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RESEARCH PAPER

Multi-Fruit Value Chain Network Design Considering Multi-Compartment Reefer Trucks

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ABSTRACT

Refrigerated trucks in the cold chain enhance the shelf-life of food. In the fruit supply chain (FSC), if each different fruit necessitates its dedicated fleet of refrigerated vehicles, the total cost of the supply chain would increase. On the other hand, if there are several fruits in a single compartment, the quality and freshness of the fruits will be impacted since each fruit requires a different operating temperature. Therefore, partitions are necessary within the container. While the use of cold chain infrastructure will result in a reduction in food loss and an enhancement in food security, it will also incur an increase in the overall cost of the supply chain. Therefore, this paper aims to create a mixed integer non-linear programming (MINLP) mathematical model considering multi-compartment reefer trucks (MCRTs) to minimize the total cost in the FSC. To assess the efficiency of the model, a case study is carried out in India, and the formulated mathematical model is solved using a heuristic approach. The findings indicate that utilizing MCRTs leads to a reduction in the number of vehicles required and a drop in total supply chain cost. Three-compartment reefer trucks offer a more significant cost-saving advantage in the FSC compared to two-compartment reefer trucks. Furthermore, it is noted that operating three distribution centers (DCs) results in a reduction in the overall cost. The decrease in total supply chain costs enhances the affordability of fruits for low-income populations and contributes to the enhancement of food security. In addition to cost reduction, implementing MCRT has also beneficial environmental impacts such as decreased emissions due to a decrease in the number of trucks utilized and reduced food waste.

KEYWORDS: Fruit supply chain; Multi-compartment reefer truck; Food security; Mathematical model.

1. Introduction

According to the National Horticultural Board [1], 2022, India ranks second in the world in fruit and vegetable production with 107.24 million metric tonnes and 204.84 million metric tonnes, respectively. During 2021–2022, the country exported fresh fruits and vegetables valued at USD 1635.95 million and processed fruits and vegetables valued at USD 2,248.96 million [2]. Despite its abundance of agricultural output, the country's hunger problem is so severe that it is ranked 111th on the Global Hunger Index 2023 [3]. The reason for this is significant post-harvest supply chain losses. According to NABCONS 2022 [4], the country loses 6.02–15.05% of its fruit crop and 4.87–11.61 % of its vegetable crop due to post-harvest losses. Critical causes of food loss in the food supply chain include a lack of cold storage facilities, inefficient logistics operation, inaccurate demand forecasting, and a lack of knowledge of modern technologies [5][6]. The fact that fruits may be consumed raw and can be preserved for a longer amount of time makes them more convenient than vegetables. Since fruits are perishable and more prone to climatic conditions, the most significant causes are inadequate transportation infrastructure and poor supply chain network architecture [7][8]. FSC has significant difficulty in replicating the fruit's freshness and flavor for customers after it has been transported from the farm. Keeping fruits in the cold chain infrastructure ensures that they will remain edible throughout the supply chain [9][10].

The cold chain is a temperature-controlled supply chain that involves the storage, transportation, and distribution of perishable goods. The cold chain helps extend the shelf life of food products and reduce the amount of waste generated. The most

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important element in the cold chain is transportation where the temperature of the product has to be maintained depending on the ambient temperature [11]. To overcome this challenge cold transport operations, entail the transportation of commodities utilizing refrigerated trucks (reefers) while ensuring the necessary temperature and humidity conditions are maintained [12].

When it comes to logistics operations, retailers order several food items from the same wholesalers. The current cold chain practice in India is shipping all the fruits together in a single truck without any partition. The existing method may assist reduce overall supply chain costs because each fruit needs to be maintained at a separate atmospheric condition, but it is ineffective in terms of extending shelf life. The utilization of MCRTs enables the delivery of diverse product categories simultaneously on a single truck [13]. This cold chain infrastructure will increase the transportation cost and operation cost further increasing the total supply chain cost which negatively impacts affordability. This also makes the intermediate stakeholders think about implementing cold storage and refrigerated logistics operations in terms of profit. Locating DCs and transportation are critical components of food supply chain management since they deal with perishable items like fruits. Choosing the right DC location will minimize the risks of delays in shipments and make every other operation in SC more efficient. The complexity of the perishable food vehicle routing challenge grows as a result of the significant value lost throughout the distribution process. As a result, it is critical to develop an efficient distribution route that minimizes transportation costs while maximizing the freshness state of the delivered items. Therefore, this study aims to propose a novel idea of implementing MCRT at the retailer's end to minimize the number of vehicles utilized, hence decreasing overall supply chain costs and enhancing environmental sustainability. With the advent of multi-capacitated distribution centers and MCRT on the retailer's end, a MINLP mathematical model is formulated to minimize total supply chain cost. To check the efficiency of a model, a real-world case scenario is considered for testing the model and a heuristic approach is opted for solving the model.

2. Literature Review

The most significant factors, such as a lack of linkages between industry, government, and institution, a lack of advanced technology, and a lack of linkage between farmers and food processing units, have been identified through an investigation of the causes of post-harvest losses in the fruit supply chain using expert opinions [14]. Furthermore, the DEMATEL method identifies the lack of proper processing, packaging, and storage facilities, insufficient cold chain infrastructure, and improved handling of the products at the farm and marketplace as the most critical factors that should be tackled to ensure progressive post-harvest loss reduction [10]. Intelligent and effective FSC was mentioned by Negi and Anand [15], as being crucial in India since it decreases losses and wastages while simultaneously raising farmer income and export revenues. Corrugated fiberboard boxes have been recommended when analysing the fruit supply chain, to reduce post-harvest losses when using the already available non-reefer truck transportation infrastructure [16]. A few studies [5][17] have used the fuzzy-DEMATEL and fuzzy-AHP tools to identify the many reliant elements of cold chain third-party logistics.

By applying graph theory principles to model delivery networks, optimize routes, and enhance security measures, this research aims to cultivate efficiency in food delivery logistics, ultimately streamlining operations and minimizing environmental footprint [18]. An efficient solution method based on a three-phase methodology is developed for the location-routing problem for the pineapple supply chain [19]. Pérez-Lechuga et. al [20] aimed to maximize the supply chain efficiency and minimise the pollution generated by refrigerated transportation by developing a stochastic routing model and solving by Generic Random Search Algorithm.

It is found that mixed integer linear programming (MILP) is the most widely employed mathematical technique in the FSC [21][22]. Through strategic transportation planning, a MILP model is created to optimize the cost and demand in India's apple fruit value chain [23]. A MINLP mathematical model is formulated for the citrus fruits supply chain to minimize costs and maximize profits [24]. In the citrus fruit supply chain, Goodarzian et al. [25] developed a bi-objective MINLP to optimize production, distribution, and inventory. A multi-period MILP for planning the supply chain of apples and pears is proposed considering profit and supply shortfall objectives [26]. The MILP model is developed to find the appropriate allocation of facilities for agri-fresh food SC while minimizing overall SC costs [27]. Considering the perishability with which agri-fresh items must be sold, Patidar and Agrawal

[28] and Cheraghalipour et al. [29] developed the MILP model. An industrial case study is used to look at the financial effect of incorporating environmental themes into the fruit value chain [30].

A supply chain network of dates fruit is investigated by developing a MILP model to effectively improve economic objectives under uncertainty [31]. The authors also considered weather conditions and economic fluctuations in different scenarios. An optimal multi-objective model for a sustainable closed-loop supply chain is designed for pomegranate fruits [32]. The article aims to minimize the cost and risk of the SC and maximize the profits of gardeners and investors in the public and Non-profit agriculture sectors. A bi-objective MINLP is formulated to maximize profit and quality of a four-echelon agricultural supply chain. The authors integrated facility location, allocation of vehicles, and temperature setting in refrigerated facilities in the objectives [33]. A mathematical model of the agricultural supply chain is developed to minimize total cost and greenhouse gas emission mitigation and maximize the employment rate by determining the optimal number and location of suppliers, assigning suppliers to distribution centers and optimal routing for the distribution with a predefined time window [34]. A multi-objective MILP model is proposed to formulate a multi-period multi-echelon problem to design the sustainable citrus closed-loop supply chain network. The model is solved using the ε-constraint approach, Strength Pareto Evolutionary Algorithm II, and Pareto Envelope-based Selection Algorithm II for small, medium, and large-sized problems respectively [35]. Jaigirdara et. al [36] proposed a tri-objective optimization model for multi-echelon and multi-products to minimize total supply chain cost and to maximize the freshness of lemon and guava. The authors formulated a MILP model for the supply chain distribution network design problem and solved using CPLEX optimisation studio. A mathematical modeling of an agricultural closed-loop supply chain is formulated considering carbon footprint through food waste minimization and traceability [37].

It has been noted that previous research has less importance on keeping the FSC's overall price as low as possible. In addition, there is a dearth of literature on the topic of capacitated trucks in the FSC, and no examples of the use of a mathematical model in conjunction with a multi-compartment reefer truck have been located. In light of the importance of reducing waste and maximizing profits, this study seeks to create a MINLP model to optimize the use of a multi-compartment refrigerated truck in the food service industry.

3. Mathematical Model

FSCs are quickly altering shape as globally interconnected networks, making it extremely difficult to handle. Also, the food loss rate in FSC is substantially higher than the overall food production rate and occurs during the storage and transportation stages of the post-harvest life cycle. Apart from the loss of revenue for farmers, it increases additional expenses in the supply chain, forcing end customers to pay hefty fees out of their own pockets. The food losses may be avoided by designing an effective FSC network, which improves supply chain management efficiency. To achieve the improved efficiency of the FSC, it is critical to choose the right location of DC and decrease the transportation cost between the nodes. A MINLP model is formulated for a multi-echelon multi-period FSC network problem. The mathematical formulation is developed for an FSC network comprising procurement centers (PC), distribution centers (DC), and retailers (RT). Farmers grow fruits on their farms and bring them to the procurement centers. Each village has a procurement center where all the farmers' produce will be collected and distributed to the distribution centers. Then the fruits in the DCs will be distributed to the retailers depending upon their demand. Finally, the retailers sell to the customers. This article aims to propose the implementation of a multi-compartment reefer truck at the retailer end to reduce the total cost in the FSC as shown in Figure 1. Two scenarios are built to check the efficiency of implementing MCRT in the FSC. In the first scenario, a regular refrigerated truck (single-compartment reefer truck) is utilized from PC to DC and DC to RT where only one fruit is carried in a single truck. In the second scenario, MCRT is introduced between DC and RT considering retailers' demand. In general, retailers will always demand a variety of fruits in different quantities. Say, retailer 1 demands apple and mango together, retailer 2 demands mango and orange together, and retailer 3 demands all three. In this scenario, the fruits must be transported in an optimal combination of fruits in MCRT to reduce the cost of transportation. Therefore, the model involves various costs including the fixed cost of opening DC, transportation cost between the nodes, inventory holding cost, and refrigeration cost. The model aims to minimize the total supply chain costs through optimized vehicle routing, the optimal location of DCs, and the optimal combination of fruits in MCRT.

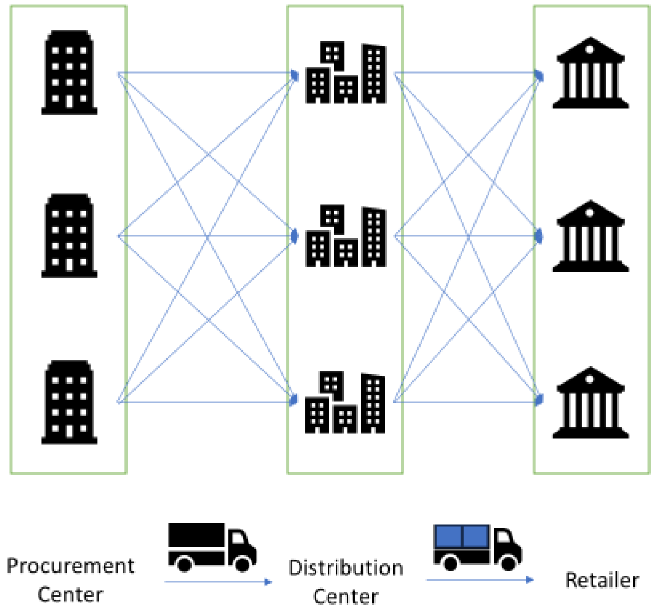

Fig. 1. Fruit supply chain considering multi-compartment reefer truck

An MINLP model is formulated to minimize the total supply chain cost in the FSC considering MCRT. The following assumptions are considered while developing a mathematical model.

- Fruits availability in the PC, storage capacity of DC, and RT demand are known.
- Potential location of DC is known and fixed.
- A finite number of vehicles are available with different PCs and DCs in each time period
- The availability of fruits in PC satisfies the RT demand in each period.
- Only DC can store extra inventory.
- All vehicles considered as refrigerated trucks and each truck carries a full truck load.

Notations

j = index of PCs, $j \in J$
m = index of DCs, $m \in M$
r = index of RTs, $r \in R$
t = index of time periods (days), $t \in T$
f = fruit types, $f \in F$
g= fruits combination, $g \in G$
w= vehicle available at PCs
y= vehicle available at DCs

Parameters:

FC_m	Fixed cost of establishing a distribution center m
$TC1$	Unit transportation cost from procurement center and distribution center
$TC2$	Unit transportation cost from distribution center and retailer
FC_w	Fixed cost of w type vehicle for transportation
FC_y	Fixed cost of y type vehicle for transportation
HC_{mf}	Inventory holding cost at distribution center m for f type fruit
RC^f	Refrigeration cost for f type fruit during transportation
RC^g	Refrigeration cost for g type fruit combination during transportation
$D1_{jm}$	Distance between procurement center j and distribution center m
$D1_{mr}$	Distance between distribution center m and retailer r
U_{jm}^{wt}	Time taken by the vehicle type w to travel from procurement center j to distribution center m in time period t
U_{mr}^{yt}	Time taken by the vehicle type y to travel from distribution center m to retailer r in time period t
V_m^{wft}	Time taken by the vehicle type w to unload the fruit type f in distribution center m in time period t
V_r^{ygt}	Time taken by the vehicle type y to unload the fruit type g in retailer r in time period t

A_{jf}^{t}	Supply quantity of fruit type f at procurement center j in time period t
Cap_m	Capacity of distribution center m
Cap_w^f	Capacity of truck type w for carrying fruit type f
Cap_y^g	Capacity of truck type y for carrying fruit combination type g
d_r^{ft}	Demand for fruits f by the retailer r in time period t
α_{jw}	Number of w type trucks available at procurement center j
β_{my}	number of y type trucks available at distribution center m

Decision variables:

X_j	1 if procurement center j is established; 0 otherwise
X_m	1 if distribution center m is established; 0 otherwise
x_{jm}^{w}	1 if vehicle w is used between procurement center j to distribution center m; 0 otherwise
x_{mr}^{y}	1 if vehicle y is used between distribution center m to retailer r; 0 otherwise
Q_{jm}^{ft}	Amount of f type fruit transported from procurement center j to distribution center m in time period t
Q'^{gt}_{mr}	Amount of g type fruit combination transported from distribution center m to retailer r in time period t
N_{jm}^{wt}	Number of w type vehicles used between procurement center j and distribution center m in time period t
N_{mr}^{yt}	Number of y type vehicles used between distribution center m and retailer r in time period t
N_{jm}^{wft}	Number of w type vehicles used between procurement center j and distribution center m for carrying f type fruit in time period t
N_{mr}^{ygt}	Number of y type vehicles used between distribution center m and retailer r for carrying g type fruit combination in time period t
Z_m^{ft}	Inventory of f type fruit available at distribution center m at the end of time period t

Objective function:

Minimize total cost = Fixed cost of opening DC + Transportation cost + Inventory holding cost + Refrigeration cost (1)

Fixed cost of opening DC = $\sum_{m\in M} FC_m . X_m$ (1.1)

Transportation cost $= \sum_{j\in J}\sum_{m\in M}\sum_{f\in F}\sum_{t\in T} D1_{jm}.TC1.Q_{jm}^{ft} + \sum_{t\in T}\sum_{w\in W}\sum_{j\in J}\sum_{m\in M} FC_w.N_{jm}^{wt} + \sum_{m\in M}\sum_{r\in R}\sum_{g\in G}\sum_{t\in T} D2_{mr}.TC2.Q'^{gt}_{mr} + \sum_{t\in T}\sum_{y\in Y}\sum_{m\in M}\sum_{r\in R} FC_y.N_{mr}^{yt}$ (1.2)

Inventory holding cost $= \sum_{m\in M}\sum_{f\in F}\sum_{t\in T} HC_{mf}.Z_m^{ft}$ (1.3)

Refrigeration cost $= \sum_{j\in J}\sum_{m\in M}\sum_{w\in W}\sum_{f\in F}\sum_{t\in T} RC^f . x_{jm}^{w}.U_{jm}^{wt} + \sum_{m\in M}\sum_{r\in R}\sum_{g\in G}\sum_{y\in Y}\sum_{t\in T} RC^g . x_{mr}^{y}.U_{mr}^{yt} + \sum_{m\in M}\sum_{w\in W}\sum_{f\in F}\sum_{t\in T} RC^f.V_m^{wft} + \sum_{r\in R}\sum_{y\in Y}\sum_{g\in G}\sum_{t\in T} RC^g.V_r^{ygt}$ (1.4)

Subject to :

$$\sum_{m\in M} Q_{jm}^{ft}.X_{jm}^{ft} \le A_{jf}^{t} \quad \forall j\in J, \forall f\in F, \forall t\in T \tag{2}$$

$$\sum_{r\in R} Q'^{gt}_{mr} \le Z_m^{ft} \quad \forall m, \forall t \tag{3}$$

$$\sum_{m\in M} Q'^{gt}_{mr} = d_r^{ft} \quad \forall r, \forall t \tag{4}$$

$$Cap_m \ge \sum_{f\in F} Z_m^{f(t-1)} + \sum_{j\in J}\sum_{f\in F} Q_{jm}^{ft}.X_{jm}^{ft}\ , t > 1 \quad \forall m, \forall t \tag{5}$$

$$Z_m^{ft} = Z_m^{f(t-1)} + \sum_{j\in J} Q_{jm}^{ft}.X_{jm}^{ft} - \sum_{m\in M} Q'^{gt}_{mr}.X_{mr}^{gt}\ , \quad t \ge 1 \quad \forall m\in M, \forall f\in F, \forall t\in T \tag{6}$$

$$\sum_{m\in M}\sum_{f\in F} Q_{jm}^{ft}.X_{jm}^{ft} \le \sum_{w\in W}\sum_{f\in F} N_{jm}^{wt}.Cap_w^f \tag{7}$$

$$\sum_{r\in R}\sum_{g\in G} Q'^{gt}_{mr}.X_{mr}^{gt} \le \sum_{y\in Y}\sum_{g\in G} N_{mr}^{yt}.Cap_y^g \tag{8}$$

$$\sum_{w \in W} N_{jm}^{wt} \leq \alpha_{jw} \ \forall w, \forall j, \forall m \quad (9)$$

$$\sum_{y \in Y} N_{mr}^{yt} \leq \beta_{my} \ \forall y, \forall m, \forall r \quad (10)$$

In this model, equation (1) is an objective function of the problem which minimizes total supply chain cost. The fixed cost for opening DC is given in equation (1.1). The transportation cost includes the cost from the procurement center to the distribution center, and the distribution center to the retailer is represented by Equation (1.2). Equation (1.3) gives the inventory holding cost at the distribution center. The refrigeration cost incurred during the transportation is given by equation (1.4). Equation (2) specifies that the total quantity of fruits transported from the procurement center to the distribution center should be less or equal to the supply quantity of fruits at the procurement center for a specific time period. Equation (3) limits that the quantity of fruits transferred from the distribution center to the retailer should be either less than or equal to the distribution center inventory in the given time period. The total quantity of fruits shipped from all distribution centers should be equal to the demand of the retailer as indicated in equation (4). Equation (5) states that the sum of the total inventory available at the distribution center from the previous period and the number of fruits arriving at that specific distribution center should be less than or equal to that distribution center's capacity. Equation 6 illustrates the total inventory level at the end of the time period for the distribution center is equal to the sum of the number of fruits received at the distribution center and the inventory of the distribution center of the previous period, minus the number of fruits dispatched from the distribution center. Equation (7) and (8) specifies that the fruit quantity transported from the procurement center to the distribution center and the combination of fruit quantity distribution center to the retailer should be less than or equal to the total capacity of trucks used. The total number of trucks used between the procurement center to the distribution center and the distribution center to the retailer should be less than or equal to the total number of trucks available at the procurement center and distribution center is represented by equation (9) and (10).

The above-described mathematical model comprises several decision variables including binary, integer, and continuous along with real-life constraints like supply, capacity, demand, inventory flow balance, combination of fruits in MCRT, DC capacity, vehicle capacity, etc.

4. Methodology

The developed MINLP mathematical model is aimed to solve using heuristic approach. The coding has been developed using java language in Intellij IDEA Community platform Edition 2023.1.1. The program has been run in the system having configuration of Intel Core i5, 2.50 GHz processor with 8GB RAM, 256GB SSD, 1GB HDD, 4GB NVIDIA GeFORCE GTX 1650. The algorithm of the heuristic approach is given below.

Step 1 : Start the algorithm

Step 2 : Accepting input (cost associated with different parameters, DC capacity for different fruits, truck capacity for different fruits, distance between the echelons, supply quantity, demand quantity, number of DCs to be operated, box capacity of fruits, truck capacity, etc.)

Step 3 : Initializing the objective function (minimizing total cost)

Step 4 : Generating maximum number of combinations for the number of DCs to be operated considered.

Step 5 : Sorting the DCs with respect to the distance between PC and DC and the distance between DC and retailers for the first combination generated.

Step 6 : Calculating the number of trucks utilized between PC and DC, DC and retailers and various costs involved.

Step 7 : Store the value.

Step 8 : Repeat the procedure from step 5 to step 7 for all the combinations generated.

Step 9 : Replace the stored value if minimum value is generated.

Step 10: Stop the algorithm

4.1 Case scenario

The efficiency of the developed model is assessed with a case study scenario from Baramulla District in India. In the Baramulla district, there are 48 villages [38] and 8 tehsils [39]. In this work, it is assumed that in each village farmers bring their produced fruits to the nearest PCs. In some cases, farmers in the village might grow more than one fruit and bring their fruits to the PC. Therefore, all the PC is considered multi-storage. It is assumed that 8 tehsils as potential DC locations and these 8 locations have 3 retailers each. The DC is considered as multi-storage and it has capacity constraints for each fruit. For example, DC1 might have 3 units of storage that can store 3 fruits separately under a specific storage condition.

Distance between the echelons is determined using Google Maps.

The quantity of fruits available at each PC is assumed to be the same. WHO recommends a minimum of 400 grams of fruits and vegetables together to be consumed per day [40]. The demand data for fruits requested by a retailer is determined by assuming a minimum intake of 200 grams of fruits per person per day. It is assumed that 100 grams of apple, 50 grams of mango, and 50 grams of orange are needed for each person per day. The demand at the retailer is calculated by multiplying the population at the retailer zone [41] with the minimum intake quantity. The estimated total demand and the assumed supply quantity are given in Table 1.

Tab. 1. Supply and demand data

Fruits	Quantity available at each PC (kg)	Quantity demanded at each retailer (kg)
Apple	40,000	650 – 2220
Mango	20,000	325 – 1110
Orange	20,000	260 – 890

It is also assumed that retailers under each potential DC location will have the same demand requirement. The various parameters are assumed close to reality and are shown in Table 2.

Tab. 2. Values of various parameters

Parameters	Values/Range of values
Fixed cost of opening DC, FC_m	25,00,000 INR
Transportation cost (per kg/km)	
From PC to DC, TC1	1 INR
From DC to retailer, TC2	1 INR
Inventory holding cost for each DC (per kg/period), HC_{mf}	1 – 3 INR
Storage capacity of each DC for each fruit (Metric tonnes/period), Cap_m	1,000 – 4,000 tonnes
Fixed cost of w type vehicle for transportation, FC_w	7,00,000 – 10,00,000 INR
Fixed cost of y type vehicle for transportation, FC_y	8,00,000 INR
Capacity of truck type w for carrying fruit type f, Cap_w^f	10 tonnes
Capacity of truck type y for carrying fruit combination type g, Cap_y^f	7 tonnes
Refrigeration cost for fruit travelled in truck type w, RC^f	100 - 200 INR
Refrigeration cost for fruits travelled in truck type y, RC^g	20 - 100 INR
Time taken by the truck type w to travel from procurement center j to distribution center m in time period t, U_{jm}^{wt}	Distance between PC and DC / average speed of truck type w
Time taken by the truck type y to travel from distribution center m to retailer r in time period t, U_{mr}^{yt}	Distance between DC and retailer / average speed of truck type y
Average speed of truck type w and y	20 – 30 kmph
Time taken by the vehicle type w to unload the fruit type f in distribution center m in time period t, V_m^{wft}	10 – 20 mins
Time taken by the vehicle type y to unload the fruit type g in retailer r in time period t, V_r^{ygt}	3 – 10 mins

5. Results and Discussion

It is assumed that the regular reefer truck capacity used between PC and DC and multi-compartment reefer truck capacity will be constant for all the cases. The problem has been solved for two-compartment reefer trucks and three-compartment reefer trucks. In all the cases, the vehicle considered between PC and DC will be a regular reefer truck. Whereas the vehicle considered between DC and the retailer in case 1 will be a regular reefer truck, case 2 will have 2 compartment reefer truck and case 3 will have 3 compartment reefer truck. Also, all the cases have been solved concerning the number of DCs to be opened. The number of DCs to be opened is considered between 1 and 3. The remaining values for the parameters considered will be the same for all the cases. For all the cases, if the number of DCs to be opened is considered 1, the result is not obtained due to lack of storage capacity in DCs. Therefore, the problem is solved considering the number of DCs to be opened as 2 and 3.

Tab. 3. Optimal results for opening 2DCs

DCs identified	Corresponding PCs serving to DC	Retailers to be served from the DC
K2	PC2, PC6, PC11, PC18, PC20, PC23, PC30, PC32, PC34, PC39, PC42, PC44, PC46 (O), PC47 (O), PC48 (O)	M4, M5, M6, M8, M9, M13, M14, M15, M24
K4	PC1, PC3, PC4, PC5, PC7, PC8, PC9, PC10, PC12, PC13, PC14, PC15, PC16, PC17, PC19, PC21, PC22, PC24, PC25, PC26, PC27, PC28, PC29, PC31, PC33, PC35, PC36, PC37, PC38, PC40, PC41, PC43, PC45, PC46 (A,M), PC47 (A,M), PC48 (A,M)	M1, M2, M3, M7, M10, M11, M12, M16, M17, M18, M19, M20, M21, M22, M23

Tab. 4. Inventory flow across the DCs for the period analysed

Fruits	K2			K4		
	Inflow (kg)	Outflow (kg)	Balance inventory (kg)	Inflow (kg)	Outflow (kg)	Balance inventory (kg)
Apple	480000	11452	468548	1440000	17762	1422238
Mango	240000	5729	234271	720000	8881	711119
Orange	450000	4581	445419	990000	7104	982896

The optimal results of linking the PCs and retailers to the DCs when the number of DCs to be opened is considered two is shown in Table 3. The optimal DC location to be opened is K2 and K4 out of eight potential locations. It is noticed that the orange alone is shipped from PC46, PC47, and PC48 to the DC (K2). Apple and orange from the PC46, PC47, and PC48 to the DC (K4). Table 4 shows the number of fruits shipped to the optimized DC and the balance inventory available at each DC after satisfying the retailers' demand.

Tab. 5. Optimal results for opening 3DCs

DCs identified	Corresponding PCs serving to DC	Retailers to be served from the DC
K2	PC2, PC6, PC18, PC20, PC30, PC32, PC34, PC39, PC42	M4, M5, M6, M13, M14, M15, M24
K3	PC10, PC11, PC17, PC19, PC23, PC26, PC40, PC44	M7, M8, M9
K4	PC1, PC3, PC4, PC5, PC7, PC8, PC9, PC12, PC13, PC14, PC15, PC16, PC21, PC22, PC24, PC25, PC27, PC28, PC29, PC31, PC33, PC35, PC36, PC37, PC38, PC41, PC43, PC45, PC46, PC47, PC48	M1, M2, M3, M10, M11, M12, M16, M17, M18, M19, M20, M21, M22, M23

Tab. 6. Inventory flow across the DCs for the period analysed

Fruits	K2			K3			K4		
	Inflow (kg)	Outflow (kg)	Balance inventory (kg)	Inflow (kg)	Outflow (kg)	Balance inventory (kg)	Inflow (kg)	Outflow (kg)	Balance inventory (kg)
Apple	36000	10050	349950	320000	2103	317897	1240000	17061	1222939
Mango	180000	5027	174973	160000	1053	158947	620000	8530	611470
Orange	270000	4021	265979	240000	840	239160	930000	6824	923176

The optimal results of linking the PCs and retailers to the DCs when the number of DCs to be opened is considered three is shown in Table 5. The optimal DC location to be opened is K2, K3, and K4 out of eight potential locations. Table 6 shows the number of fruits shipped to the optimized DC and the balance inventory available at each DC after satisfying the retailers' demand.

Tab. 7. Optimal total supply chain cost (in INR) for different scenarios generated

	2 DCs			3 DCs		
DCs identified and Corresponding Cost involved	Single-compartment reefer truck	Two-compartment reefer truck	Three-compartment reefer truck	Single-compartment reefer truck	Two-compartment reefer truck	Three-compartment reefer truck
DCs identified	K2,K4	K2,K4	K2,K4	K2,K3,K4	K2,K3,K4	K2,K3,K4
Fixed cost of opening DC	5000000	5000000	5000000	7500000	7500000	7500000
Transportation cost from PC to DC	348153000	348153000	348153000	344160000	344160000	344160000
Transportation cost from DC to retailer	51525629	39525629	22725629	22597624	39397624	22597624
Inventory holding cost	5209881	5209881	5209881	5209881	5209881	5209881
Refrigeration cost	108195	92664	89310	104498	89928	86862
Total cost	409996705	397981174	381177820	379572003	396357433	379554367

From Table 7, it is noticed that considering MCRT yields better results in minimizing total cost. The number of single-compartment reefer trucks used between PC and DC in all cases is 288. The number of single-compartment reefer trucks used between DC and retailers is 72. While considering MCRT, the number of trucks used between DC and retailers has reduced rapidly. The number of trucks used when two-compartment trucks and three-compartment trucks are considered is 48 and 27 respectively. The cost of opening DC, transportation cost from PC to DC, and inventory holding cost remain the same while considering the same number of DCs opened. Whereas the transportation cost from DC to retailer and refrigeration cost varies in all the instances while considering the same numbers of DCs opened.

It is evident from the mathematical model's results that there is a drastic reduction in number of vehicles used if the MCRT is utilized. Reducing the number of vehicles used will result in advantages in various aspects. First, the emissions will be reduced when the number of vehicles used is less. Lower the emissions higher the environmental sustainability. Second, the total cost of the supply chain gets reduced resulting in the reduction of the cost of fruits. The fruits are now more accessible to low-income families with an increased affordability and as a result, food security has improved. Thirdly, the fruits are stored and transported under a controlled atmosphere to increase the shelf-life. Again, food security is achieved by maintaining food quality and reducing food loss.

5. Conclusion

Compared to other supply chains, the perishables supply chain has always been more difficult to manage. The fruit's susceptibility to spoilage is influenced by the conditions of its journey to the consumer. When it comes to maintaining the freshness and safety of perishable goods, having access to a reefer truck has always been a plus. However, its viability and expense are being questioned. In this effort, a novel idea of implementing MCRT between DCs and retailers has been presented. An MINLP mathematical model is presented for a multi-echelon multi-period FSC network problem. The formulated mathematical model is solved using a heuristic technique, and its robustness is tested by considering a real-world case study in the Baramulla district of Kashmir, India. Using multi-compartment reefer trucks to transport fruits has been shown to significantly reduce supply chain expenses. Using the stated mathematical model, several different scenarios were constructed and evaluated. There is a greater supply chain cost savings with three-compartment reefer trucks compared to two-compartment trucks. It is also noted that running three DCs rather than two DCs results in a net cost savings. The operational cost and emission levels are both positively impacted by a decrease in the total number of trucks on the road. The total supply chain cost has lowered, making fruits more affordable for low-income people and enhancing food security. The proposed method would not only assist the bottom line, but also the economy, society, and environment by lowering food waste and increasing food quality. The model can be extended by assuming more number of fruits, more intermediate stages in the supply chain, considering MCRT between PC and DC, and considering CO2 emissions in the future.

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Annexure – A

Distance between PC and DC

		Tangmarg	Rafiabad	Boniyar	Wagoora	Zaingeer	Kunzer	Singhpora	Sangrama
Procurement center		DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8
Bada Mulla	PC1	21.9	28.6	21.7	15.4	36	29.6	37.5	25
Baramula (M Cl + OG)	PC2	28.5	13.9	23.7	14.6	21.3	40.5	33.9	15
Bulbul Abad (Kawahar)	PC3	15	26.7	30.8	10.2	31.2	22.7	38.7	19.8
Chaklu	PC4	28.4	16.1	30	9.6	21.9	33.2	31.9	12.6
Danger Pora	PC5	13.6	28.1	30.1	11.7	32.6	21.3	39.6	21.2
Dilna	PC6	26.8	7.5	34.5	8.8	12	28.6	21.9	3.1
Fateh Pora (OG)	PC7	30.2	13.2	26.3	11.7	20.9	37.5	30.9	12

Fatehgadh	PC8	21.7	27.7	22.2	15.2	35.1	29.4	37.3	24.8
Frastahar (OG)	PC9	16.7	20.5	47	6.6	25	13.8	21.1	10.5
Gantamulla Bala	PC10	32.7	30.7	23.9	26.2	38.1	40.4	51.7	32.8
Gantamulla Pain	PC11	33	24.4	10.7	26.1	31.8	40.7	45.4	26.5
Gohan Lari Jungle	PC12	19.9	23.4	37.7	6.9	27.9	30.4	29	16.5
Gotiyar (OG)	PC13	30.8	20.8	26	12.3	25	38.2	31.6	12.7
Gulistan (Hardukhel)	PC14	26.7	53.9	57.9	37.5	58.4	36.8	55.1	47
Haji Bal	PC15	8.2	28.7	49.1	12.2	33.2	13.3	31.6	21.7
Heewen	PC16	20.8	24.3	29.6	7.8	26.3	31.3	29.9	17.4
Jagiyar	PC17	28.8	25.7	21.4	22.3	33	36.5	46.7	27.8
Jahama	PC18	34.2	6.4	31.3	12.4	13.7	36	29.4	10.5
Jalsheri	PC19	26.6	23.2	19.1	20.2	30.6	34.4	44.2	25.4
Kalander Pora (Wankeri)	PC20	43.2	23.2	31.5	24.7	30.6	50.6	43.9	25
Kanis Pora (OG)	PC21	28	11.1	27.3	9.5	18.8	35.4	28.8	9.9
Katian Wali	PC22	18.7	19.4	39.8	2.9	23.9	29.2	25	12.5
Khadaniar	PC23	28.3	21.8	16.6	23.6	29.2	36	42.8	23.9
Khai Tangan	PC24	18	18.9	39.4	2.5	23.4	28.5	23,6	12
Khusual Pora (Chinar Bitchri Gund)	PC25	22.1	12.3	38.9	6.4	16.8	27.2	22	2.3
Kitcha Hama	PC26	28.9	27	20.1	22.5	34.4	36.7	48	29.1
Lal Pora (Lara Dura)	PC27	13.1	28.8	30.8	12.3	33.3	20.8	39.1	21.9
Latifabad (Khuda Pora)	PC28	20.5	30	27.3	13.5	34.5	28.2	35.6	22.2
Mala Pora	PC29	18.6	28.6	25.4	12.2	33.1	26.3	34.2	21.7
Maqbool Abad (Ohlitra)	PC30	35.6	10.6	25.5	17.1	18	42.8	36.2	17.3
Mirher	PC31	23	26.5	24.8	10	31.1	33.5	32.1	19.6
Naid Hal (nadihal)	PC32	36.9	11.8	31.3	15.1	17.9	38.7	32.1	13.2
Nambalan	PC33	26.9	54.1	58.1	37.6	58.6	37	55.2	47.2
Nawgam	PC34	38	7.6	28.8	16.2	15	40.4	33.2	14.3
Nowpora Jagir	PC35	23.5	12.2	33.2	4.9	16.7	28.5	24.2	5.3
Nowrang (Naraderi)	PC36	15.9	31.1	27.8	14.6	35.6	23.6	41.8	23.3
Odura	PC37	19.3	30.4	27.2	13.9	34.9	27	36	22.6
Puna Cheter	PC38	28.1	14	26.7	12.5	21.7	38.4	31.7	12.8
Sadi Pora	PC39	30.8	11.4	32.5	12.8	15.9	32.5	25.9	7
Sheern Abad (Sheri Narawaw)	PC40	28.1	24.9	20.7	21.6	32.3	35.8	45.9	27
Sherwani Abad (Bener Kahdura)	PC41	29.4	12.5	26	10.9	20.2	36.8	30.2	11.3
Shitlu	PC42	37.4	12.3	27.2	18.9	19.7	44.6	37.9	19
Singh Pora Kalan	PC43	21.2	14.7	36.1	4	19.2	26.3	24.3	4.7
Takia Sultan (OG)	PC44	27.5	22.2	18.1	23.9	33.2	35.2	43.2	24.3
Tari Pora Wansaran	PC45	15.3	31.5	28.3	15.1	36	23	41.3	24.6
Wahdat Pora (Huda Pora)	PC46	14.7	20.2	40.6	3.8	24.7	19.8	23.6	13
Weri Nar	PC47	12.8	23	43.5	6.6	27.5	17.9	24.4	13.8
Zamzam Pora (Zanda Foran)	PC48	24.9	26.9	20	18.4	34.3	32.6	47.9	29

Annexure – B

Distance between DC and retailer

		Tangmarg	Rafiabad	Boniyar	Wagoora	Zaingeer	Kunzer	Singhpora	Sangrama
Market		DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8
Tangmarg1	M1	4.2	34.4	43.8	19.1	38.9	8.2	26.5	28.3
Tangmarg2	M2	5.8	36.6	47.9	20.5	43.8	10	32.1	32
Tangmarg3	M3	6.7	39.7	49.6	23.3	45.4	13.2	30	24.2
Rafiabad1	M4	46.7	3.5	40.2	26.8	11.2	47.1	41.6	21.5
Rafiabad2	M5	44.2	6.1	43.1	23.5	15.3	50.2	38.2	24.3
Rafiabad3	M6	40.1	7.3	44.6	28.5	14.7	48.8	39	27.3
Boniyar1	M7	43.8	38.1	3.7	37	46.3	51.5	56.2	37.3
Boniyar2	M8	59.7	40.8	5.8	44	48.8	55.2	53.6	40
Boniyar3	M9	53.5	35.2	7.4	41	44.4	58	58	42
Wagoora1	M10	18.5	18.9	37	7.5	28.8	31	22.1	9.5
Wagoora2	M11	20.5	16.5	40	11	31	24.7	28.4	12
Wagoora3	M12	23.5	20	44	14	33.1	27	35.5	14.5
Zaingeer1	M13	47.9	11.2	46	24.6	5.5	44.4	37.7	23
Zaingeer2	M14	42.6	14.6	49.9	28.8	7	49	40	18.8
Zaingeer3	M15	45	12.5	47.8	27	9	55	42	20.5
Kunzer1	M16	8.2	36.2	51.5	31	44.4	5.3	15.9	29.6
Kunzer2	M17	10	39	62.9	33.8	47.1	6.8	19.4	27
Kunzer3	M18	12.5	40.6	56	36	49	9.5	25	32
Singhpora1	M19	26.5	41.2	56.2	22.1	37.7	19.4	3.8	20.3
Singhpora2	M20	32.1	40	53	28.4	42.5	25	5	23
Singhpora3	M21	29.3	44	58	25	40	22	6.9	25
Sangrama1	M22	24.4	10	37.3	9.5	21	27	20.3	7.7
Sangrama2	M23	28.8	13	40	12	23.6	29	23	10
Sangrama3	M24	32.8	11.7	43	13.8	18.8	32	25.5	5

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