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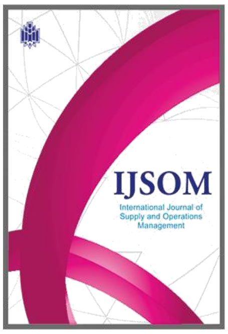

A Two-Stage Optimization Model for Tactical Planning in Fresh Fruit Supply Chains: A Case Study of Kullu, India

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Abstract

In this study, a two-stage mathematical model has been developed that facilitates tactical planning of supply of apples from the various location of farmers to the marketplaces and then to the cold storage facilities. The model enables efficient network planning by finding the most suitable and cost-effective dispatching method operating in multiple stages using a mixed fleet of jeeps and trucks. The model aims to optimize the cost and demand. The paper used a multi-stage model to examine the most effective and efficient route for the supply. Kullu has been taken as the case location, which is famous as key apple production location in India. The lack of infrastructure in the area poses challenges for the farmers to select a mix of both trucks and jeeps to make their goods available in the market. The present paper attempts to address these issues, facilitating an effective transportation planning of apple produce.

Keywords: Multi-stage model; Transportation; Fresh fruit supply chain; Optimization.

1. Introduction

There has been significant growth in the fresh fruit sector because of healthier food habits as well as quality consciousness in customers (Recanati *et al.,* 2019). On account of the increased demand for high-quality products, backed by stiff competition and regulations, the fresh fruit sector has become more specialized and dynamic (Behzadi *et al*., 2018; Jabarzadeh *et al*., 2020; Zhu *et al*., 2018). The consumers' expectations of fresh food products at low prices led to the globalization of the markets (Joshi et al., 2015). Further, the management of fresh fruits is complex because of the quality changes in them as they move downstream (Pereira *et al*., 2020). Due to their perishable nature, the supply chain of fresh food products including fruits, dairy, vegetables, and meat, from producer to the marketplaces and customers, is a complex process (Li et al., 2020). Since the fresh fruit supply chains are associated with longer lead times and significant demand and supply uncertainties, their effective management becomes imperative using sophisticated decision-making tools. The timely delivery of fresh produce of high quality to the customers at minimum cost becomes a challenge, needing cautious planning and implementation. This calls for advanced planning models that incorporate decisions related to harvesting, logistics, risk management, and coordination. Supply chain planning and analysis have been areas of immense research in the past few decades. Based on time horizons, planning may be strategic, operational, or tactical (Pereira *et al*., 2020). Logistical decisions of timely and efficient distribution of goods from point of supply to the point of demand are critical to the success of any supply chain, and thus, should be carefully planned.

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Apple supply chains involve complex interactions between production, storage, and distribution, thereby drawing motivations from several studies from a planning standpoint (Jabarzadeh *et al*., 2020; Joshi *et al*., 2020a; Joshi *et al*., 2020b; Nguyen *et al*., 2020). Their complexity arises from the fact that with each link in their supply chains, the quality is affected either positively (ripening) or negatively (deterioration).

The motivation of the present research work is to assist the farmers in a complex and competitive fresh fruit industry. In this paper, we propose a mathematical formulation that addresses various difficulties associated with network planning while finding the most suitable and cost-effective dispatching method operating in multiple stages using truckloads served by a mixed fleet of jeeps. The proposed multi-stage model is further applied to a real case of apple produce in the Indian district of Kullu, Himachal Pradesh.

The rest of the paper is as follows. Section 2 provides an overview of the fresh fruit sector and reviews the literature on the fresh fruit supply chain. The mathematical model is presented in Section 3 while the case study is discussed in Section 4 The results are presented in Section 5 while the last section concludes the study and delineates future research directions.

2. Literature review

Fresh fruit supply chains have been addressed from all the different decision horizons in the past. A majority of studies have focused on tactical and operational planning perspectives while strategic planning is also being considered in a few studies. Joshi *et al*. (2017) discussed various demand forecasting models for the short life cycle products.

Caicedo Solano et al. (2020) used a dynamic simulation model while detailing the complex biological and economic inter-relationships existing in an apple orchard system. Sharma et al. (2020) also used a simulation environment to implement an integrated approach towards logistics food quality analysis and sustainability. In another study by Joshi et al. (2020), a planning model was developed to maximize the performance of agri-food activities including packaging, sorting, storage, and the raw material purchase costs. Nguyen et al. (2020) proposed a strategic planning optimization model to help in investment planning for Dragon fruit farms. Although several works have focussed on planning and inventory decisions, the majority of studies have confined themselves to address production and distribution. Jabarzadeh *et al.* (2020) proposed a mixed-integer linear programming model to optimize capital investment in food preservation facilities and selection of technology routes for crops between harvest and market. Ji et al. (2020) developed a mixed-integer linear programming (MILP) model to improve the operational effectiveness of a fruit distribution center, seeking a tactical level allocation and storage planning.

Li *et al.* (2020) optimized agri-supply chain using a dynamic programming approach involving product quality development as well as appearance. Cheraghalipour et al. (2019) used two models to determine the maximum weekly flow of yield crops through the national export infrastructure. In another study, Paz (2020) proposed tactical and operational models to study the fruit industry business in Argentina while Nakandala, & Lau (2019) developed a hybrid model that considers the changing value of perishable foods over time. A few studies have considered both distribution and inventory decisions together (Biuki *et al*.,2020; Wei *et al*., 2020). Jabarzadeh et al. (2020) discussed various modeling approaches that have been adopted for fresh fruit supply chain planning, integer linear programming being the most extensively employed among all. Soto-Silva *et al*. (2016) discussed various mathematical models to plan and organize input variables for fresh fruit supply chains whereas, Munhoz, & Morabito (2014) proposed a linear programming model that aimed to maximize total profits for citrus fruits by using a fractional decision variable representing the part of the orange grove to be harvested for every time slot. González-Araya et al (2015) proposed a MILP model that minimizes the number of resources used and ensures a high-quality fruit production in an orchard. Similarly, Varas et al. (2020) employed a MILP model for scheduling grape harvesting operations to wine production while considering the harvesting costs and loss of quality of the grapes. Further, Arnaout & Maatouk (2010) applied the model proposed by Ferrer et al. (2008) in the European context and employed two heuristics to reduce the computational time. Liao et al (2020) used a stochastic extension of the MILP model to design the closed-loop supply chain network of citrus fruits while Yu et al. (2020) developed integrated methods to address logistics decisions of fruit and vegetable among retailers while exploring alternatives and limitations in separate technological, logistical and marketing business processes. Nadal-Roig, & Plà-Aragonés(2015) presented a linear programming model for planning daily transport of fruit from warehouses to processing plants, aiming to minimize transport costs. Joshi & Sharma (2018) discussed various optimisation models to integrate lean processes with sustainable supply chains. Few studies discussed the other applications of Fuzzy clustering (Prasad et al., 2015; Rajora et al., 2018). Although, past few studies have addressed two-stage supply chains. Ertek, & Griffin (2002) analyzed the bargaining powers of buyer and seller on price, the sensitivity of market price, and profits in a two-stage supply chain while the value of information sharing between retailer and manufacturer was analyzed by Simchi-Levi, & Zhao (2003). The model by Kaminsky, & Simchi-Levi (2003) used featured capacitated production and fixed cost for transportation in a manufacturing supply chain. Xu, & Zhai (2010) optimized vertically integrated two-stage supply chain under perfect coordination and contrast with the non-coordination case by using fuzzy numbers to depict customer demand. A similar study by Ma et al. (2013) investigated manufacturer-retailer channel coordination. Another study by Sajadieh, & Jokar (2009) proposed an integrated production–inventory–marketing model considering the joint total profit of both the vendor and the buyer while Cachon & Zipkin (1999) used the game-theoretic investigation to address two-stage supply chain with stochastic demand. Genetic algorithms have also been used in transportation scheduling (Zegordi et al. 2010) and distribution issues (Jawahar, & Balaji 2009) of two-stage supply chains. Although studies have addressed fresh fruit supply chains from multiple perspectives, consideration of fixed setup costs at various stages of fresh-produce supply chains along with a selection of optimal routes has still been a lacuna in existing research.. The present research aims to address this gap. The objective of this paper is to find a least-cost strategy for supplying fresh produce (apples) from the farmers to cold storages, keeping the daily demand a local marketplace (Mandi) can meet, making it a two-stage supply chain problem. Certain farmers use a combination of trucks and jeeps to supply their products owing to the non-accessibility of trucks to certain points using both jeeps and trucks.

3. Case background

India is among the top five apple producers in the world (Shahbandeh, 2019), with most of the production concentrated in two states. The production of fruits, especially apples, in India has shown significant growth in the last decade. For instance, in 2009-10, apple production was 1.77 million tonnes that grew to 2.4 million tonnes in 2017-18. A concentrated growth often leads to a resultant demand-supply mismatch across these agricultural commodities, imperatively requiring proper transportation planning (Joshi *et al*.,2020a; Joshi *et al*., 2020b; Kamble *et al*.,2019). Himachal Pradesh is the second-largest producer of apples in India after Kashmir (NHB,2019). Its major apple-producing areas are Shimla, Kullu, Sirmour, Mandi, Chamba, and Kinnaur. Kullu region alone accounts for one-fourth of the supply of apples. The supply chain for apples in the region of Kullu begins from the producers, as the majority of the farmers are producing apples on a very small scale (Wahi et al., 2020). A procurement manager (Ardhti) collects apples from the farmers and grades them. Three grades of apples are widely circulated in the market, namely *A*, *B*, and *C*, where *A* being the highest grade capable of being stored. The rest of the apples are required to be consumed within a few weeks, thereby posing a major logistical challenge. The apples, after being graded, are either bought down to local marketplaces, also known as *Mandis*, where they are packed and transported to major cities or are stored in cold storage units. The traditional supply chain followed in the region consists of a multi-stage network where the farmers make use of Jeeps and trucks to supply the apples to the Mandis and cold storage houses. The combination of trucks and jeeps depends on factors including the distance of farmers to the highways and road conditions.

In the present study, eight leading farmers of Kullu region are taken into consideration, supplying their produce to five Mandis located in Manali, Patlikul, Bandrol, Kullu, and Bhuntar. Further, in the second stage of the network, the apples are transported to four cold storages located in Patlikul, Katri, Shriyuagi, and Shimla. The price for the apples that the farmers get as well as the price that Mandis receive is assumed constant in the chosen time horizon.

4. Mathematical model

This paper develops a two-stage integer linear programming (ILP) to minimize cost and find the most optimal supply route in a fresh fruit supply network. A basic description of the model used is given in Figure 1.

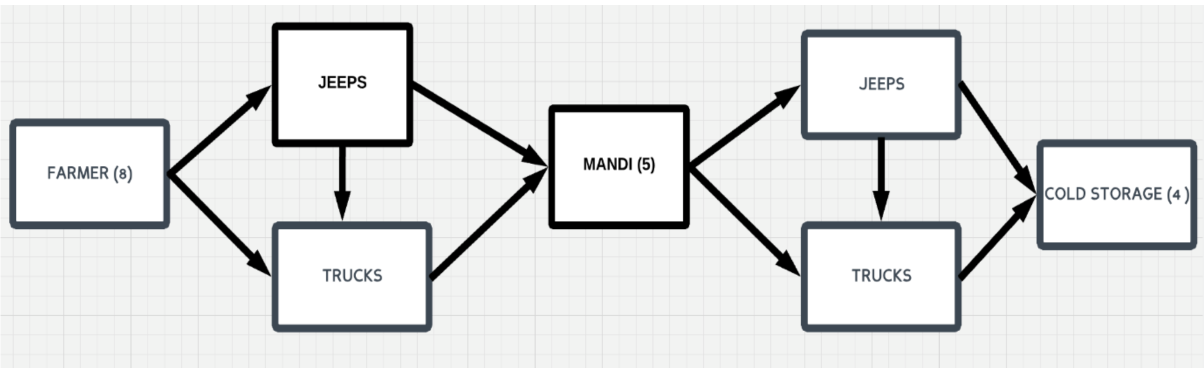

Figure 1. Description of a two-stage supply network

Sets:

I : Set of farmers

J : Set of Mandis

K : Set of cold storages

Parameters:

X_{ij}= No. Of cartons transported from farmer i to Mandi j

Y_{jk}= No. Of cartons transported from Mandi $j$to cold storage k

T_{ij}= No. Of Trucks used for transportation from farmer i to Mandi j

G_{ij}= No. Of Jeeps used for transportation from farmer i to Mandi j

C_{ij}= Unit cost of transportation from farmer i to Mandi j

C_{jk}= Unit cost of transportation from Mandi j to cold storage k

CAM_j= Capacity of Mandi$j$

CAF_i= Production of apples by farmer i

CAC_k= Capacity of cold storage $k$unit in a day

FCM_j= Fixed setup cost of a Mandi

FCB_k = Fixed setup cost of a cold storage

P_j: Binary Variable if a Mandi is selected

Q_k: Binary Variable if a Cold Storage is selected

CT : Capacity of a single truck

CJ : Capacity of a single jeep

KT : Fixed cost of using a single truck

KJ : Fixed cost of using a single jeep

Inputs:

- The daily production of apples from the farmers
- The daily supply of apples a Mandican cater to.
- The daily supply of apples a cold storage can cater to.
- Cost of transportation of per carton(20 kgs) of apples from farmer to Mandi
- Cost of transportation of per carton(20 kgs) of apples from Mandi to cold storage
- Distance to the highway from a farmer's orchard

Decisions:

Most cost-effective supply route using mixed fleet transportation.

Assumptions:

- Cost of transportation is fixed
- Fixed cost is associated with building infrastructure for cold storage and Mandis.
- Labor rates are the same in the region
- Price of apples are constant
- Capacity of trucks and jeeps are fixed
- All the apples are of A-grade

The mathematical formulation is presented below:

Minimize

$$\sum_{i}\sum_{j} C_{ij}X_{ij} + \sum_{j}\sum_{k} C'_{jk}\, Y_{jk} + \sum FCM_j * P_j + \sum FCB_{k} * Q_k + \sum T_{ij} * \mathrm{KT} + \sum G_{ij} * \mathrm{KJ}$$

The objective function (1) minimizes the total cost throughout the planning horizon. The above formulation will help in selecting the alternative for the supply of the apples. The above formulation is subject to the following constraints:

$$\sum_j X_{ij} \leq CAF_i \qquad \forall\ i \qquad (1)$$

Eq. (1) states that the total quantity a farmer i can supply should be less than his production capacity

$$\sum_i X_{ij} \leq CAM_j * P_j \qquad \forall\ j \qquad (2)$$

According to Eq. (2), the total supply of apples that a Mandi j can receive cannot exceed its capacity and will receive only if it is selected.

$$\sum_i X_{ij} = \sum_k Y_{jk} \qquad \forall\ i \qquad (3)$$

Eq. (3) implies that the total supply from a Mandi j should balance the total supply to the cold storage k.

$$\sum_j Y_{jk} \leq CAC_k * Q_k \qquad \forall\ k \qquad (4)$$

Eq. (4) ensures that the total supply that a Mandi can supply to a cold storage has to be less than or equal to its capacity it can accommodate in a day and will be supplied only when a cold storage is selected.

$$\sum_i X_{ij} \leq M.P_j \qquad \forall\ j \qquad (5)$$

Eq. (5) states that a Mandi will get the supplies only if it is selected.

$$\sum_j Y_{jk} \leq M.Q_k \qquad \forall\ k \qquad (6)$$

Eq. (6) states that a cold storage will get the supplies only if it is selected.

$$X_{ij} \leq T_{ij} * CT + G_{ij} * CJ \qquad (7)$$

Eq. (7) ensures that the total supplies from both the fleets meet the farmers' outputs.

$$X_{ij} = integers \qquad (8)$$

$$Y_{jk} = integers \qquad (9)$$

$$T_{ij} = integers \qquad (10)$$

$$G_{ij} = integers \qquad (11)$$

$$P_j = Binary \qquad (12)$$

$$Q_k = Binary \qquad (13)$$

5. Results and Discussions

In this section, we present the results from the case under consideration and identify the optimal design for the supply chain. The integer programming model was solved using Gurobi solver engine V.9.0.0.0 on Risk Solver Platform (Frontline systems) in PC having Intel Core i5 processor with 4 Gigabytes RAM. The engine solution time came out to be 2.8 seconds.

Table 1. Distribution of supplies from farmers to Mandis

	Manali (M1)	**Patlikul (M2)**	**Bandrol(M3)**	**Kullu(M4)**	**Bhuntar(M5)**
Shirar Orchards(Raison)	0	3000	0	0	0
Pushap Orchards (Kanyal)	5500	2000	0	0	0
Sanjay Fruit Garden (Dhalogy)	4000	0	0	0	0
Manu Orchards (Fojal)	0	2000	0	0	0
Chamunda Orchards (Katrain)	0	3000	0	0	0
Bashu Orchards (Banala)	0	0	0	1000	0
Thankur Orchards(Pallan)	0	0	0	3000	0
Ganga Ram Orchards (Naggar)	0	5000	0	0	0

Table 1 analyses the first stage of the supply network that entails the selection and allocation of apples (cartons) between farmers and Mandis. It shows that the most optimal Mandi is Patlikul (M2), being the most centrally located location for all the farmers. The values in Table1 represent the number of cartons to be supplied from farmers to Mandisfor optimized transportation. Shirar orchards should supply 3000 cartons of apples to Patlikul that will, in turn, be the most cost-effective destination for the farmers. The two Mandis M3 (Bandrol) and M5 (Bhuntar) are not selected as intermediaries for any farmers. The capacity utilization is maximum for the two Mandis M1 and M2, while Mandi M4 (Kullu) is utilized to a very limited extent.

Table 2. Distribution of supplies from Mandis to cold storage facilities

	CB1(Patlikul)	**CB2(Katria)**	**CB3(Shiyaugi)**	**CB4(Shimla)**
Manali (M1)	0	9500	0	0
Patlikul (M2)	6100	8900	0	0
Bandrol(M3)	0	0	0	0
Kullu(M4)	4000	0	0	0
Bhuntar(M5)	0	0	0	0

Table 2 presents the distribution of supplies in the second stage of the supply network. Out of the four cold storages, only two are selected, Patlikul and Katria, to serve as storage facilities of all apple supplies from the farmers through the Mandis. The table also reveals that there is no supply from the Mandis M3 and M5 as they were not selected in the first stage of the network. The supplies reaching cold storage 2, Katria, are nearly double in quantity as compared to those reaching Patlikul storage facility.

The proposed mathematical model presented in the present study also employs a combination of a mixed fleet of trucks and jeeps to supply apples from farmers to Mandis. Table 3 shows the number of trucks employed between farmers' orchards and Mandis while Table 4 enlists the number of jeeps employed for the same.

Table 3: Number of Trucks between orchards to Mandis

No. of Trucks	Manali (M1)	Patlikul (M2)	Bandrol(M3)	Kullu(M4)	Bhuntar(M5)
ShirarOrchards(Raison)	0	0	0	0	0
Pushap Orchards (Kanyal)	55	20	0	0	0
Sanjay Fruit Garden (Dhalogy)	0	0	0	0	0
Manu Orchards (Fojal)	0	0	0	0	0
Chamunda Orchards (Katrain)	0	0	0	0	0
Bashu Orchards (Banala)	0	0	0	0	0
ThankurOrchards(Pallan)	0	0	0	0	0
Ganga Ram Orchards (Naggar)	0	0	0	0	0

It can be seen from Table 3 that a total of 75 trucks are used to supply farmers' produce to the respective Mandis. The trucks are used only from the Pushap orchards while the other orchards are connected to the Mandis by jeeps.

Table 4. Number of Jeeps between orchards to Mandis

No. of Jeeps	Manali (M1)	Patlikul (M2)	Bandrol(M3)	Kullu(M4)	Bhuntar(M5)
Shirar Orchards(Raison)	0	60	0	0	0
Pushap Orchards (Kanyal)	0	0	0	0	0
Sanjay Fruit Garden (Dhalogy)	80	0	0	0	0
Manu Orchards (Fojal)	0	40	0	0	0
Chamunda Orchards (Katrain)	0	60	0	0	0
Bashu Orchards (Banala)	0	0	0	20	0
Thankur Orchards(Pallan)	0	0	0	60	0
Ganga Ram Orchards (Naggar)	0	100	0	0	0

The results of Table 4 reveal that Patlikul Mandi receives supplies from four orchards by jeeps while Mandi of Manali also receives apples from Sanjay fruit Garden by Jeeps. Further, it can be seen from Table 3 and Table 4 that Mandis receive supplies from only one of the two transportation modes.

To further analyze the effect of various input parameters on the overall objective of cost minimization, a sensitivity analysis is also carried out. Figure 2 represents the Tornado chart pictorially describing the sensitivity of output (represented by cell J21) concerning the input parameters. The chart depicts that the overall cost is highly sensitive towards the cost of transportation between the orchards and the Mandis. The results reflect a relatively low sensitivity to the setup costs of cold storages.

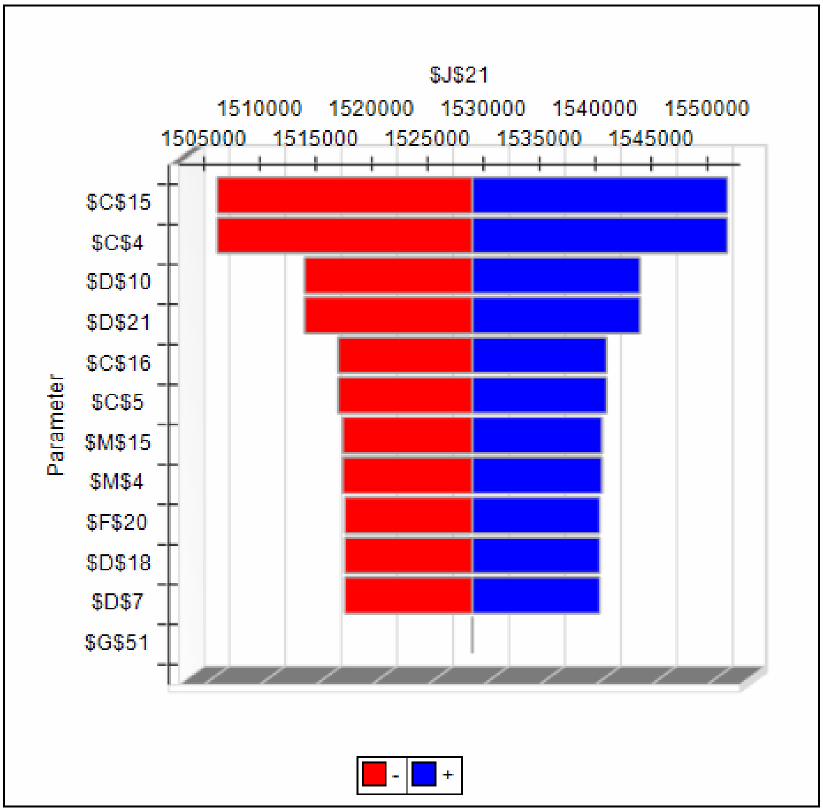

Figure 2. Tornado Chart for sensitivity analysis

The input parameters of costs of the fleet (Trucks and Jeeps) were further analyzed for their effect on the overall logistics costs (The objective function). To perform this sensitivity analysis, the cost associated with the use of a single truck was iteratively changed to ten different levels (2-20) in ‘000 currency units and multiple optimizations were run to identify the corresponding changes in the objective function. The results are shown in Figure 3. The costs are exhibiting a change up to the fifth level of truck cost, and after that they become constant.

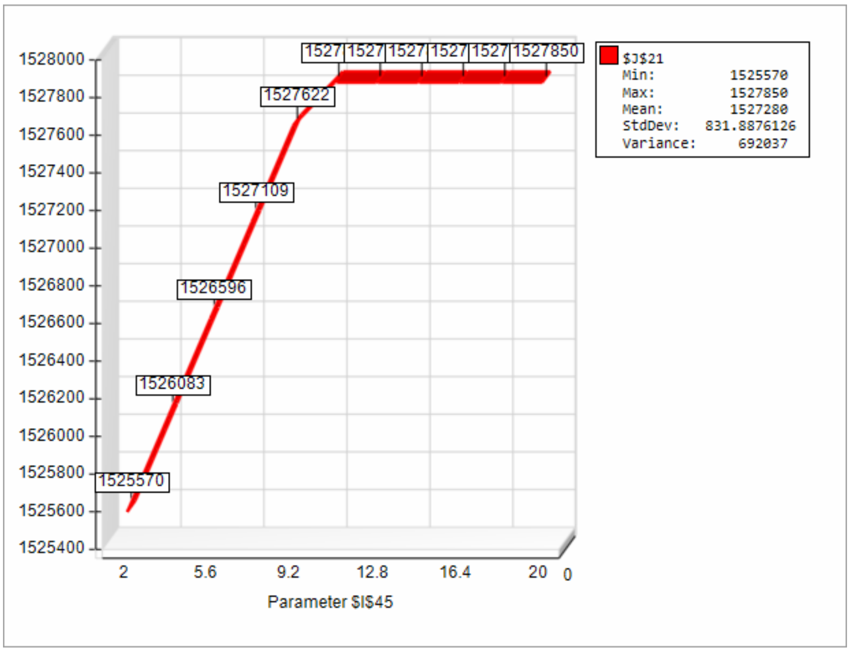

Figure 3. Multiple optimization outputs by changing truck costs

A similar observation can be seen in Figure 4, depicting the multiple optimizations for jeep cost changes. The result reveals a lower variance in the total costs as compared to that of trucks, thereby indicating that the costs are less sensitive to changes in costs per jeep.

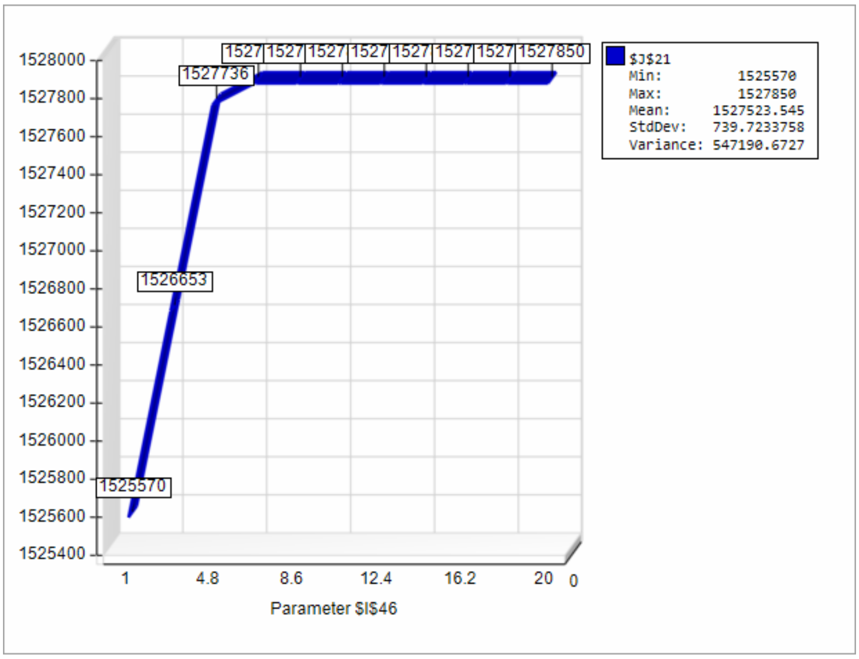

Figure 4. Multiple optimization outputs by changing Jeep costs

6. Conclusion

In this paper, the authors developed a two-stage programming model for a mixed fleet dispatching design of apple produce for an Indian district. The objective was to find a least-cost strategy for supplying fresh produce (apples) from the farmers to cold storages, keeping the daily demand a local marketplace (Mandi) can meet, making it a two-stage supply chain problem. A combination of trucks and jeeps was employed to supply farmers' produce from orchards to Mandis.The model was tested using a real case study of the apple supply chain of Kullu region in India. The proposed model has several implications for practitioners. First, it will help the apple growers in the region of Kullu to optimize the supply chain by selecting the most efficient supply route in multiple stages. Further, the proposed model in this research integrates certain key strategic decisions while keeping several constraints in mind, including the holding capacities of *Mandis* and the cold storages, set up costs at various stages, as well as the distance to the nearest orchards where goods can be loaded into a truck. The model also successfully incorporates the limitations associated with the number of Mandis visited and cold storage selected and also helps to achieve balanced networks for the transportation of apples. The model can further be tuned to different other input scenarios, resulting in a more robust plan that can be customized to different apple producers.

7. Future research

Several extensions to the present paper are possible. The current formulation has assumed a deterministic production of apples, which can be extended to uncertain production volumes using stochastic modeling. The various costs in the model are assumed to be fixed, and the dynamic cost functions may be employed in future works. The model can further be extended to multiple stages, extending the supply network further downstream. It can also be expanded by some more inputs and features that may potentially increase the profitability of farmers especially in a hilly geography The present study took kullu, Himachal Pradesh as the case locartion. Although, future studies may include other locations of similar geographies.With this inclusion, many new research dimension can be added and help to make the study more generalised. Also, the future studies can include more empirical angle to the work and can use various quantitiative statistical techniques including Structural Equation Modeling (SEM) and other multivariant analysis. The future studies also can include the adjacent activities those encourage or aid to the fruit supply chain management. The role of different stakeholders can be assessed in the development of an ecosystem from the triple bottom line perspective.

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