ISSN: 2633-4828 Vol. 5 No. S1, (Jan - Feb 2023)

International Journal of Applied Engineering & Technology

OPTIMIZATION OF MULTI ECHELON SUPPLY CHAIN MANAGEMENT

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ABSTRACT
Linear Programming is one of the best optimization techniques for solving real-life problem. In today's highly competitive environment and faster economic development industries striving to optimize complex supply chain network by developing a supply chain model that effectively manages and optimizes operations in a deterministic environment.

In this paper optimization model is developed by using Linear Programming problem (LPP) for Multi-Echelon and Multimodal supply chain system considering opportunity cost in order to configure the network to minimize total cost. Total cost includes shipping cost from supplier to plant, transportation cost between plants and distribution centre, distribution cost between distribution centre and customer zones and opportunity cost associated with untimely material availability. At the last an Industrial case study is used to demonstrate the feasibility of applying general Linear Programming Model which results in total cost reduction of supply chain network. This method serves as a straightforward and efficient approach to obtaining optimal solutions for multi-echelon supply chain networks. The proposed model is versatile and applicable to both small-scale and large-scale industries.

Keywords: Linear Programming Problem, Optimization, Supply Chain Management

1. INTRODUCTION

In Today's highly competitive market place the Logistic and Distribution planning is one of the most important factors in most of the industrial cases. The Supply Chain (SC) is an extensive network consist of various entities responsible for supplying raw material transforming this raw material into intermediate and final product and ultimately delivering them to end customer. A typical supply chain network includes supplier, manufacturer, distributor and customer zone. In this regard supply chain management (SCM) stands out as a crucial research domain, capturing the interest of both business leaders and the academic community. This collaborative and collective approach gives rise to a distinct form of association known as the supply chain relationship among these enterprises.

Over the past few years, numerous studies have been put forth, and extensive research has been conducted on the design and optimization of supply chain networks. Network optimization techniques play a crucial role in designing and managing supply chain networks efficiently. Simchi-Levi et al. [1] discuss the application of network optimization models for facility location, distribution network design, and transportation routing to minimize overall costs and improve operational performance. Linear programming has been extensively utilized in supply chain management for optimizing various operations, including production planning, inventory management, and transportation logistics. For instance, Chopra and Meindl [23] discuss the application of LP in developing optimal production schedules considering constraints such as resource availability and demand variability. In a particular study Temesgen Garoma et al. [4] introduces a linear programming model for optimizing supply chain networks, focusing on reducing distribution costs and improving service levels. Ameen Alawneh et al. [7] developed a linear programming model to optimize the supply chain management system for a steel company in Qatar. Their model determines the optimal quantities of raw materials from suppliers, product deliveries to customers, and raw material inventory levels. Using GAMS software. Can Celikbilek et al. [18] propose a novel approach using Fuzzy Mixed Integer Linear Programming (FMILP) to address complex challenges in supply chain network design, aiming to maximize net profit while minimizing associated risks. H. C. W. Lau et al. [6] present an intelligent approach utilizing fuzzy logic to optimize supply chain operations and evaluate supplier performance. Martina Grubisic et al. [5] explore linear programming for land allocation in vegetable production, extending their analysis to dynamical optimization and crop rotation rules. S. Ariafar et al. [22] develop a production-distribution model using fuzzy optimization, addressing uncertainties in real-world production systems. Tadeusz Sawik et al. [17] propose coordinated decision-making models for supply chain scheduling under disruption risks. Kittipong Luangpantao et al. [21] emphasize the importance of effective supplier selection processes, utilizing fuzzy set theory to handle uncertainties. Nordin Hj. Mohamad et al. [19] focus on crop mix planning in agriculture, employing linear programming to maximize returns. Tsan-Ming Choi et al. [12] highlight the challenges of uncertainty in supply chain activities and advocate for innovative optimization models. Mariana E. Cóccola et al. [9] present an integrated approach to optimizing resource flows in the dairy industry. Paweł Sitek et al. [11] propose an integrated supply chain model using Mixed Integer Linear Programming for cost minimization. Dhanaji S. Jadhav et al. [20] develop a deterministic model for e-shopping agencies' supply chain strategies, aiming to minimize overall costs.

In this paper, a cost-effective deterministic model is developed using Linear Programming Considering shipping cost, transportation cost, distribution cost and opportunity cost with shipping option, transportation option and distribution option. The main objective of this paper is to minimize overall supply chain cost. This paper comprises four sections. Following the introduction, which outlines various supply chain models, the subsequent sections are organized as follows. Section 2 introduces the proposed multi-stage supply chain model, solved using specialized software. The outcomes of the implementation are deliberated in Section 3. Result and discussion are elaborate in Section 4 and Section 5 provides the conclusions.

2. Multi stage supply chain model:

2.1. Model Formulation

In this study, a multi-echelon model with the objective of minimizing the total cost is developed. Here three stage supply chain crisp model is considered below fig (1).

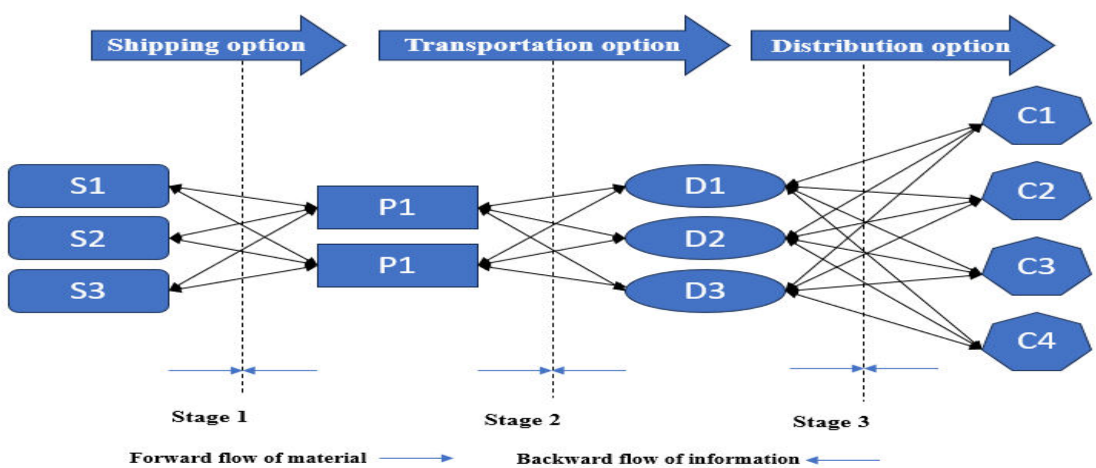

Fig. 1: Three stage supply chain networks with multimodal transport

Indices:

i: is index of supplier, for all i=1. 2,….,I

j: is index of plants, for all j=1.2,….,J

k: is index of distributor zones, for all k=1.2,….,K

l: is index of customer zones, for all l=1.2,….,L

t: is index of option for shipping

u: is index of option for Transportation

v: is index of option for distribution

Decision variable:

P_{ijt}: Quantity shipped from supplier i to plant j using option t

Q_{jku}: Quantity transported from plant j to distribution centre k using option u

R_{klv}: Quantity distributed from distribution centre k to customer zone l using option v

Parameter:

C_{ijt}: unit cost of shipping from supplier i to plant j using option t

C_{jku}: unit cost of transportation from plant j to distribution centre k using option u

C_{klv}: unit cost of distribution from distribution centre k to customer zone l using option v

x: unit opportunity cost of shipping from supplier to plants

y: unit opportunity cost of transportation from plants to distribution centres

z: unit opportunity cost of distribution from distribution centre to customer zones

e_{ijt}: shipping time from supplier i to plant j using option t

f_{jku}: transportation time from plant j to distribution center k using option u

g_{klv}: distribution time from distribution centre k to customer zone l using option v

α_{ijt}: Opportunity loss of shipping time from supplier i to plant j using option t

β_{jku}: Opportunity loss of transportation time from plant j to distribution center k using option u

γ_{klv}: Opportunity loss of distribution time from distribution centre k to customer zone l using option v

a_i: capacity limit of supplier i

b_j: capacity limit of plant j

c_k: capacity limit of distribution centre k

d_l: Demand of customer zone l

2.2 Assumptions of the Model:

1.The capacity constraints for suppliers, plants, and distribution centres are fixed.

2.The opportunity costs associated with shipping, transportation, and distribution are treated as precise and known values.

3.The shipping time, transportation time, and distribution time parameters are assumed to be known.

4.The demand from customer zones is considered deterministic.

Objective Function:

min Z=Supply cost +transportation cost +distribution cost+ opportunity cost

$$\min Z = \left[\sum_i \sum_j \sum_t (C_{ijt} * P_{ijt}) + \sum_i \sum_j \sum_t (C_{jku} * Q_{jku}) + \sum_i \sum_j \sum_t (C_{klv} * R_{klv})\right] + \left[x * \sum_i \sum_j \sum_t P_{ijt} * \alpha_{ijt} + y * \sum_j \sum_k \sum_u Q_{jku} * \beta_{jku} + z * \sum_k \sum_l \sum_v R_{klv} * \gamma_{klv}\right] \quad \ldots\ldots \quad (1)$$

Subject to Constraint:

1. Supplier Capacity Constraint

$$\sum_{j,t} P_{ijt} \le a_i \; \forall \, i \in I \quad \ldots\ldots \quad (2)$$

2. Plant Capacity Constraint

$$\sum_{i,t} P_{ijt} \le b_j \; \forall \, j \in J \quad \ldots\ldots \quad (3)$$

3. Distribution Center Capacity Constraint

$$\sum_{j,u} Q_{jku} \le c_k \; \forall \, k \in K \quad \ldots\ldots \quad (4)$$

4. Customer Zone Demand Constraint

$$\sum_{k,v} R_{klv} \le d_l \; \forall \, l \in L \quad \ldots\ldots \quad (5)$$

Flow Conservation Constraints:

1. Supply Conservation: -

$$\sum_{j,t} P_{ijt} = a_i \; \forall \, i \in I \quad \ldots\ldots \quad (6)$$

2. Transportation Conservation Constraint:

$$\sum_{i,t} P_{ijt} = \sum_{k,u} Q_{jku} \; \forall \, j \in J \quad \ldots\ldots \quad (7)$$

3. Distribution Conservation Constraint:

$$\sum_{j,u} Q_{jku} = \sum_{l,v} R_{klv} \; \forall \, k \in K \quad \ldots\ldots \quad (8)$$

Non - Negativity Constraint:

All decision variables must be non-negativity

$$P_{ijt}, Q_{jku}, R_{klv} \ge 0, \qquad \forall\, i \in A,\, j \in J,\, k \in K,\, l \in L,\, j \in J,\, k \in K,\, t \in T,\, u \in U \qquad (9)$$

Opportunity Loss Constraints:

Opportunity loss constraints for shipping, transportation, and distribution

$$\alpha_{ijt} \geq 0,\ \beta_{jku} \geq 0, \gamma_{klv} \geq 0 \qquad \forall i \in A,\ j \in J,\ k \in K,\ l \in L,\ j \in J,\ k \in K,\ t \in T,\ u \in U \qquad (10)$$

Opportunity Cost Constraints:

Opportunity Cost constraints for shipping, transportation and Distribution

$$x \geq 0,\ y \geq 0,\ z \geq 0 \qquad (11)$$

Time Constraints:

Shipping time, transportation time and distribution time constraints

$$e_{ijt}, f_{jku}, g_{klv} \geq 0 \qquad \forall\ i \in A,\ j \in J,\ k \in K,\ l \in L,\ j \in J,\ k \in K,\ t \in T,\ u \in U \qquad (12)$$

The proposed model considered the concept of opportunity cost into the supply chain design problem. This study aims to

1. Develop a supply chain model that effectively manages and optimizes operations in a deterministic environment.
2. Accurately represent and optimize the utilization of resources, such as shipping, transportation, and distribution capacities, to minimize overall costs.
3. Provide decision-makers with an efficient and deterministic supply chain model that supports informed decision-making under stable conditions.

3. Numerical Example:

To demonstrate the validity and practicality of the proposed model and solution method, an industrial case scenario is presented. This supply chain involves three suppliers, two manufacturing plant, three Distribution centre and four Customer zones. The company buy in raw material from three suppliers, employing transportation options such as railway, highway and airway. After manufacturing, products are directly dispatched to distribution Centre, with the manufacturer covering transportation costs. In subsequent stages, the company selects trucks based on preferences and routes, categorized as new, middle-aged and old. Trucks are assigned according to their capacities for transporting products from plants to distribution Centre. Parameters for this include z=2.25 rs/h, y=2.25 rs/h, and x=0.9 rs/h. The input data required for the design of supply chain for the above stated industry is given below.

Input Data

Table1. Capacities and Demand

Capacities of Supplier			Capacities of Plant			Capacities of Distribution Centre			Demands of Customer Zones		
$S1$	a_1	22000	P1	b_1	31000	$D1$	c_1	23000	$C1$	d_1	17500
$S2$	a_2	28000	P2	b_2	39000	$D2$	c_2	22500	$C2$	d_2	19000
$S3$	a_3	20000				$D3$	c_3	24500	$C3$	d_3	16000
									$C4$	d_4	17500

S- Supplier; P- Plant; D - Distribution Centre; C- Customer Zone

Table 2. Transportation cost (from supplier to plant) per unit

Transportation Alternative	Supplier 1	Supplier 2	Supplier 3	
Railway	27	36	45	Plant 1
Highway	45	56.25	72	
Airway	225	270	315	
Railway	29.25	45	56.25	Plant 2
Highway	56.25	72	65.25	
Airway	225	315	382.5	

Table 3. Transportation cost (from plant to Distribution centre) per unit

Transportation Alternative	DC 1	DC 2	DC 3	
Old Truck	6.3	4.05	8.1	Plant 1
Middle Truck	9	5.4	13.05	
New Truck	10.8	6.3	14.4	
Old Truck	8.5	5.85	9.45	Plant 2
Middle Truck	12.15	8.1	14.4	
New Truck	14.85	9	16.2	

Table 4. Transportation cost (from Distribution centre to Customer Zone) per unit

Transportation Alternative	Customer 1	Customer 2	Customer 3	Customer 4	
Old Truck	1.62	2.25	3.15	4.05	DC 1
Middle Truck	1.8	2.7	3.6	4.95	
New Truck	2.7	3.6	4.5	5.4	
Old Truck	5.4	6.3	4.05	2.25	DC 2
Middle Truck	6.3	7.65	4.5	2.7	
New Truck	7.2	8.55	4.95	3.15	
Old Truck	8.55	8.55	8.1	7.2	DC 3
Middle Truck	10.8	9.9	9.9	8.1	
New Truck	12.15	12.15	10.8	9.9	

Table 5. Opportunity loss of shipping time from supplier to plant using option

Transportation Alternative	Supplier 1	Supplier 2	Supplier 3	
Railway	120	192	240	Plant 1
Highway	72	96	120	
Airway	0	0	0	
Railway	168	240	288	Plant 2
Highway	96	120	144	
Airway	0	0	0	

Table 6. Opportunity loss of transportation time from plant to distribution centre

Transportation Alternative	DC 1	DC 2	DC 3	
Old Truck	2.5	2.5	3	Plant 1
Middle Truck	1.5	0.5	2	
New Truck	0	0	0	
Old Truck	3.5	4.5	5	Plant 2
Middle Truck	1.5	1.5	2	
New Truck	0	0	0	

Table 7. Opportunity loss of distribution time from distribution centre to customer zone

Transportation alternative	Customer 1	Customer 2	Customer 3	Customer 4	
Old Truck	1	1	2	2.5	**DC 1**
Middle Truck	0.5	0.5	1	1.5	
New Truck	0	0	0	0	
Old Truck	3	4	2.5	1.5	**DC 2**
Middle Truck	2	2	1.5	1	
New Truck	0	0	0	0	
Old Truck	5	5	5	4	**DC 3**
Middle Truck	3	2	3	2	
New Truck	0	0	0	0	

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

4. RESULTS AND DISCUSSIONS:

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

The solution for the numerical example is described as follows.

Optimum Objective Function	**1,00,83,850**
Decision Variable	
P_{112} (Quantity shipped from supplier 1 to plant 1 using shipping option Highway)	22000
P_{212} (Quantity shipped from supplier 2 to plant 1 using shipping option Highway)	28000
P_{312} (Quantity shipped from supplier 3 to plant 1 using shipping option Highway)	20000
Q_{123} (Quantity transported from plant 1 to distribution centre 2 using option New Truck)	31000
Q_{223} (Quantity transported from plant 2 to distribution centre 2 using option New Truck)	39000
R_{113} (Quantity distributed from distribution centre 1 to customer zone 1 using option New Truck)	17500
R_{123} (Quantity distributed from distribution centre 1 to customer zone 2 using option New Truck)	5500
R_{233} (Quantity distributed from distribution centre 2 to customer zone 3 using option New Truck)	5000
R_{243} (Quantity distributed from distribution centre 2 to customer zone 4 using option New Truck)	17500
R_{323} (Quantity distributed from distribution centre 3 to customer zone 2 using option New Truck)	13500
R_{333} (Quantity distributed from distribution centre 3 to customer zone 3 using option New Truck)	11000

5. CONCLUSIONS

In order to optimize supply chain network operations, the study presents a Linear Programming Problem (LPP) model that integrates production, distribution, and procurement planning tasks within a multi-echelon framework. The effectiveness of the model is proved numerically by using an objective function with a cost reduction focus. The final outcome comes at a total cost of **1,00,83,850** rupees.

This technique offers a simple and effective way to get the best answers for supply chain networks with multiple tiers. The suggested approach is particularly adaptable and useful for both large and small-scale companies. The concept is intended to allow for the addition or removal of any stage within the supply chain, simplifying corresponding modifications, and emphasizes its real-time application.

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