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Linear Programming Model for Sunflower Oil Supply Chain Network

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ABSTRACT

Food supply networks are vital to the global economy, producing and consuming products worldwide. Supply chain management (SCM) has emerged as a crucial technique to optimize the integrated network of suppliers, factories, warehouses, customers, and distribution channels. SCM aims to ensure efficient raw material sources, transformation, transportation, and timely customer delivery. Edible oil, a crucial ingredient for cooking and food preparation, is utilized by people from all social classes. Vegetable oils, particularly sunflower, soybean, peanut, and others, are the main source of edible oils, which have less unsaturated fatty acids compared to animal oils. The production and consumption of edible oils have substantial environmental impacts, necessitating increased research to address these implications. Sunflower, a valuable oilseed crop, is grown worldwide due to its short growing season and adaptability to various climates and soil types. Sunflower seeds have high oil and protein content, making them popular for their health benefits. In this article, a linear optimization model is designed for the sunflower oil supply chain from the farmer to the end user. The objective is to minimize the overall transportation cost subject to capacity, demand fulfillment, and waste management.

Keywords: Sunflower oil production, food supply chain, supply chain management, linear programming
(MSC2020) Codes: 90C05, 90C08

1 | INTRODUCTION

Food supply networks are a significant component of the global economy. Products are created and consumed globally, and processes are concerned with pollution, employment, and the use of natural resources. High volume, quickly moving products readily available to consumers are presented characteristics. Most of the food often has a short shelf life, and there are strict traceability requirements and pricing constraints [1].

Edible oil is a crucial dietary ingredient for cooking and food preparation. Despite uneven global per capita consumer preferences, the product is utilized by almost all social classes. A plethora of plants can synthesize edible oil. One of the major gripes for the oil processing plants is conserving the product's decent quality after processing until it can be utilized by the user. The predominant consumption of edible oils worldwide is related to vegetable oils since they include fewer unsaturated fatty acids than animal oils. Edible oil is one of the main items in the home food basket. Edible oil is one of the goods with the highest environmental impacts throughout all production and consumption stages [2]. To discover environmental implications along the entire chain of edible oil production, research activities seem to be increased [3]. The world's second-largest food resource presently, after cereals, is oil crops. These compositions exhibit plentiful fatty acid deposits. The synthesis of vegetable oil is now regarded as a crucial industry in the preponderance of countries around the globe. Oil seeds notably soybean, sunflower, hazelnut, and biodiesel are the major source of vegetable oils [4].Sunflower is placed third due to its high-quality oil, behind soybean, and peanut, along with other oil seed crops including rapeseed and cotton [5]. Because of the therapeutic benefits of its oil, which incorporates enormous amounts of fatty acids called polyunsaturated, these seeds have become exceedingly renowned [6].

The sunflower crop can be grown twice a year because it only lasts 90 to 120 days [7]. Due to its wide range of soil and climatic adaptation, short growing season, and optimal positioning in the cultivation system, this plant has a special value and has received significant attention in response to the rising need for vegetable oils [8]. The early 1990s saw the emergence of one of the most crucial management techniques: supply chain management (SCM): an integrated network of suppliers, factories, warehouses, customers, and distribution channels. These entities work together to receive raw materials, transform them into finished goods, locate distribution centers choose the best modes of transportation, and then distribute goods to the customer hubs in the appropriate amounts, at the appropriate times, and at the proper locations. SCM takes into account all of the elements that come together to deliver goods or services to clients. At various points in strategic design, operational thinking, and production strategy, supply chain managers always look for the optimal choices [9].

Grabbing a marketing domain for businesses in the global market requires a well-organized and rigorous supply chain network. In supply chain management, the contest of network design is addressed by determining positions and counting actors, calculating product flow, and reducing transportation costs. The value and relevance of the supply chain's constituents are important to satisfy market demand and establish a sustainable link between all the stages from raw material to consumer end. The massive and tremendously intricate logistics services involved in local and global supply chain networks critically need to minimize transportation costs, which seems to be a challenging task to accomplish [10]. A network of facilities and transportation methods that are interconnected and used for the production, distribution, and storage of materials and goods is known as a supply chain [11], [12], [13]. Typical supply chain components may include suppliers, manufacturers, distributors, consumers, and retailers as shown in Figure 1.

Figure 1. Supply Chain Network

The best arrangement and functioning of each of these components should be reflected in a supply chain that has been created to the highest degree possible using several measures [14]. Optimization supply chain at a larger scale involving various products, distribution networks, and customer satisfaction is a difficult task to handle [15]. In addition, several concerns, such as supply disruption and fluctuations in the worldwide pricing of basic items, would affect the supply chain. For large-scale and complicated supply chains to operate seamlessly under uncertainty, there is significant economic potential as well as a practical necessity to design and coordinate the activities of all supply chain entities properly. As a result, businesses and academics have shown a lot of interest in optimization models and techniques for supply chain design and operations during the past few decades [16], [17], [18], [19].

Food production, preservation, processing, and distribution are among the top industries worldwide. Only in Europe it generates a revenue of 1048 billion euros and employs over 4.2 million people [20].It is well noted that the processed food sectors do not adhere adequately to the traditional supply chain management strategies [21]. Especially in comparison to other supply chains, the peculiarities of food supply chains are also very dissimilar. The fundamental contrast is the ongoing change in raw material quality, from the producer to the point of treatment at the plants and in final product quality. Food supply chains are more complex and harder to manage than other supply chains. The shelf-lives of raw, intermediate, and final goods together with the strong uncertainties in the whole chain challenge good supply chain management and planning [22], [23].

Food commodities frequently create significant logistic and transportation challenges due to their postharvest losses, limited storage space, and requirements for sanitation and authenticity. The average distance that food travels from producers to end consumers has increased significantly over the past two decades, and food supply chains around the world have become more complex due to the numerous individuals involved. Global food systems are a major source of pollution and a contributing factor in climate change due to a high demand for greater food production and an increase in logistics and transportation. The reduction of transportation and environmental costs involves cooperation amongst supply chain participants, as one supply chain unit working alone may achieve very little [24].

The edible oil supply chain is concerned with the production, distribution, and handling of edible oils for human use. There are often multiple steps in the supply chain for edible oil, including farming, processing, packaging and storage, transportation, and distribution.

Optimization is a method used to solve complex problems. It is beneficial to find the solution that produces the best outcome, obtains the maximum profit, output, or happiness, or results in the least amount of waste, suffering, or cost. Making the best use of resources including cash, time, equipment, personnel, inventories, land, and water often involves solving these difficulties [25]. Optimization refers to making the greatest use of available resources and technologies. Many difficulties can be optimized with better strategy and execution. For better results, use mathematical methods like linear programming and quantitative models. Mathematical techniques are now used to handle a variety of operational planning issues relating to transportation. For modeling most of these transportation issues, linear programming is used [26]. One of the core issues in network flow is the transportation problem, which is typically used to reduce transportation costs for industries with many sources and destinations while meeting supply and demand constraints. Countless investigations have been conducted in this arena.

Dynamical sub-models have also been used to formulate mathematical programming models for integrated supply chains [27]. A model of a simple integrated production-distribution system was provided, and its practical aspects were analyzed. A method for discovering near-optimal solutions was proposed, focusing on a simple, one-product, three-location network consisting of a single shop, a finished goods stockpile, and a single factory with one station. This basic network is designed to highlight the key trade-offs of interest. A distribution/production optimization model was designed, encompassing manufacturer headquarters and adjacent warehouses [28]. The suggested model operates under limitations on production capacity and inventory equilibrium, aims to reduce wage costs, including those related to stock and transportation.

Conventional optimization techniques become potentially more complicated when flexible supply connections are involved. Therefore, a hybrid genetic algorithm is used for the location-allocation model, contributing a robust method to address these challenges [29]. The problem of order allocation in supply chain management, particularly through the adoption of Mass Customization Logistics Services (MCLS), is addressed by incorporating the role of a Logistic Service Integrator (LSI), who manages logistics services and outsources specific tasks to Functional Logistics Service Providers (FLSPs). The findings help the decision-makers to optimize order allocations, thereby minimizing supply chain costs while utilizing MCLS [30].

Using a systematic literature review, the research identifies four technological groups and their applications, objectives, and benefits within the agri-food sector. It also categorizes three types of agri-food supply chains, analyzes their configuration and dynamics, and identifies the most suitable technologies for each type [31]. Stochastic multi-objective programming models have also been developed to improve sustainability in the agricultural food supply chain network, addressing issues like greenhouse gas emissions and water consumption due to increased production [32]. To signify the ambiguous information structure, a multi-stage stochastic integer programming approach is developed. The proposed dynamic programming model is based on scenario trees. The model provides near-optimal solutions for large-size instances with the least computational effort [33]. A two-stage stochastic programming model was designed to improve the quality of dehydrated apple products by optimizing producer selection and cold storage management. The model addresses uncertainties in the conversion rate of fresh apples to dehydrated products and the purchase cost of apples, using scenarios generated from historical data [34].

A Sustainable Closed-Loop Supply Chain Network (CLSCN) is a supply chain system formulated to incorporate forward logistics (traditional supply chain processes) with reverse logistics (processes that return products and materials to the supply chain for reuse, recycling, or safe disposal) while considering environmental, economic, and social sustainability factors. This framework address's location, allocation, and inventory decisions with objectives to minimize total cost and CO2 emissions and maximize job opportunities. For small instances, the model is solved using the epsilon-constraint method, while for large-scale networks, innovative hybrid optimization algorithms are introduced [35]. Artificial intelligence is used to upgrade the sustainability of closed-loop supply chain (CLSC) for pomegranates, integrating forward and reverse logistics over multiple periods. The logistics network incorporates manufacturers, distribution centers, customers, factories, recycling centers, and compost markets. Wasted pomegranates are recycled into ethanol and compost. The model aims to minimize supply chain costs, reduce risks, and increase profits for gardeners and investors in Iran [36]. AI-based technologies' impact on reducing waste and minimizing costs in the agri-food supply chain, ultimately increasing organizational profitability. Utilizing dynamic capability view (DCV) and organizational information-processing theories, the research also examines how outbound logistics and distribution network efficiency (DNE) mediate the relationship between AI and agri-food supply chain efficiency (AFSCE) [37]. A coalition reliability index is established to synthesize and optimize an integrated oil palm value chain (OPVC) network, aiming to improve economic and environmental performance under different supply chain management systems [38].

Sustainability is a crucial part of any supply chain network. Several optimization models and multi-criteria decision-making techniques have been introduced, including the two-stage methodology [39]. In Stage 1, sustainability scores for potential suppliers are calculated using the Interval Type 2 Trapezoidal Best Worst Method, incorporating various qualitative and quantitative criteria. These scores are then used in Stage 2, where a multi-objective optimization model with four objective functions is formulated to maximize total profit, job opportunities, and supplier sustainability while minimizing CO2 emissions.

Significant research has been conducted to find useful machine learning technologies for improving the efficiency of biodiesel supply chain management, given its higher production costs compared to traditional fossil fuels. Various machine learning algorithms are evaluated and employed to estimate feedstock harvest, predict biodiesel production, and ensure biodiesel quality [40]. To mitigate disruption risk and enhance resilience in a multi-product Cooking Oil Supply Chain (COSC) network, the Analytical Network Process (ANP) is employed as a decision-making tool [41]. The study estimates supplier resilience and identifies strategies to improve network resilience. A stochastic mathematical model with three objectives is proposed, considering partial and complete disruptions. The model incorporates suppliers' scores and resilience strategies and employs a robust counterpart formulation and the Normalized Normal Constraint (NNC) method to generate Pareto optimal solutions.

Although it hasn't been addressed in the earlier literature, the processing, remaining characteristics, and environmental-related limitations that are inherent to the food supply chain call for a special optimization model. To overcome this difficulty, the study creates an optimization model for the logistics and transportation network from farmer to the consumer. It carries out an example of the supply chain for edible oil, involving various production stages that are common in many processed foods.

Furthermore, past research has highlighted the necessity for more intricate supply chain modeling that considers a variety of product types and transportation options. This proposed linear programming model endeavors to simultaneously minimize the total transportation costs while addressing these complexities. In addition, the study makes significant developments to the existing body of literature. Firstly, it provides a comprehensive model for understanding the edible oil supply chain, precisely focusing on the transportation links and product flows between various stakeholders such as suppliers, silos, extraction plants, refineries, filling points, branded oil stores, and consumers. This detailed approach allows for a complete view of the complete supply chain, identifying potential inefficiencies. Secondly, the study presents a mathematical model that, while designed for the edible oil supply chain, is flexible enough to be applied to other food supply chains. This adaptability ensures that the model can be a valuable tool for optimizing various types of supply chains, enhancing its utility and relevance across different industries. Thirdly, the mathematical model rigorously ensures the minimization of transportation costs by incorporating constraints related to capacity, demand fulfillment, and waste management. By doing so, it not only reduces costs but also promotes sustainable practices within the supply chain. The model's ability to handle multiple stages of production and distribution, along with its focus on cost efficiency, makes it a robust framework for decision-making in supply chain management. Overall, this research bridges gaps in current supply chain models by providing a detailed, adaptable, and cost-efficient solution, thereby contributing valuable insights and tools for both academic research and practical applications in the area of supply chain optimization.

2 | PRELIAMINARIES

The nine important participants in the supply chain for edible oil are the supplier, sunflower seed silo, seed extraction plant, oil refinery plant, edible oil refinery plant, filling point, branded oil store, consumer, and waste center. Suppliers supply sunflower seeds to sunflower seed silos. Sunflower seed silo supplies sunflower seeds to seed extraction plants, where the sunflower seeds are processed and extracted seeds are obtained. The extracted seeds are sent from the seed extraction plant to the oil refinery plant, where the extracted seeds are processed and refined oil is obtained. The refined oil is sent from the oil refinery plant to the edible oil refinery plant, where the refined oil is processed, and edible oil is obtained. The edible oil is sent from the edible oil refinery plant to the filling point, where the edible oil is filled in tin cans and pet bottles and edible oil in packing form is obtained. Then the edible oil in packing form is sent from the filling point to the branded oil store (see Figure 2). The consumer has a specific demand for edible oil which is met from branded oil stores.

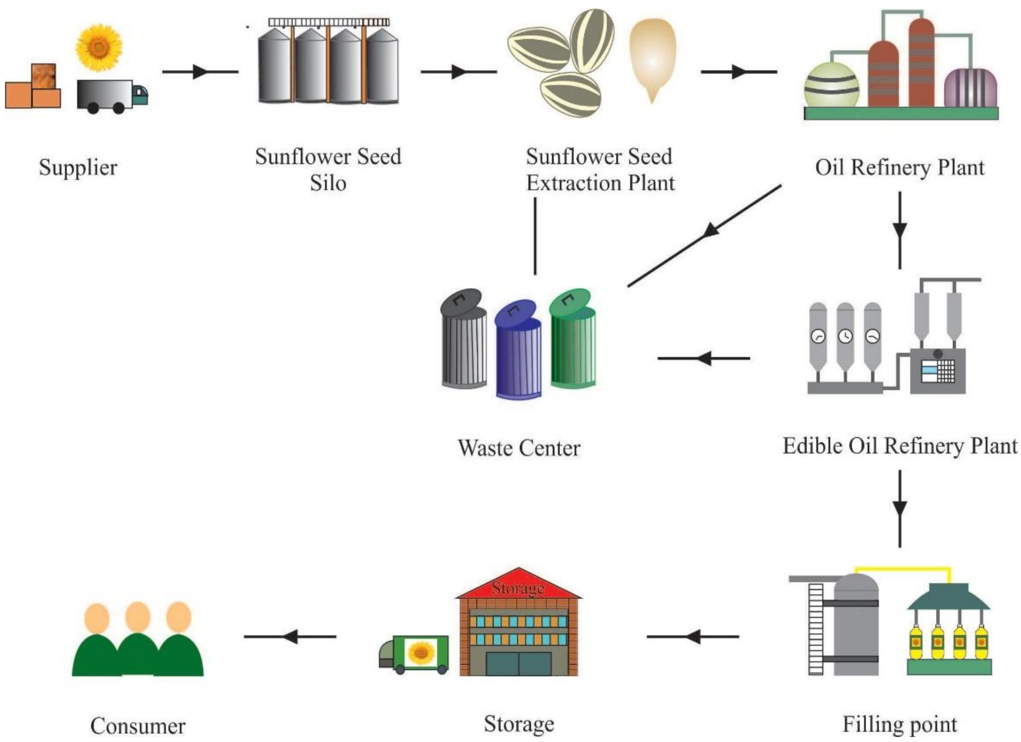

Figure 2. Sunflower Oil Supply Chain Network

Utilizing diverse forms of shipment (e.g., road, maritime, and air) is necessary for the transportation of various types of goods. Additionally, demand for different products varies greatly amongst actors and across the network. Processing different product types leads to certain wastage after processing. For example, processing sunflower seeds at seed extraction plants, processing extracted seeds at oil refinery plants, and processing refined oil at edible oil refinery plants ensure that wastage is also obtained from each of the processing activities.

The study work is innovative and addresses the network of edible oil supply chains using a mathematical formulation. The mathematical models' primary goal is to assist decision-makers involved in the food supply chain in reducing the transportation cost. The models also consider a variety of real-world constraints relating to product supply, customer demand, and transportation capacity, as well as fluctuating storage capacity and stakeholder needs. Additionally, the proposed mathematical models aid in addressing the variability in the cost elements related to transportation.

3 | MATHEMATICAL MODEL

To present the mathematical model following indices, parameters, and decision variables are used:

Indices and sets

s = Supplier
i = Sunflower seeds silo
j = Seed extraction plant
k = Oil refinery plant

l = Edible oil refinery plant
b = Branded oil store
c = Consumer
u = Tin filling point
v = Pet bottle filling point
p = A set of tin package size
q = A set of pet bottle size
α_p= Size of tin package p
β_q= Size of pet package q
$\widetilde{V}$= Capacity of vehicle

Parameters

$\tilde{C}_s$: Capacity of sunflower seed supplier s
$\tilde{C}_i$: Capacity of sunflower seeds silo i
$\tilde{C}_j$: Capacity of seed extraction plant j
$\tilde{C}_k$: Capacity of oil refinery plant k
$\tilde{C}_l$: Capacity of edible oil refinery plant l
$\tilde{C}_u$: Capacity of filling line u (for filling tin cans)
$\tilde{C}_v$: Capacity of filling point v (for filling pet bottles)
$\tilde{C}_b$: Capacity of branded oil store b
TC_{si} : Cost of transportation per unit of sunflower seeds fromsunflower seed supplier s to sunflower seed silo i
TC_{ij} : Cost of transportation per unit sunflower seeds from sunflower seed silo i to seed extraction plant j
TC_{jk} : Cost of transportation per unit extracted seeds fromseed extraction plant j to oil refinery k
TC_{kl} : Cost of transportation per unit refined oil from oilrefinery plant k to edible oil refinery plant l
TC_{lu} : Cost of transportation per unit edible oil from edibleoil refinery plant l to filing line u
TC_{lv} : Cost of transportation per unit edible oil from edibleoil refinery plant l to filing line v
TC_{ub} : Cost of transportation per unit of tin cans from filling line u to oil store b
TC_{vb} : Cost of transportation per unit of pet bottles from filling line v to oil store b
TC_{bc} : Cost of transportation per unit tin cans/bottles from branded oilstore b to consumer c
TC_{jw} : Cost of transportation of wastage amount from seedextraction plant j to waste center w
TC_{kw}: Cost of transportation of wastage amount from oilrefinery plant k to waste center w
TC_{lw} : Cost of transportation of wastage amount from edible oil refinery plant l to waste center w
W_j : Waste produced at seed extraction plant j
W_k : Waste produced at oil refinery plant k
W_l : Waste produced at edible oil refinery plant l

Decision Variables

$\ddot{X}_{si}^{SS}$: Quantity of sunflower seeds transported from the supplier s to sunflower seeds silos i

$\ddot{X}_{ij}^{WS}$: Quantity of sunflower seeds transported from sunflower seeds silo i to extraction plant j

$\ddot{X}_{jk}^{ES}$: Quantity of extracted seeds transported from extraction plant j to oil refinery plant k

$\ddot{X}_{kl}^{RO}$: Quantity of refined oil transported from oil refinery plant k to edible oil refinery l

$\ddot{X}_{lu}^{EO}$: Quantity of edible oil transported from edible oil refinery plant l to filling line u (in cans)

$\ddot{X}_{lv}^{EO}$: Quantity of edible oil transported from edible oil refinery plant l to filling line v (in bottles)

$\ddot{X}_{ub}^{TIN}$: Quantity of transported edible oil in tin cans from filling line u to branded oil store b

$\ddot{X}_{vb}^{BTL}$: Quantity of transported edible oil in pet bottles from filling line v to branded oil store b

$\ddot{X}_{bc}^{BOC}$: Quantity of branded oil in tin cans transported from branded oil store b to consumer c

$\ddot{X}_{bc}^{BOB}$: Quantity of branded oil in pet bottles transported from branded oil store b to consumer c

W_{jw}^{WS}: Quantity of waste transported from seed extraction plant j to waste center w

W_{kw}^{ES}: Quantity of waste transported from oil refinery plant k to waste center w

W_{lw}^{RO}: Quantity of waste transported from edible oil refinery plant l to waste center w

3.1 | Objective Function

The objective function seeks to minimize the total transportation cost across the entire supply chain of sunflower seeds and edible oil. This cost involves the shipment of sunflower seeds from suppliers to silos, from silos to seed extraction plants, from seed extraction plants to oil refinery plants, and from oil refinery plants to edible oil refinery plants. It also contains the costs associated with transporting the refined oil from edible oil refinery plants to various filling lines, and subsequently, from these filling lines to branded oil stores. Moreover, the transportation costs for delivering the final edible oil products to consumers are accounted for, as well as the costs for transporting waste products to waste centers from different stages of the supply chain. The comprehensive approach ensures the minimization of total transportation costs, thereby enhancing the overall efficiency and cost-effectiveness of the edible oil supply chain.

3.2 | Constraints

The objective function is subjected to the following set of constraints.

1. Supply constraints

$$\sum_{i=1}^{I} \ddot{X}_{si}^{SS} \leq \tilde{C}_s \quad \text{for all } s$$

$$\sum_{j=1}^{J} \ddot{X}_{ij}^{WS} \leq \tilde{C}_i \text{ for all } i$$

$$\sum_{k=1}^{K} \ddot{X}_{jk}^{ES} \leq \tilde{C}_j \text{ for all } j$$

$$\sum_{l=1}^{L} \ddot{X}_{kl}^{RO} \leq \tilde{C}_k \quad \text{for all } k$$

$$\sum_{u=1}^{U} \ddot{X}_{lu}^{EO} + \sum_{v=1}^{V} \ddot{X}_{lv}^{EO} \leq \tilde{C}_l \quad \text{for all } l$$

$$\sum_{b=1}^{B} \ddot{X}_{ub}^{TIN} \leq \tilde{C}_u \quad \text{for all } u$$

$$\sum_{b=1}^{B} \ddot{X}_{vb}^{BTL} \leq \tilde{C}_v \quad \text{for all } v$$

$$\sum_{c=1}^{C} \ddot{X}_{bc}^{BOC} + \sum_{c=1}^{C} \ddot{X}_{bc}^{BOB} \leq \tilde{C}_b \quad \text{for all } b$$

2. Demand Constraints

$$\sum_{b=1}^{B} \ddot{X}_{bc}^{BOC} + \sum_{b=1}^{B} \ddot{X}_{bc}^{BOB} \geq D_c \quad \text{for all } c$$

3. Balance Constraints

$$\sum_{i=1}^{I} \ddot{X}_{si}^{SS} = \sum_{j=1}^{J} \ddot{X}_{ij}^{WS} \tilde{C}_i \text{ for all } i$$

$$\sum_{j=1}^{J} \ddot{X}_{ij}^{WS} = \sum_{k=1}^{K} \ddot{X}_{jk}^{ES} \quad \text{for all } j$$

$$\sum_{k=1}^{K} \ddot{X}_{jk}^{ES} = \sum_{l=1}^{L} \ddot{X}_{kl}^{RO} \quad \text{for all } k$$

$$\sum_{l=1}^{L} \ddot{X}_{kl}^{RO} = \sum_{u=1}^{U} \ddot{X}_{lu}^{EO} + \sum_{v=1}^{V} \ddot{X}_{lv}^{EO} \quad \text{for all } l$$

$$\sum_{u=1}^{U} \ddot{X}_{lu}^{EO} + \sum_{v=1}^{V} \ddot{X}_{lv}^{EO} = \sum_{b=1}^{B} \ddot{X}_{ub}^{TIN} + \sum_{b=1}^{B} \ddot{X}_{vb}^{BTL} \quad \text{for all } u, v$$

$$\sum_{b=1}^{B} \ddot{X}_{ub}^{TIN} + \sum_{b=1}^{B} \ddot{X}_{vb}^{BTL} = \sum_{b=1}^{B} \ddot{X}_{bc}^{BOC} + \sum_{b=1}^{B} \ddot{X}_{bc}^{BOB} \quad \text{for all } b$$

4. Waste Constraints

$$\sum_{w=1}^{W} W_{jw}^{WS} \leq W_j \quad \text{for all } j$$

$$\sum_{w=1}^{W} W_{kw}^{ES} \leq W_k \quad \text{for all } k$$

$$\sum_{w=1}^{W} W_{lw}^{RO} \leq W_l \quad \text{for all } l$$

4 | CASE STUDY

A sunflower oil-producing company has three suppliers, four sunflower seeds silos, five seed extraction plants, three oil refinery plants, two edible oil refinery plants, three tin filling points, two pet bottle filling points, four branded oil stores, two waste centers, and six customers. Their capacities and demands are given in Table 1.

Table 1: Capacities and demand

<table>
<tr><td colspan="8">Capacity (in tons)</td><td rowspan="2">D_c (in tons)</td></tr>
<tr><td>$\tilde{C}_s$</td><td>$\tilde{C}_i$</td><td>$\tilde{C}_j$</td><td>$\tilde{C}_k$</td><td>$\tilde{C}_l$</td><td>$\tilde{C}_u$</td><td>$\tilde{C}_v$</td><td>$\tilde{C}_b$</td></tr>
<tr><td rowspan="2">150</td><td>100</td><td>120</td><td rowspan="2">130</td><td rowspan="3">140</td><td rowspan="2">150</td><td rowspan="3">140</td><td>120</td><td>100</td></tr>
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<tr><td rowspan="2">250</td><td rowspan="2">110</td><td>140</td><td rowspan="2">160</td><td rowspan="2">160</td><td rowspan="2">130</td><td>110</td></tr>
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<tr><td>140</td></tr>
</table>

Transportation cost for the shipment of per unit sunflower seeds from sunflower seed supplier s to sunflower seed silo i is given in Table 2.

Table 2. Transportation cost TC_{si}

Supplier	Sunflower seed silo			
	1	2	3	4
1	0.8500	5.2702	8.1283	7.1265
2	9.2236	1.1885	2.4410	3.7815
3	0.5360	3.8014	8.8442	2.4892

Transportation cost for the shipment of per unit sunflower seeds from the sunflower seed silo i to the seed extraction plant j is given in Table 3.

Table 3. Transportation cost TC_{ij}

Sunflower seed silo	Seed extraction plant				
	1	2	3	4	5
1	2.5285	6.2028	2.6021	0.9096	3.5503
2	7.6724	7.4668	8.7747	5.6427	3.1478
3	0.4986	9.7726	8.0610	1.8738	7.2674
4	6.8529	3.8391	4.6112	5.3169	5.1577

Transportation cost for the shipment of per unit extracted seeds from seed extraction plant j to oil refinery k is given in Table 4.

Table 4. Transportation cost TC_{jk}

Seed extraction plant	Oil refinery		
	1	2	3
1	7.9064	6.7857	6.1490
2	2.0449	9.4601	3.1607
3	6.7811	0.9156	0.7749
4	0.5249	9.0844	8.5061
5	8.0117	5.0995	1.4453

Transportation cost for the shipment of per unit refined oil from the oil refinery plant k to the edible oil refinery plant l is given in Table 5.

Table 5. Transportation cost TC_{kl}

Oil refinery	Edible oil refinery plant	
	1	2
1	3.7049	5.1734
2	6.2239	9.9051
3	9.9755	2.2653

Transportation cost for the shipment of per unit edible oil from the edible oil refinery plant l to tin filing line u is given in Table 6.

Table 6. Transportation cost TC_{lu}

Edible oil refinery plant	Tin filling line		
	1	2	3
1	3.9801	0.6464	4.2040
2	6.9657	7.4766	8.1132

The cost of transportation per unit of edible oil from the edible oil refinery plant l to filing line v is given in Table 7.

Table 7. Transportation cost TC_{lv}

Edible oil refinery plant	Pet bottle filling line	
	1	2
1	3.7961	9.8605
2	3.1907	7.1818

The cost of transportation per unit of tin cans from the filling line u to the branded oil store b is given in Table 8.

Table 8. Transportation cost TC_{ub}

Tin filling line	Branded oil store			
	1	2	3	4
1	4.1318	6.3731	9.8160	0.5383

2	0.9863	0.7384	4.9680	1.4087
3	7.3456	1.2051	0.2241	8.9347

The cost of transportation per unit of pet bottles from the filling line v to the branded oil store b is given in Table 9.

Table 9. Transportation cost TC_{vb}

Pet bottle filling line	Branded oil store			
	1	2	3	4
1	4.6582	4.9446	8.9765	2.6905
2	5.6086	0.6779	2.8857	5.9419

Transportation cost for the shipment of tin cans/bottles from branded oil store b to consumer c is given in Table 10.

Table 10. Transportation cost TC_{bc}

Branded oil store	Customer					
	1	2	3	4	5	6
1	4.7588	6.2043	0.2725	5.1992	5.4801	0.7823
2	3.6831	2.8284	8.7618	0.5382	5.6686	4.5635
3	6.5561	2.0518	6.1009	8.6219	6.8039	0.4784
4	9.3820	4.3913	2.0359	4.4293	3.7138	7.3826

Transportation cost for the transportation of waste material from seed extraction plant j to waste center w is given in Table 11.

Table 11. Transportation cost TC_{jw}

Seed extraction plant	Waste center	
	1	2
1	7.8310	2.4877
2	6.8569	3.1930
3	4.6622	9.1080
4	2.6032	8.8522
5	5.6927	7.9459

Transportation cost for the transportation of waste material from the oil refinery plant k to the waste center w is given in Table 12.

Table 12. Transportation cost TC_{kw}

Oil refinery plant	Waste center	
	1	2
1	9.2581	6.2701
2	1.7884	9.1318
3	5.1754	6.6397

The transportation cost for the transportation of waste material edible oil refinery plant l to waste center w is given in Table 13.

Table 13. Transportation cost TC_{lw}

Edible oil refinery plant	Waste center	
	1	2
1	3.8919	8.1763
2	7.4001	6.0034

The amount of waste material produced (in tons) at different plants is given in Table 14.

Table 14. Waste material produced

<table>
<tr><th>W_j</th><th>W_k</th><th>W_l</th></tr>
<tr><td>10</td><td rowspan="2">12</td><td rowspan="3">14</td></tr>
<tr><td>20</td></tr>
<tr><td>15</td><td rowspan="2">22</td></tr>
<tr><td>25</td><td rowspan="2">16</td></tr>
<tr><td>18</td><td>18</td></tr>
</table>

5 | RESULTS AND DISCUSSION

The optimization model is solved on MATLAB2018a for the above data the minimized transportation cost is 7.0656545583e+03 (in Dollars). The values of the decision variable are given in Table 15-.

Table 15. Quantity of sunflower seeds transported from the supplier s to sunflower seeds silos i

Supplier	Sunflower seed silo			
	1	2	3	4
1	0.1004	0.1094	0.1026	0.1036
2	0.1095	0.4743	249.1129	179.6854
3	149.6807	0.3102	0.1099	0.1011

Table 16. Quantity of sunflower seeds transported from sunflower seeds silo i to extraction plant j

Sunflower seed silo	Seed extraction plant				
	1	2	3	4	5
1	0.1060	0.1009	0.1045	0.1040	248.9152
2	0.1043	0.1045	0.1065	0.1088	0.1029
3	0.2708	0.1064	0.1083	329.0445	0.1028
4	0.1026	0.1013	0.1031	0.1024	0.1001

Table 17. Quantity of extracted seeds transported from extraction plant j to oil refinery plant k

Seed extraction plant	Oil refinery		
	1	2	3
1	0.1037	0.1094	0.1049
2	0.2144	0.1086	0.2082
3	0.1030	0.3657	329.1416
4	249.0172	0.1048	0.1018
5	0.1024	0.1056	0.1086

Table 18. Quantity of refined oil transported from oil refinery plant k to edible oil refinery l

Oil refinery	Edible oil refinery plant	
	1	2
1	578.3734	0.7817
2	0.1033	0.1017
3	0.1075	0.5323

Table 19. Quantity of edible oil transported from edible oil refinery plant l to filling line u (in cans)

Edible oil refinery plant	Tin filling line		
	1	2	3
1	0.1054	577.9437	0.4215
2	0.1025	0.3680	0.2124

Table 20. Quantity of edible oil transported from edible oil refinery plant l to filling line v (in bottles)

Edible oil refinery plant	Pet bottle filling line	
	1	2
1	0.3279	0.1006
2	0.1031	0.3149

Table 21. Quantity of transported edible oil in tin cans from filling line u to branded oil store b

Tin filling line	Branded oil store			
	1	2	3	4
1	0.1013	0.1089	0.1029	0.1073
2	0.1593	0.2101	0.1025	0.1020
3	0.1040	0.1084	577.8447	0.1022

Table 22. Quantity of transported edible oil in pet bottles from filling line v to branded oil store b

Pet bottle filling line	Branded oil store			
	1	2	3	4
1	0.1098	0.1030	0.1090	0.1000
2	0.1059	0.1097	0.1019	0.1071

Table 23. Quantity of branded oil transported from branded oil store *b* to consumer *c*

Branded oil store	Customer					
	1	2	3	4	5	6
1	0.1087	0.1060	0.1095	0.1024	0.1080	0.1005
2	0.1012	0.1052	0.1087	577.8454	0.1080	0.1071
3	0.1004	0.1001	0.1011	0.1061	0.1078	0.1099
4	0.1060	0.1069	0.1035	0.1030	0.1035	0.1016

Table 24. Quantity of waste transported from seed extraction plant *j* to waste center *w*

Seed extraction plant	Waste center	
	1	2
1	0.1011	14.8919
2	9.8989	24.8995
3	0.1048	0.1005
4	19.8952	0.1061
5	0.1081	17.8939

Table 25. Quantity of waste transported from oil refinery plant *k* to waste center *w*

Oil refinery plant	Waste center	
	1	2
1	0.1051	0.1050
2	11.8949	0.1033
3	21.8950	17.8967

Table 26. Quantity of waste transported from edible oil refinery plant *l* to waste center *w*

Edible oil refinery plant	Waste center	
	1	2
1	13.8942	0.1075
2	0.1058	15.8925

6 | CONCLUSION

The optimization model established for the transportation and processing of sunflower seeds into edible oil provides an efficient framework to minimize transportation costs while sustaining capacity and demand constraints at various stages of the supply chain. By including waste management and ensuring the balanced distribution of resources, the model realistically addresses the complexities of the supply chain.

Key outcomes of the model include:

Cost minimization: the central objective of minimizing transportation costs is achieved by optimizing the flow of materials from suppliers to consumers through transitional processing and filling points.

Capacity constraints: the model ensures that all capacity constraints at suppliers, silos, extraction plants, refineries, filling points, and branded oil stores are respected, avoiding overloading and make sure smooth operations.

Demand fulfillment: consumer demands are met accurately, with the model distributing the appropriate quantities of edible oil to diverse consumers, ensuring customer satisfaction.

Waste management: the inclusion of waste transportation and processing constraints ensures that waste produced at different processing stages is efficiently managed and transported to waste centers, adhering to environmental regulations.

Non-zero decision variables: by incorporating slight variations in the lower bounds of decision variables, the model prevents trivial solutions and ensures a more realistic distribution of flow quantities across the entire supply chain network.

In conclusion, the optimization model serves as a robust tool for decision-makers in the sunflower seed oil industry, providing significant insights into cost-effective transportation and processing strategies. Future work can expand the model to include dynamic demand variations, multiple product types, and further integration of sustainability measures to enhance the overall efficiency, effectiveness, and environmental friendliness of the supply chain.

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