model aimed at minimizing total costs, including transportation and inventory holding costs, within an integrated supply chain framework.

The proposed model optimizes procurement, production, and distribution processes in a three-stage supply chain network. The hypothetical network provides a structured framework for the movement of raw materials and finished products, enabling the determination of optimal resource allocation and material flow while adhering to constraints on capacity, inventory levels and demand satisfaction.

3.1 Input Data

Table 1 Supplier to Manufacturer Transportation Cost

Supplier (x)	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Manufacturer 1	3.52	28.96	39.86	31.42	93.28	36.69
Manufacturer 2	36.28	6.62	72.86	61.12	114.18	3.59
Total	195.80	47.30	357.50	49.50	24.20	22.00

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Table 2 Manufacturer 1 to Warehouse Transportation Cost

Manufacturer 1 (w)	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Total Units
Warehouse 1	3.59	3.59	3.59	3.59	3.59	3.59	48453.9
Warehouse 2	13.09	13.09	13.09	13.09	13.09	13.09	15220.9
Warehouse 3	14.96	14.96	14.96	14.96	14.96	14.96	9630.5
Warehouse 4	9.79	9.79	9.79	9.79	9.79	9.79	7522.9
Warehouse 5	8.32	8.32	8.32	8.32	8.32	8.32	3492.5
Total	25648.7	10480.8	7700.0	3671.8	3852.2	33287.1	-

Table 3 Manufacturer 2 to Warehouse Transportation Cost

Manufacturer 2 (w)	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Total Units
Warehouse 1	11.99	11.99	11.99	11.99	11.99	11.99	30979.3
Warehouse 2	4.97	4.97	4.97	4.97	4.97	4.97	9731.7
Warehouse 3	3.59	3.59	3.59	3.59	3.59	3.59	6156.7
Warehouse 4	21.78	21.78	21.78	21.78	21.78	21.78	4810.3
Warehouse 5	20.24	20.24	20.24	20.24	20.24	20.24	2233.0
Total	4104.0	2193.4	0.00	137.5	3852.2	31207.0	-

Table 4 Transportation Cost (Warehouse to Customer)

Warehouse (w)	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Warehouse 1	0.00	14.59	13.16	8.90	7.56
Warehouse 2	14.48	0.00	3.30	3.30	4.77
Warehouse 3	9.96	1.39	0.00	4.69	5.90

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Warehouse 4	9.79	3.30	4.69	0.00	1.36
Warehouse 5	8.32	4.51	6.12	1.36	0.00

Table 5 Inventory Holding Cost at Warehouse

Warehouse (w)	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
Warehouse 1	0.077	0.055	0.077	0.055	0.077	0.055
Warehouse 2	0.077	0.055	0.077	0.055	0.077	0.055
Warehouse 3	0.077	0.055	0.077	0.055	0.077	0.055
Warehouse 4	0.077	0.055	0.077	0.055	0.077	0.055
Warehouse 5	0.077	0.055	0.077	0.055	0.077	0.055

Table 6 Demand for Different Goods at different customer Location

Warehouse (w)	Good 1	Good 2	Good 3	Good 4	Good 5	Good 6	Warehouse Demand
Warehouse 1	26136	11993	7700	3519	3986	26099	79433
Warehouse 2	1179	5086	0	0	334	18352	24952
Warehouse 3	1379	3920	0	117	2284	8087	15787
Warehouse 4	1058	3557	0	0	887	6831	12333
Warehouse 5	0	215	0	174	212	5125	5726
Total/goods demand	29752	24772	7700	3810	7703	64494	138231

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Table 7 Capacities of Warehouse for different Goods

w\g	1	2	3	4	5	6	Warehouse Capacities
1	27500	110000	7700	3300	4400	27500	180400
2	1650	5500	0	0	1100	22000	30250
3	1650	4400	0	550	2200	8800	17600
4	1100	3300	0	0	1100	6600	12100
5	0	550	550	550	330	5500	7480
Total/goods	31900	123750	8250	4400	9130	70400	247830

The Problem is solved using LINDO (Linear Interactive Discrete Optimization) software.

4. Results and discussion:

The LPP problem is solved using the LINDO program. We define the objective function and constraints according to our model based on numerical values.

The solution for the numerical example is described as follows.

Table 8 Result Output

Optimum Objective Function	1,416,377
Decision Variable	
AM11(Quantity of Materials transported from Supplier 1 to Manufacturer 1)	68.0
AM21(Quantity of Materials transported from Supplier 2 to Manufacturer 1)	357.0
AM22(Quantity of Materials transported from Supplier 2 to Manufacturer 2)	127.5
AM24(Quantity of Materials transported from Supplier 4 to Manufacturer 2)	47.5
AM25(Quantity of Materials transported from Supplier 5 to Manufacturer 2)	49.0
AM26(Quantity of Materials transported from Supplier 6 to Manufacturer 2)	24.5
AM31(Quantity of Materials transported from Supplier 3 to Manufacturer 1)	22.0
QM111(Quantity of Product 1 transported from Manufacturer 1 to Warehouse 1)	195.0

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QM112(Quantity of Product 2 transported from Manufacturer 1 to Warehouse 1)	47.0
QM113(Quantity of Product 3 transported from Manufacturer 1 to Warehouse 1)	357.0
QM114(Quantity of Product 4 transported from Manufacturer 1 to Warehouse 1)	49.0
QM115(Quantity of Product 5 transported from Manufacturer 1 to Warehouse 1)	24.0
QM116(Quantity of Product 6 transported from Manufacturer 1 to Warehouse 1)	22.0
QM215(Quantity of Product 5 transported from Manufacturer 2 to Warehouse 1)	3852.0
QM216(Quantity of Product 6 transported from Manufacturer 2 to Warehouse 1)	17651.0
QM222(Quantity of Product 2 transported from Manufacturer 2 to Warehouse 2)	2193.0
QM224(Quantity of Product 4 transported from Manufacturer 2 to Warehouse 2)	138.0
QM226(Quantity of Product 6 transported from Manufacturer 2 to Warehouse 2)	7400.0
QM236(Quantity of Product 6 transported from Manufacturer 2 to Warehouse 3)	6156.0
QM12(Quantity of goods transported from Warehouse 1 to Customer Zone 2)	68737.0
QM14(Quantity of goods transported from Warehouse 1 to Customer Zone 4)	233.0
QM15(Quantity of goods transported from Warehouse 1 to Customer Zone 5)	9130.0
QM32(Quantity of goods transported from Warehouse 3 to Customer Zone 2)	9350.0
QM42(Quantity of goods transported from Warehouse 4 to Customer Zone 2)	12100.0
QM52(Quantity of goods transported from Warehouse 5 to Customer Zone 2)	3313.0
QM54(Quantity of goods transported from Warehouse 5 to Customer Zone 4)	4167.0
S12(Inventory level of goods at Warehouse 1 for Product 2)	24772.0
S16(Inventory level of goods at Warehouse 1 for Product 6)	54661.0
S21(Inventory level of goods at Warehouse 2 for Product 1)	17252.0
S23(Inventory level of goods at Warehouse 2 for Product 3)	7700.0
S31(Inventory level of goods at Warehouse 3 for Product 1)	2145.0
S34(Inventory level of goods at Warehouse 3 for Product 4)	3809.0

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S36(Inventory level of goods at Warehouse 3 for Product 6)	9833.0
S41(Inventory level of goods at Warehouse 4 for Product 1)	4630.0
S45(Inventory level of goods at Warehouse 4 for Product 5)	7703.0
S51(Inventory level of goods at Warehouse 5 for Product 1)	5726.0
QM241(Quantity of product 1 transported from Manufacturer 2 Warehouse 4)	4104.0
QM11(Total quantity of goods transported from Warehouse 1 to customer zone 1)	31900.0
QM16(Total quantity of goods transported from Warehouse 1 to customer zone 6)	70400.0
QM22(Total quantity of goods transported from Warehouse 2 to customer zone 2)	30250.0
QM33(Total quantity of goods transported from Warehouse 3 customer zone 3)	8250.0

This study provides a comprehensive analysis of the supply chain network, emphasizing its efficiency and effectiveness in meeting demand across various customer zones. The results underscore the pivotal role of Supplier 2 in material supply and the strategic importance of Warehouse 1 as the central hub for product distribution. The network demonstrates a well-optimized transportation system, ensuring the timely delivery of materials and products while maintaining balanced inventory levels. High-demand products, such as Product 6, are prioritized through robust inventory management and distribution mechanisms. Despite the system's overall effectiveness, there is scope for further improvement through the optimization of transportation costs, enhanced supplier collaboration, and the integration of predictive analytics to improve demand forecasting. These recommendations could further enhance the performance and resilience of the supply chain, making it more adaptable to dynamic market conditions.

5. Conclusions:

The LINDO solution for this supply chain optimization model effectively minimizes the total supply chain cost to Rs1,416,377, while fully satisfying all key constraints, including production capacities, warehouse limitations, and inventory requirements. This provides a practical and cost-effective framework for managing material procurement, production, transportation, and storage throughout the supply chain.

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References:

1. R. K. Vladova, E. G. Kirilova, T. S. Petrova, and K. T. Kirilov, "A sustainable multi-objective optimization model for design of supply chain under uncertain products demands and products prices: A real case of dairy industry," *Chemical Engineering Transactions*, vol. 105, pp. 385–390, 2023.
2. M. Bhatia and G. Bhat, "Agriculture supply chain management - An operational perspective," *Brazilian Journal of Operations & Production Management*, vol. 17, no. 4, pp. 1–18, 2020.
3. S. A. Bas and B. A. Ozkok, "A fuzzy approach to multi-objective mixed integer linear programming model for multi-echelon closed-loop supply chain with multi-product multi-time-period," *Operations Research and Decisions*, vol. 30, no. 1, pp. 25–46, 2020.
4. K. C. Nayak, J. K. Mantri, and M. Pattnaik, "Multi-stage, multi-product and multi-period milk supply chain network design: A case of coastal region of Odisha," *J. Math. Comput. Sci.*, vol. 11, pp. 2301–2340, 2021
5. A. Pourrousta, S. Dehbari, R. Tavakkoli-Moghaddam, A. Imenpour, and M. Naderi-Beni, "A fuzzy mixed integer linear programming model for integrating procurement-production-distribution planning in supply chain," *International Journal of Industrial Engineering Computations*, vol. 3, no. 3, pp. 403–412, 2012.
6. S. M. J. Mirzapour Al-E-Hashem, H. Malekly, and M. B. Aryanezhad, "A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty," *International Journal of Production Economics*, vol. 134, no. 1, pp. 28–42, 2011.
7. D. K. Kanna and D. Dandigi, "Optimum cropping pattern for farmers of Bidar district, Karnataka," *International Journal of Engineering and Advanced Technology*, vol. 9, no. 1, 2019.
8. V. M. Albornoz and C. Urrutia-Gutiérrez, "A mixed-integer linear optimization model for a two-echelon agribusiness supply chain," *Electronic Notes in Discrete Mathematics*, vol. 69, pp. 253–260, 2018.
9. N. H. Mohamad and F. Said, "A mathematical programming approach to crop mix problem," *African Journal of Agricultural Research*, vol. 6, no. 1, pp. 191–197, 2011.
10. P. Chetthamrongchai, J. Dayupay, S. Alshiqi, T. A. H. Alghazali, A. H. Iswanto, L. P. L. Cavaliere, and M. M. Kadhim, "Design a mathematical planning approach to

DOI: https://doi.org/10.71058/jodac.v9i4005

optimize the supply chain taking into account uncertainties in distributors," *Foundations of Computing and Decision Sciences*, vol. 47, no. 4, pp. 409–420, 2022.

11. M. Alrefaei, A. Alawneh, and M. Hassan, "Fuzzy linear programming for supply chain management in steel industry," 2014.
12. H. Ge, R. Gray, and J. Nolan, "Agricultural supply chain optimization and complexity: A comparison of analytic vs simulated solutions and policies," *International Journal of Production Economics*, vol. 159, pp. 208–220, 2015.
13. K. T. Raj, B. Arunmozhi, and R. Sivasankaran, "Minimization of transportation cost in dairy industry," *International Journal of Engineering Research and Technology*, vol. 9, no. 5, pp. 78–84, 2020.
14. C. T. Scaria and J. Joseph, "Optimization of transportation route for a milk dairy," *International Journal of Engineering Research and Technology*, vol. 3, no. 11, pp. 854–859, 2014.
15. R. Verma, K. Moeed, K. Sinha, and K. Chopra, "Improvement of supply chain management by mathematical programming approach," unpublished.
16. B. H. Tabrizi and J. Razmi, "Introducing a mixed-integer non-linear fuzzy model for risk management in designing supply chain networks," *Journal of Manufacturing Systems*, vol. 32, no. 2, pp. 295–307, 2013.
17. R. Babagolzadeh, J. Rezaeian, and M. V. Khatir, "Multi-objective fuzzy programming model to design a sustainable supply chain network considering disruption," *International Journal of Industrial Engineering & Production Research*, vol. 31, no. 2, pp. 217–229, 2020.
18. D. Andalib Ardakani, H. Soleimanizadeh, S. H. Mirfakhradini, A. Soltanmohammadi, and D. Shishebori, "A fuzzy multi-objective optimization model for designing a sustainable supply chain forward network: A case study," *Journal of Industrial and Systems Engineering*, vol. 13, no. 1, pp. 181–215, 2020.
19. J. F. Chang, C. J. Lai, C. N. Wang, M. H. Hsueh, and V. T. Nguyen, "Fuzzy optimization model for decision-making in supply chain management," *Mathematics*, vol. 9, no. 4, p. 312, 2021.
20. N. Sutthibutr and N. Chiadamrong, "Fuzzy multi-objective optimization with α-cut analysis for supply chain master planning problem," *Uncertain Supply Chain Management*, vol. 7, no. 4, pp. 635–664, 2019.
21. S. Gupta, A. Haq, I. Ali, and B. Sarkar, "Significance of multi-objective optimization in logistics problem for multi-product supply chain network under the intuitionistic

DOI: https://doi.org/10.71058/jodac.v9i4005

fuzzy environment," *Complex & Intelligent Systems*, vol. 7, no. 4, pp. 2119–2139, 2021.

22. P. Sitek and J. Wikarek, "Integrated supply chain optimization model using mixed integer linear programming," *Logistics and Transport*, vol. 20, 2013.
23. K. V. Subbaiah, K. N. Rao, and K. N. Babu, "Supply chain management in a dairy industry–A case study," in *World Congress on Engineering*, vol. 1, pp. 595–599, 2009.
24. H. Feili and M. Khoshdoon, "A fuzzy optimization model for supply chain production planning with total aspect of decision making," *The Journal of Mathematics and Computer Science*, vol. 2, no. 1, pp. 65–80, 2011.
25. J. M. Spitter, C. A. J. Hurkens, A. G. de Kok, J. K. Lenstra, and E. G. Negenman, "Linear programming models with planned lead times for supply chain operations planning," *European Journal of Operational Research*, vol. 163, no. 3, pp. 706–720, 2005.
26. Ö. Kabak and F. Ülengin, "Possibilistic linear-programming approach for supply chain networking decisions," *European Journal of Operational Research*, vol. 209, no. 3, pp. 253–264, 2011.
27. A. Jindal and K. S. Sangwan, "Closed-loop supply chain network design and optimisation using fuzzy mixed integer linear programming model," *International Journal of Production Research*, vol. 52, no. 14, pp. 4156–4173, 2014.
28. K. Douaioui, et al., "MILP model for procurement, production, and distribution integration under uncertainty," *Supply Chain Integration Journal*, vol. 5, no. 2, pp. 77–94, 2010.
29. K. Govindan, H. Soleimani, and D. Kannan, "Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future," *European Journal of Operational Research*, vol. 240, no. 3, pp. 603–626, 2015.
30. B. Fahimnia, J. Sarkis, and H. Davarzani, "Green supply chain management: A review and bibliometric analysis," *International Journal of Production Economics*, vol. 162, pp. 101–114, 2015.
31. M. S. Pishvaee and S. A. Torabi, "A possibilistic programming approach for closed-loop supply chain network design under uncertainty," *Fuzzy Sets and Systems*, vol. 161, no. 20, pp. 2668–2683, 2010.
32. M. Eskandarpour, P. Dejax, J. Miemczyk, and O. Péton, "Sustainable supply chain network design: An optimization-oriented review," *Omega*, vol. 54, pp. 11–32, 2015.

DOI: https://doi.org/10.71058/jodac.v9i4005

33. M. T. Melo, S. Nickel, and F. Saldanha-da-Gama, "Facility location and supply chain management–A review," *European Journal of Operational Research*, vol. 196, no. 2, pp. 401–412, 2009.
34. M. Mohammadi and S. F. Ghomi, "Integrated production-distribution planning in multi-echelon supply chain networks under demand uncertainty: An improved Lagrangian relaxation approach," *Computers & Industrial Engineering*, vol. 124, pp. 163–179, 2018.
35. A. K. Sangaiah, E. B. Tirkolaee, A. Goli, and S. Dehnavi-Arani, "Robust optimization and mixed-integer linear programming model for LNG supply chain planning problem," *Springer-Verlag GmbH Germany*, 2019.
36. H. M. Bidhandi, R. M. Yusuff, M. M. H. Ahmad, and M. R. A. Bakar, "Development of a new approach for deterministic supply chain network design," *European Journal of Operational Research*, vol. 198, no. 1, pp. 121–128, 2009.
37. A. Kaur and A. Kumar, "A new method for solving fuzzy transportation problems using ranking function," *Applied Mathematical Modelling*, vol. 35, no. 12, pp. 5652–5661, 2011.