Citrus Supply Chain Optimization under Seasonal Demand and Retailer Segmentation

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Sabah Naveed

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Declaration

I, Sabah Naveed declare that this Master's degree thesis entitled as "Citrus Supply Chain Optimization under Seasonal Demand and Retailer Segmentation" submitted to NBS for the degree of MS L& SCM is the result of my own work. Acknowledgements are also provided wherever any material is utilized.

Student ID: 275992

Sabah Naveed

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Abstract

Agri-food supply chains are complex to understand and manage. Perishable nature of fresh fruits involves unique problems such as quality and quantity loss under time dependent demand which are difficult to formulate and solve. This research aims to study and optimize multi-period mixed-integer linear programming model to minimize fruit waste, carbon emissions, and associated costs. Citrus supply chain is divided into two cases, one being traditional or non-branded supply chain and the other being processed or branded supply chain. Augmented epsilon constraint method with lexicographic optimization is used as solution methodology. Goal programming – weighted sum method is also used to compare methodologies for both branded as well as non-branded supply chains. The models are coded and solved using optimization software, where the results revealed that traditional citrus supply chain encountered less fruit waste as compared to processed citrus hence improving consumption, although it creates a tradeoff between quality and cost. This research includes implications for efficient transportation, enhancing lead time and supply flexibility. The research also includes a binary variable for retailer segmentation that enables selection of market that has maximum capacity to fulfill desired retailer demand.

Keywords: Citrus supply chain, multi-objective optimization model, augmented epsilon constraint method, exponential decay function, seasonal demand pattern, waste minimization

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CHAPTER 1: Introduction

Fresh fruits and vegetables hold more buying and selling patterns as compared to other perishable items, primarily driven by consumption trends and therefore have equally greater market structure. Every perishable fresh fruit and vegetable possesses a specific seasonal time-period in which it is grown, harvested, and distributed in market. There are little known artificial practices that yield fresh fruits off season, but they lack pure taste and freshness compared to the one grown within its specific season. The top fruit that holds backbone of fruit market in Pakistan is Citrus. Citrus fruits are well known by their distinctive nutritional benefits along with the specific aroma and sour taste that distinguishes them from the rest of the fruits at a wider desirability.

The uses and importance of citrus in daily diet has now been highlighted at a greater extent because of its Vitamin C rich source and thus has created an equally greater demand for the fruit consumption in the world market. Citrus plants require a tropical fertile soil for cultivation and are grown in more than 140 countries around the globe. It has a greater percentage of production as compared to rest of the fruits combined, while the commercially important kinds of citrus include oranges, lemon, lime, tangerines, grapefruit, and other similar citrus hybrids (FAOSTAT, 2022).

Every kind of citrus is commonly available all-around globe without any difference, yet the developed countries keep exploring new and improved hybrids. Citrus is enjoyed in the fresh form or processed form and is widely consumed as juice or pulp extracts. According to the survey data of 2021, processed citrus is consumed and preferred 4% more than the fresh fruit form and has a higher percentage of exports as well (USDA, 2021). Internationally, Brazil and United States of America holds a stronger position in the production of Citrus, while China claims to be the next strong competitor in the next couple years to come whereas it faced a decline to 7.2 million tons due to unfavorable weather conditions. Brazil and United States has the greatest productive land for citrus around the globe and is reported to have expanded by 4.2 million metric tons as compared to the previous year (USDA, 2021).

The data shows that 35% of the world's citrus comes from Brazil and thus makes it the top producer of citrus. Sao Paulo has 500,000 hectares of land as well as large numbers of farmers, and favorable climate that makes Brazil gain the top position and retain it. China and United States strive each year to gain the second position and therefore has a minimal difference of production. Only 5% of Chinese citrus is consumed processed while the rest is preferred fresh, whereas China claims to export only 2% of its total produce making 98% of citrus available for domestic consumption. Mexico helps USA in the exports of Citrus although the only thing that effects its production is the climate changes. India has the third largest citrus industry after bananas and mangos, contributing almost 4% in the global output.

On the added similar stances, other countries involved in the production of citrus also reported projection during the year 2019-20, the tabulated data of which is represented below.

Table 1.1

Global citrus production stats

Countries	**Production (in million tonnes)**
Global	124.248
China	32.7
Brazil	16.55
India	9.7
USA	7.8
Spain	6.8
Mexico	6.6
Egypt	4.9
Turkey	3.6
Italy	3.1
Morocco	2.0
Pakistan	1.9

Source; (FAOSTAT, 2022)

Similarly, Spain is known to be the largest exporter of citrus worldwide and is placed as the seventh largest producer of oranges. Iran has been cultivating citrus for 303 years and is the number one producer of fruits in North African and Middle East areas, thus has dedicated thousands of hectares of land for the cultivation of citrus to keep the tradition going. Nigeria does not produce specific citrus like lemons, oranges, grapefruit or limes etc. but has a huge production of unspecified citrus or hybrids of the kind and has therefore dedicated as much as three million hectares of land especially for citrus cultivation (Jegede, 2019). Pakistan has a very rich fertile soil and is recognized to produce over 30 different types of Citrus fruits.

Provinces of Pakistan have distinctive fruit growing statistics such that Punjab constitutes share of about 97%, Khyber Pakhtoonkhaw 1.4%, Sindh 1.28%, and Balochistan has about 0.32% of share in the total citrus production, while overall citrus production of Pakistan is

2,289,262 tons (AMIS, 2021). Similarly, the land measurement also differs significantly where Punjab has most of the citrus producing fertile land (PBS, 2021).

The difference of production in certain provinces makes it only possible to fulfill the local needs and possess little to no share in exporting perishables, except Punjab with greater production capacity. In order to develop a clearer understanding of the above-mentioned data, following bar graph has been drawn to compare production statistics along with the area over which it is grown, among each different provinces in the graphical representation as per in the early year of 2021. The area of production is estimated in hectares while citrus produce in tonnes of unit weight. The total land used to produce citrus-kinnow as well as the number of productions of citrus in thousand tonnes at provincial level is graphically presented below.

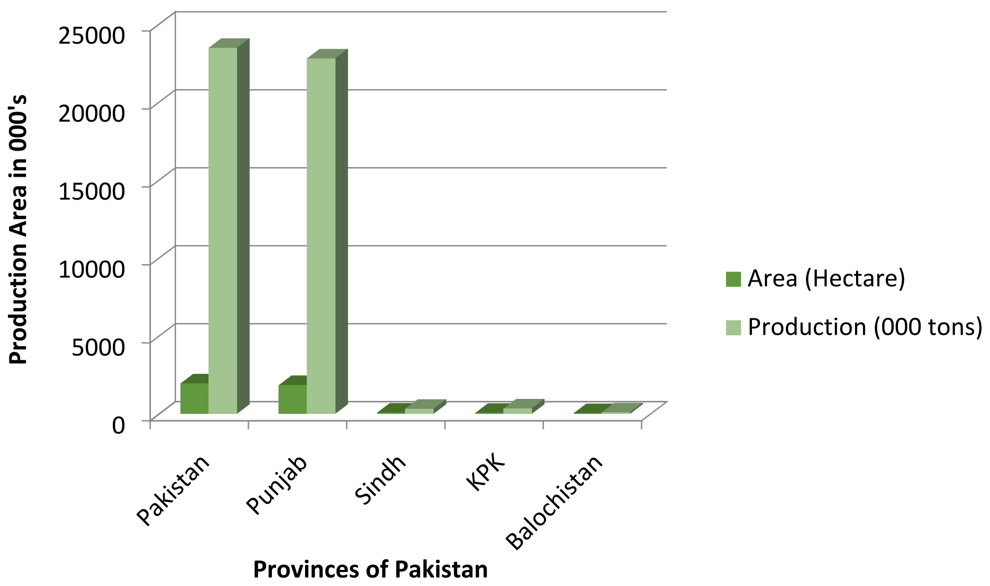

Figure 1.1 Province-wise citrus area and production
Source; (PBS, 2021)

1.1 Research problems

Since 97% of Pakistan's citrus is produced in Punjab province, it is therefore responsible for catering the excessive demand of nation overall as well as to meet the export demands. This research problem is manyfold, including the industry wide research problems which citrus as well as other perishables are currently facing in the markets of Pakistan.

- ✓ Fruit diseases and lower yield per hectare that makes it impossible to compete in national as well as at international grounds (Ahmad, et al., 2018; Khurshid, 2019; Shahid & Abbasi, 2011; Shah, et al., 2010).

- ✓ Low quality of fruit that has now become greater concern for growers and exporters, which not only exists because of fruit diseases but also because of low rates of quality production, effecting availability in terms of quantity as well (Ahmad, et al., 2018; Shah, et al., 2010).
- ✓ Shortage of resources and appropriate technology that facilitates progress (Aslam, et al., 2019; Khurshid, 2019; Sharif, Farooq, & Malik, 2005).
- ✓ Unskilled labor, unsuitable packaging, improper transportation facilities, inadequate handling and storage mechanisms, and bizarre cold chains increases input costs and lays negative effect on the financial flow (Aslam, et al., 2019; Ahmad, et al., 2018; Shahzad, 2017; Shah, et al., 2010).
- ✓ Inappropriate transportation vehicles are one of the biggest reasons for loss of quality, especially when the fruit has to cover long distances within minimal shelf life span to reach market before it starts deteriorating (Khurshid, 2019; Shahid & Abbasi, 2011; Sharif, Farooq, & Malik, 2005).

Since the area of conducting research comprises of logistics and supply chain perspective, therefore the main focus of research includes the economic outlook on cost minimization, enhancing green environmental impact by carbon emission minimization, along with minimizing loss of fruit quantity, the major apprehension in citrus fruits production and consumption cycle.

1.2 Research Objectives

Perishable products are primarily subjected to quality and quantity losses therefore, reducing waste, overcoming delays and optimizing fruit transportation (Drexl, 2012) in minimal seasonal time to all nodes is the main concern of this research. It covers reduction of excessive costs incurred along the supply network, also laying forward huge impact on the reducing the greenhouse emissions and lead time efficiency of the fruit supply chain. The conducted research contributes to existing literature of agri-fresh perishables with a combination of multi-period and multi-objective study. “Augmented Epsilon Constraint Method with Lexicographic Optimization” is used as solution methodology.

Augmented epsilon constraint method is an effective method for multi-objective mathematical programming since it provides greater pareto optimal solution, also conveying more information to the decision makers by which they can make effective decisions (Mavrotas, 2009). This method is chosen because of its ability to transform multi-objective approach into single objective by keeping one of the objective functions as the main objective of research while other objectives as constraints to the main one (Ahmed & Sarkar, 2018). It is an efficient and satisfactory solution method because it evades the redundant iterations that may lead solution to infeasibility and is being widely applied over multi-objective research areas such as engineering, agriculture, resource industries, and economics.

1.3 Format of Thesis

The first step comprises of a research problem that prevailing in the context of study, along with the basic research gap. The data is collected with the goal of searching and analyzing insight according to the variables and parameters required for formulating accurate mathematical modeling, being the second step of methodology. Perishable supply chain, citrus production and consumption, multi-period supply chain, multi-objective optimization, quantity loss of fruit, and seasonal demand are covered in this research. The third step involves defining the procedure of solution process as how it works and decision-making preferences. Fruit waste minimization, carbon emission minimization and cost minimization are the objective functions of the research under focus. The detailed analysis of method and related past studies are discussed below in chapter 3 and 5 respectively.

CHAPTER 2: Industry Background

The perishable market structure has a complex multi-flow of materials from the area of production i.e., farms to markets, retailers, and finally to the consumers. The supply chain in Pakistan, either for perishable fruits or vegetables, has limited reach in the field of logistics and/or supply chain while market fluctuations, involvement of excessive intermediaries, farmer-vendor relations and price forecasting etc. has the basic attention.

2.1 Citrus Market Structure

The production of perishable items in Pakistan is depended primarily on its growers, where their decisions are influenced by greater profitability and increased prices in the markets that aid in larger earnings (Shahzad, 2017). Agriculture provides farmers with different opportunities to increase their livelihood and contribute positively to the upbringing of economy via farming input. According to a survey, the traditional marketing system still exists where better price yielding profits and forecasting information is path to the supply of commodities to the markets, meeting demands and avoiding surplus or shortage of items (Aslam, et al., 2019). Like all other perishable commodities, citrus also has its distinctive supply chain flow that begins at agriculture zones and extends till retailing at national levels or exporting to international destinations.

Citrus has its major growing areas in Punjab where the contribution ranges between 92-96%. Basic post-harvesting activities that follow in process are the sorting, packing, and loading of citrus fruits in suitable vehicles. Citrus is packed in cartons, fruit crates made of wooden or grooved board, or in net sacks/ bags, manually loaded into transportation trucks. The packing operation is mostly handled at farms and rarely has a separate packing house. Licensed producers and exporters also label each of the fruit item before final packing and transportation. The fruit is then either transported directly to the registered shops or to the local area markets where vendors and other market intermediaries further transports it to registered shops after keeping significant amount in local market stores. The registered shops are listed by the government and are responsible for price settlement and transportation to various other city markets in the country.

Usually, a third party is involved in assisting transportation or materials outwards and sharing back finances and profits to the registered shops, charging as much as 6-8% commission along each transaction. The commodity is finally supplied to the main bigger markets, either present in the same city or in different city, or even in a different province. The supply is directed on the bases of forecasted market demand and as introduction of new consignment in the market, basically seeking profits. Some citrus producers also sale the entire citrus orchard or some of it to a third party, which are usually the buyers from a processing plant or are third party involved in buying citrus from farms and transporting it to processing units by keeping considerable commission in the chain.

The sale and purchase operations are conducted either on the bases of a pre-signed contract or on the bases of on spot buying. The processing activities are carefully designed and are directed towards the execution of maintained quality as in fresh fruits. The process comprises of grading and washing where soil, foreign particles are washed away and stains removed, followed by waxing, labelling and packing. The packing in processing plant is more reliable and environment friendly. Packed items are then transported to whole sellers and retailers where most of the purchasing parties are from super stores and other large shops. Processed fruits are even further subjected to waxing where fruits are covered with a thin layer of wax, so as to enhance citrus appearance and prevent loss of water from its outer covering. This process is primarily done for the amount to be exported internationally and waxing helps in preserving the freshness of fruits over a longer period.

The fresh fruits that reach markets are further bought in bulk by retailers or whole sellers, till it is finally purchased by end consumer. The long supply chain of perishable fruit leaves it at the end point with minimal shelf life before it starts deteriorating. Delays in transportation, numerous loadings and unloading practices, quality compromised packing, large number of intermediaries' etc. play a vital role in reducing the quality as well as the shelf life of citrus till the time it reaches its final consumer. Besides, quality compromised items are subjected to waste since it reaches bigger markets, then to whole sellers, retailers, and even the consumer.

2.2 Citrus Value Chain

The value chain of citrus fruits depicted in Figure 2.1 shows the series of activities by which value is transferred and retained along each activity to enhance chain contribution and promote consumption patterns. The functions, activities, operators, enablers, and facilitators are all involved in the value chain to endorse value up at each step. Value chains can often be challenging because of lack of control or direct influence of any of the involved party but on the other hand, it provides competitive edge to the kind of chain carried on. Citrus is transported to both local area markets as well as the bigger markets at national levels, overlooking the exports to international grounds for the case. There are a number of self-governed activities that take place while exporting perishables to local area markets, including the involvement of third-party logistics for packing and transportation, and vendors that either receive batches of citrus as per signed contract or themselves approach farmers for spot buying.

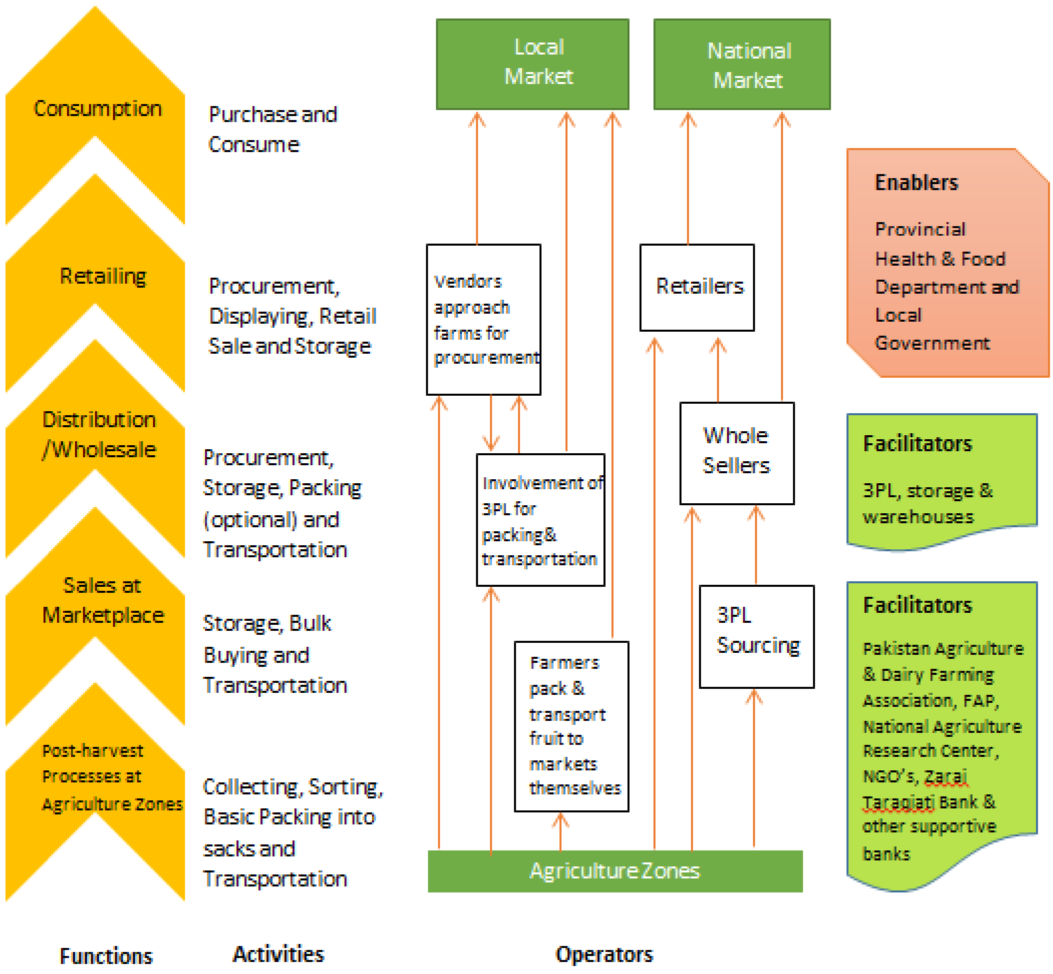

Figure 2.1. Value chain map of citrus in Pakistan

While for the case of bigger national markets, third party logistics sourcing, whole sellers and retailers are all actively involved at a large scale. The enablers are basically members of an organization, or the organization itself that controls the progression of activities and enable the exact goal to be met as intended, such as enablers for citrus value chain in Pakistan are provincial health and food department and local government of the country. Facilitators are responsible for providing coordination and facilitation to the local government and other projected government departments to assist them with capacity, maintenance and development of the chain over longer period. Facilitators for citrus value chain in Pakistan are third Party Logistics, storage areas and warehouses for temporary storage, Pakistan Agriculture and Dairy

Farming Association, Farmers Association of Pakistan, National Agriculture Research Center, NGO's that facilitate agriculture, Zarai Taraqiati Bank and other supportive banks. The potential end users of this research consist of the public nationwide who buy and consume fresh citrus as a part of their basic diet. The public includes people of all age, buying in-house grocery, for restaurants, for local cafés or processing industries that buy for the extraction of juice and pulp extracts etc.

2.3 Production of Citrus in Pakistan

Citrus is produced in all the provinces of Pakistan. Punjab outstands citrus production, as discussed in chapter 1, while rest of the provinces produces enough to fulfill demand in each if its local markets. Production of fruits face continuous fluctuation mainly because of weather conditions, use of fertilizers, or pesticides. Following bar chart in figure 2.2 shows the total production of citrus fruits compared to the production of Kinnow – citrus variety under focus of this research study.

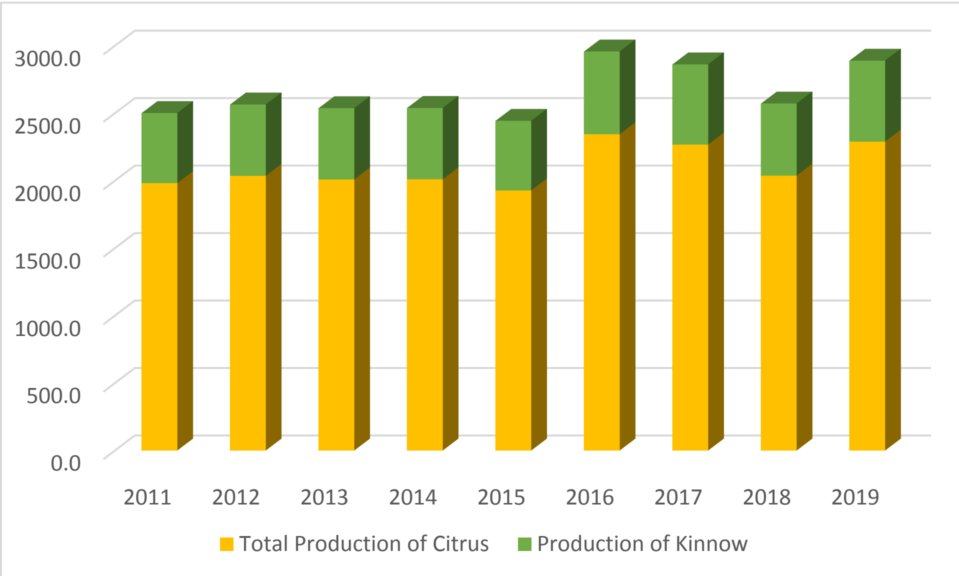

Figure 2.2 Production of citrus in Pakistan (FAOSTAT, 2022)

The above chart clarifies that year 2016, 2017, and 2019 had greater production of total citrus quantities in thousand tonnes, whereas Kinnow had consistent rate of production in all years from 2011 to 2019 (FAOSTAT, 2022). Citrus is not only eaten raw in the fresh form but is also available as processed fruits, as extracted pulps, as frozen fruits, and even as high on-demand fresh juices. Citrus forms the backbone of Pakistan's fruit agriculture therefore need special attention on production and supply of fruits in national as well as international markets.

2.4 Export of Citrus

Citrus, specially the Kinnow variety is exported to a few countries from Pakistan. Farmers, intermediaries, and exporters are trying best to ensure quality and taste of citrus to be recognized around globe. This effort is now turning successful as citrus – Kinnow exported in year 2020-2021 was recorded 30% higher than the previous years (TRIBUNE, 2021). Following bar chart in figure 2.3 shows the quantity of Kinnow exported to 40 different countries from Pakistan (TRIBUNE, 2021), as compared to total export of citrus variety from year 2011 to 2019 (FAOSTAT, 2022).

Figure 2.3 Export of citrus in Pakistan (FAOSTAT, 2022)

Citrus farming, production, packaging, role of intermediaries, transportation via third party logistics, demand of fresh as well as processed citrus in its specific season, processing of fruit, different cost structures, loss of fruit due to varied number of reasons and emissions of harmful gases in the entire network supply chain of perishable fruit is discussed in the next chapter – Literature Review.

CHAPTER 3: Literature Review

The research study conducted holds in-depth literature review of all past studies as discussed in this section. The section includes introduction and details regarding citrus fruit and perishable supply chain. It also includes review on multi-period, multi-objective, and time-dependent demand, considering significance and application of carbon emissions minimization in supply chain.

3.1 Citrus fruit

Citrus fruit has its unique importance that stands fast in the fruits category. The taste and amazing aroma of the fruit is increasing its consumption worldwide, where many nutritional researchers have highlighted the importance of citrus in-take either as a part of daily diet or as medicinal immunity (Liu, Heying, & Tanumihardj, 2012). Citrus fruit, especially the 'Blood Red' variety is covered in a thin layer of bee wax, paraffin wax, CMC, shellac, or any other synthetic chemical that not only protects the fruit from external damages caused by weather, transport, loading and unloading of fruit from vehicles, but also aid in prolonged shelf life of the fruit by preventing the loss of moisture from its outer layer, however the rate off loss of fresh fruit is increasing at a constant pace (Shahid & Abbasi, 2011). Salts such as Potassium Carbonate, Sodium Carbonate and their bi-carbonates, ammonium bi-carbonate etc. are added to the wax as coating layer over the citrus for quality and shelf life enhancement, which not only increases the decay period but also protects citrus fruits from deteriorated fungal diseases (Youssefa, Ligorioa, Nigroa, & Ippolitoa, 2012).

3.1.1 Farming and Production

Citrus is known to be among the highly demanded fruit, at national grounds as well as at international levels. Production and sales of citrus fruits contributes to rise in the economy by the rotation of revenues and consumption of fruits, while the exports of it further add as a prominent key of contribution to the economy (Ahmad, et al., 2018). The production and consumption of citrus extends from fresh fruit to processed fruits. Processed citrus has longer shelf life compared to fresh citrus, while making it possible for consumers to store fruit for a longer time period (Monteiro, et al., 2013).

Citrus has a huge significance in maintaining and improving human health. The scarce data for production and consumption brings forward beneficial facts along with each of the consumed constituent. The citrus consumption comparison between developed and developing countries shows that lack of fruits in diet leads to malnutrition and deficiencies, which is growing at a faster pace in the under-developed countries (Turner & Burri, 2013). At certain areas, main emphasis of research and improvement resides by lemons, oranges, and mandarins while other kinds of citrus are either given less or no importance at all. The lack of consumptions heaps up the production and storage where the limited shelf-life breaks lose the stock by deteriorating it. This creates negative environmental issues such as land degradation, increasing waste, and air emissions etc. (Beccali , Cellura , Iudicello, & Mistretta, 2009).

3.1.2 Packing and Distribution

Packing the fresh fruits as a whole or as fresh-cut by an innovative modified atmosphere packaging (MAP) can resolve the issues of deterioration and spoilage to a much greater extent (Grau, et al., 2009). The fresh fruit supply chains are generally measured in low profit margins, larger lead time and uncertain market conditions in terms of demand and supply of the fruit, therefore several operational research methods and tools are developed, compared and evaluated to assist in proficient decision making and active management (Silvaa, et al., 2016).

The profits earned by selling citrus is relatively low, primarily due to improper regularization of revenues in the market, no interaction of growers with either market or the consumers, and non-transparent demand patterns and consumer preferences etc. (Sharif, Farooq, & Malik, 2005). Most of the earned share goes to vendors, commission agents, contractors and wholesalers that are running the entire market. The exports and market situation of citrus is unpredictable for the growers because of the non-visible pricing methods that prevail strongly in the market and makes it impossible for the growers to realize consumer demand patterns (Ahmad, et al., 2018). The basic goal of an effective supply chain is to take the fresh farm products from the area of production to the consumer in an exact fresh state with maximum food safety and low costs, such as the discarded costs that arises because of storage, spoilage, processing or distributional activities (Yu & Nagurney, 2013).

The advancements around the world have forged the supply networks to have traditional efficiency and responsiveness along with quality, safety, and integrity therefore; the redesigning of Agri-Food supply networks are being linked with the notion of 'Quality Controlled Logistics' (QCL) by instruments of 'Critical Quality' and 'Controlled Logistics' point for the perishable fruits (Van Der Vorst, Kooten, & Luning, 2011). Several non-thermal processes are also being applied industrial wide to enhance fruit safety and quality along with its shelf-life extension to achieve the growing market demand of fresh as well as processed fruits (Ramos, et al., 2013). A mixed integer linear programming model is developed to integrate quality and decision making in planning and distribution of fresh food or fresh farm products in a supply chain (Rong, Akkerman, & Grunow, 2011).

Developed countries are working on the effective reverse logistics of almost every product that conquers the market. Fruits and vegetables are a major concern in the market as the processed goods may stay on the shelf for a longer duration while the fresh farm products deteriorate quickly. Several mathematical models such as MOKA, NSGA-II, NRGA and MOSA etc. are proposed and compared, to achieve objectives of cost minimization and maximizing responsiveness by bringing back the spoiled citrus to re-enter it into the supply chain with minor improvements or as new products (Cheraghalipoura, Paydarb, & Keshteli, 2018).

Fresh citrus deteriorates before time; largely due to the presence of multiple distribution channels and long-distance markets that not only increases the transportation costs but also adds to the costs due to spoilage of fresh fruit (Yu, Wang, & Liang, 2011). The involvement of multiple distribution channels has caused malpractices that rotates a very low percentage of profits to growers due to which they are unable to improve their harvesting and post harvesting processes (Shah, et al., 2010). Changing quality is at crucial importance to every food industry and is becoming more basic with the globalization and amplified consumer demands and purchase patterns (Yossef, 2014). The integrated approach of ALADIN towards the logistics uncertainties creates place for more flexibility and increases sustainability and safety in the food supply chains (Van Der Vorst, Tromp, & Van Der Zee, 2009), whereas on the contrary practical practices are drifted along the uncertainties with a highly indefinite market demand and consumption stats, along with losses in the chain processes that becomes the reason of less quality and less value.

3.2 Perishable Supply Chain

Perishable supply chain constitutes the distribution of fragile products through a series of channel till they reach its final consumer. Perishable supply chain for fresh farm products involves greater time accuracy, security and efficiency so as deliver exact quality and taste. The model of 'marginal value of time (MVT)' for sensitive in perishable products is used, which is the end limit of a perishable product before they deteriorate, fruits and vegetables, to determine cost of loss of value in the chain that helps improving the chain (Blackburn & Scudder, 2009). System dynamic models are applied to study the effect of logistics performance and food security on the perishable fruit supply chains and find independent ways to enhance responsiveness, flexibility, availability and efficiency in the fruit chain (Castro & Jaim, 2017). Markets possess increased value of perishable products and has therefore made it a matter of immense importance to utilize integrated production and planning mechanisms. These methods make it possible to ensure quality and safety of the perishables because of the fixed and loose shelf life while the deterioration point lines for spoilage and waste, adding more product costs in the chain functions (Amorim, Gunther, & Lobo, 2012).

3.2.1 Causes to Perishable Waste

Perishable items are spoiled and thrown away in the supply chain at several points from the point of production till it ultimately reaches its end consumer. There are a number of researches in which 'fuzzy MICMAC' and 'total interpretive structural modeling' (TISM) modeling approaches are used to recognize the causes of wastage and provide ways to overcome the damage. The overall results depict that lack of scientific methods in harvesting, appropriate packaging, as well as large number of intermediaries are the main reason for spoilage in agri-fresh supply chain (Balaji & Arshindera, 2016). A few other things that add damage to perishability of fruits and vegetables comprises limited and inappropriate transporting carriages, longer transportation routes, lacking quality in fruit, reliability of forecasted demand, and supply safety etc. Mathematical model designed to cater some of these issues involves linear programming model which is developed and tested for all regional and mountainous areas to solve key issues and ensure value of perishable product, quality and safety of product at each step (Castro, Coronado, & Lozano, 2017).

Fruit packaging has been known as one of the factors that can bring loads of improvement in increasing the sustainability of fruit and in maintain the texture through pressurized loading and unloading of citrus, especially orange. Certain improved packaging has been introduced and applied to overcome the problems of spoilage and recover the lost quality and taste in fruit. All the advancements have been successfully made for the processed oranges while cost effective packaging for fresh oranges is yet to be made effective, since the material availability is minimal for fresh produce (Defraeye, et al., 2014). Similarly, if perishables are viewed from a deteriorating point, keeping large inventories and not making effort into replenishing these products can create hurdles for the retailers. Fruits and vegetables are usually supplied in the form of a truck load or quantity lot sized which is ordered by the retailer on the bases of market predictions. All the costs associated with the order may increase if these fruits and vegetables cross pass their shelf life, spoil, also adding damage to the environment (Yan, Banerjee , & Yang, 2011).

Fruits possess a sensitive pre-harvest natural conditions such as land, weather, fertilizers etc. that carry major role in the abundant and healthy production of citrus while the post-harvest conditions ensure quality and safety in the fruits that bring profits to the business therefore, model regarding 'shelf-life based pricing policy' is developed with the objectives of total profit earned, and mean value for product freshness (Grillo, et al., 2017; Teimoury, et al., 2013). Information sharing and communication are an essential key to petter performance but their lack lays a major threat to the traceability of fruits and vegetables in agri-fresh supply chain. Most of the researches are carried out on the quality control and safety of the perishable products while little or no focus is rested on the stalking of loss of fruit which requires careful observance via "Smart Logistic Unit (SLU)" for active performance (La Scalia, et. al, 2015). Location re-routing and proposed models have somewhere turned useful in resolving issues of perishable. It can be proven that perishable chains possess a continuous threat of damage, especially the fruits where they are on the edge of rapid deterioration, and can be improved through sustainability and flexibility in respective supply chains.

3.3 Quantity and Quality Loss of Fruit

Waste and spoilage of fruit, either in the form of quality or quantity, lays a negative impact on the economy as it contributes to the loss of revenue for the farmers who reaped the fruit meant for consumption. Spoilage also adds harm to the environment where the decomposition initiates green-house gases and fosters waste (Lipinski, et al., 2013). Lack of proper communication between the farmers and vendors in the market, lack of authenticity in information that reaches farmers and preferences of the consumers, little or no transparency of circulating finances and shares earned in the business, large number of people involved as intermediaries for the supply of that perishable item, lack of latest technology in production, and the application of scientific methods are the reasons for loss of fresh products in a supply chain (Balaji & Arshindera, 2016).

The citrus fruits are marked by diminishing of the outer layer causing blue or black microbial growth on the surface of the fruit, discoloration, loss of water and moisture from the fruit result in quality loss. Processing activity such as waxing the fruit helps in preserving the texture and taste of the fruit, also segregates the perishable fruit from the fresh farm products (Shahid & Abbasi, 2011). Fruit and vegetable loss is characterized into two types; qualitative loss of fruit that reduces the overall quality of fruit such as due to pesticides, crop diseases, contamination mainly because of limited substructure and supply management, and quantitative loss of fruit that reduces numbers of consumable fruit such as due to physical loss because of transport and lack of proper fruit packing mechanism, the spoilage caused by human inefficiency to store and buy fruit on time (Aulakh, et al., 2013).

The perishable products have a very sensitive life span that usually ranges from about a week to almost one month. Most of them start to deteriorate soon after they are produced and hence need a lot of handling, packaging and transportation care. The value along the product is only delivered when it is received as expected while when it comes for fruits and vegetables, they do not have a fixed time span and may spoil before the normal predicted time due to temperature, moisture or due to any other unknown factor (Amorim, Gunther, & Lobo, 2012). Food loss contributes significantly to the loss of quality, loss of value, loss of resources that may be used by the generations today to feed the upcoming generations and make sure for loss to no shortage of food at all, loss of money that is spent to purchase a particular food item, along with the loss of food security and all the energy that was utilized in the production of that specific food item therefore, the loss as a whole is an important factor for chain effectiveness (Buzby & Hyman, 2012).

Post-harvest losses are not new in the system around. It has been a problem since ages and is worked on continuously for reduction and betterment. The collaboration of producers and vendors in the market, effective transportation, and commitment to integrated approach is highlighted to be the only answer to the problem of loss (Atanda , Pessu, Agoda, Isong, & Ikotun, 2011). While collaboration in the chain functions can never be the sole solution to all the issues around and does need more effort to overcome hazards of food shortage and availability in the upcoming years. Data available for the analysis of production and consumption is known to be uncertain due to impractical adaptation, also requires the inquiry of consumption and loss statistics via per capita GDP and not through individual household stats (Xue, et al., 2017).

3.3.1 Global Loss of Fruit

A balance supply chain needs to focus on the issue of loss of fruit as well as the loss of quality associated with it through ‘Holistic Approaches’ and ‘Systematic Methodology’ because the damage is not entirely limited to the producers or the consumers, but it also effects the economy directly and largely (Affognon, et al., 2015). In a report published in year 2009, it was estimated by United Nations that food losses are around 1.3 million and projected it to grow more till more years to come while this percentage was unexpectedly calculated to be higher for developed countries as compared to the developing or the under-developed countries (Aulakh, et. al, 2013). “US Department of Agriculture’s Economic Research Service’s Loss-Adjusted Food Availability”, brought forward data collected from fruits and vegetables that are exposed to 17% of annual loss and will equally add almost 10% more over a decade. This global issue necessitates large initiatives to avoid food shortage for the upcoming generations (Buzby & Hyman, 2012). When discussing the production and supply chain of Pakistan, Citrus fruits are exposed to an approximately 20%-40% post-harvest losses that hampers large quantity of consumption nationally, while also stops farmers from achieving track record of great citrus yield in spite of fertile land (Ahmad, et al., 2018).

Perishable loss is not limited to the damage caused to the perishable items, but also includes their deterioration, its declined quality, and loss of value to be purchased for consumption. This factor also points out to the other direction that makes a country concerned for its food accessibility to the public at large. The loss of fruit mainly arises due to the ineffective education and information at farmers end, also because of ineffective handling procedures, the kind of transport used, routing, vibrations and delays of the vehicle to reach markets, and the neglected inappropriate supply chain functions. If the data and stats are compared of a developed country with an underdeveloped or developing country, The process of spoilage begins on the very first point of the chain when fruit is loaded onto the vehicles and moved on roads for developed countries. For an underdeveloped or developing countries, the process of spoilage of fruits and vegetables began during the pre-harvest period (Hodges, Buzby, & Bennett, 2011).

Billions of people can be fed with the lost food that accounts to be one-third of the total global produce, and fruits and vegetables being half of the total produce. This marks for an inefficient supply chain that makes way for reduced value and quality. These losses also retain environmental harm such as spoiling water and land (Kummu, et al., 2012). According to the statistics of year 2018, out of all the steps and functions in the supply chain, ranging from the post-harvest supply measures, loading, transport of the fruits to market, unloading, shelfing in the local markets or in retail stores, up till the buying behavior and preferences of consumer; major loss of fruit arises at the retail and consumer ends which basically happens because of efficient handling and throwing away of fresh fruit in the light of spoilage and off shelf life (Porata, et al., 2018).

Consumer satisfaction and the delivery of food products with maximized quality and value are the two most critical goals of any processing industry that processes perishables such as fruits. Since the products need side by side replenishment and can rarely be processed to stock, they require efficient supply structures and responsive market demand that can facilitate the objective of freshness and quality in the products, whereas the involvement of the producer is neglected despite of the fact that the quality in produced items has a major effect on driving the market demand and purchase patterns (Grillo, et al., 2017). Food processing companies are trying their best to search for possibilities of extending shelf life of the perishable products as well as to reduce the loss of quality during the processing processes, adding value along with the purchased product, and meeting market demand with a cost-effective method.

World population is increasing per year and demand for an equal increase in the per capita consumption of either fresh or processed food. The availability of food to such large numbers in best quality and enlarged value is not only becoming a top consumer demand but also the goal for responsive and efficient supply chain drivers and functionaries involved. According to the researchers, the loss data of food cannot be quantified, either when talking about the developed country or the developing country, the rate of post-harvest loss is way greater than mentioned and tabulated so far, amplifying it for more years to come (Parfitt, Barthel, & Macnaug, 2010).

3.4 Time-Dependent Seasonal Demand

Every product has its specific lifetime after which it is subjected to decay. Perishable commodities and specifically fruits cannot be stored or stocked above their respective shelf lives, even if coated with moisture preventive layers or not. Fruits such as citrus has a seasonal and time specific demand therefore 'Differential Equations' and 'Sensitivity Analysis' are carried out in the context of 'Weibull Decay' to keep a check for inventory, replenish with minimum possible lead time, and to reduce the total cost (Muluneh & Srinivasa Rao, 2012). In the case of deteriorating items, the rate of decay is generally assumed known and constant while on the true side such as regarding fruits and vegetable it may vary with random shelf life. Therefore, when considering production rates, Weibull decay rates for increase, decrease, and constant falloff must also be followed since decay is largely dependent on the production schedule of any perishable food product (Rao, Rao, & Subbaiah, 2011).

The replenishment of deteriorating items is directed by the environmental conditions, kind of transport, effectivity of packaging, and approximate freshness etc. while the cost reduction and performance improvement can be obtained via 'Pareto Distribution' where market demand is a function of time. All the costs involved in a series of activities can be optimized easily by forming a total cost function. This cost function has been established and worked by many researchers in the past with different variables and products under focus therefore; the difference that resides in this research is the sensitivity analysis, i.e. the effect of significant time on the ordering and pricing attributes of perishable items (Rao & Rao, 2016; Sarkar, Mandal, & Sarkar, 2014). By keeping random production and replenishment of deteriorating items in attention, the results proved that the model is largely emphasized by the distribution and deteriorating parameters, especially for the case of fruits and vegetables market.

Deterministic models are developed and tested if it is created for deteriorating products or day to day items. In case of such scenario, demand rate is considered as a function of shelf-life storage or the holding cost of perishable items on the shelves as well as the selling price, keeping the time of decay perpetual. Since selling price is the main concern of consumers when selecting items to buy and the basic attribute that drives the buying behavior of consumers, direct spoilage of the products when they are left on the shelf for longer duration or if the consumers refuse to buy due to minute damage to the product, caused by excessive time laps can lead to reduced demand and no profits (Roy, 2008). Similarly, the spoiled item not only contributes to falling purchasing rates but also to the falling prices, and extremely low to no profits at all.

Since the consumption demand is random for the perishable products because of the seasonality factor that affects fruits and vegetables overall, the replenishment schedule cannot be determined exactly (Yan, Banerjee , & Yang, 2011). Therefore, probabilistic approach is used to determine average demand rate as well as the probability of consumption rate. This is also governed by quality ensured products with minimal or no loss of quality. Mathematical models prove that if the demand is high, the time will have no effect of the deterioration of perishable items while if the demand is low, the perishable items spoil lying on shelves for long (Maihami & Kamalabadi, 2012).

Although packaging is directly linked with cost effectivity, more security, greater quality, increased purchase preference, and attractive appeal for the fruits yet the only way to recover the damages in fresh farm with limited time case is to make the handling perfect enough by incorporating cold chain into the supply chain to deal with the issues of spoilage and food damage due to creased shelf life (Defraeye, et al., 2014). The rate of spoilage for sensitive items such as fruits and vegetables are evaluated by external damages caused to the fruit as well as internal damage because of expired shelf-life of fruits and vegetables. This way it increases total cost and creates hurdles for efficient supply mechanisms.

In a nutshell, the decay time and shelf-life of fruits depends greatly on the seasonality of a particular fruit. If the season is at its bloom, the buying demand patterns is also high while by the end of the season buying rate falls significantly where storage is still full in the markets, which creates way for fresh fruits to speed up in deterioration. Present national supply chain infrastructure for perishable and agri-fresh food items is not reliable and flexible enough to fix all the issues that are commonly responsible for decreased supply chain performance. The fruit quality and quantity are continuously restored by several preservation techniques targeting extends shelf life, called processing of fruits. Mathematical model of present research study focuses on both fresh as well as processed citrus supply chains. Keeping the seasonal demand of citrus in view, along with other chain functions in focus, mathematical model for research is drawn and evaluated to reach an optimal solution and improve citrus supply performance.

3.5 Multi-period Supply Chain

Almost all the citrus fruits are cultivated in different seasons and perhaps follow an elastic demand pattern. Multi-period supply chain involves different supply and production timings over a greater horizon that makes it easy for all the parties of the supply chain to work on collaborative multi-period planning effectively (Liu & Nagurney, 2011). In order to reach equilibrium in multi-period planning, variational inequalities are considered, for the case of profit maximization over a future assumption, where the product patterns of prices, transactions, quantity, quality, output, inventories etc. are evaluated by careful decision making. Transportation that consists of paths and flow of materials over these paths is also considered alongside the equilibrium. The final framework developed aids in modeling flexibility in the chain and the numeric values attained after analysis helps in solving the problems that reside in the supply chain (Akbari & Karimi, 2015). Achieving cost effective supply chain management with a blend of tactical decisions and strategic decisions under uncertainties, such as production, logistics, procurement, supply, market fluctuations etc., is an unlimited challenge for the present industries.

Researchers have been designing an optimized network chain by keeping manufacturers, distributors and customers as prime nodes, further including all possible fixed and variable costs, production time, demand rate and demand flow in mathematical formulation of framework. Basic goal associated with production related multi-period extends up till cost minimization and storage maximization. Similarly, researchers used mixed integer linear programming for solving multi-period problems using genetic algorithms “NSGA-II” and “NRGA”, to reach an optimized best comparative result from the chosen methodology, while this research too is directed towards the multi-product production and voided the concept of perishable products such as fresh farm fruits, specifically citrus (Pasandideh , Niaki, & Asadi, 2015).

Besides production and availability of a product over significant period, another factor namely orders placement to the suppliers is also studied under multi-period time horizon. After selection and evaluation of the supplier, orders are allocated to each of the selected supplier. For organizing the process of order allocation, the researchers have used fuzzy criterion model as well as to overcome the uncertainty. “MCDM Method” is used to allocate orders to the best supplier possible while fuzzy linear programming is used to optimize the entire chain. Since suppliers for citrus are the farmers, similar selection is also applicable in their case (Haleh & Hamidi, 2011).

Perishable products with deterministic shelf life are studied under multi-period time horizons which is directed towards robust optimization and evaluated with variational inequalities, as considered for other product types. Uncertain demand patterns, uncertain market circumstances, growing competition, and dynamic pricing of the product are all evaluated over each time-period, according to which the researchers concluded that the competitive pricing levels are high in the beginning of a time horizon while becomes worthless by the end of it (Perakis & Sood, 2006).

Citrus network on the other hand, not only faces competitive issues at retailer’s ends but also at the wholesaler and market nodes as well. To remove loopholes in the previous researches that deployed integer linear programming and made use of genetic algorithms, an optimal solution is developed that makes use of general mathematical model and proposed the conclusion that a multi-period problem can be solved using any mathematical solver (Barrón & Garza, 2014). Sustainability in a supply chain is ensured by economic excellence, environmental as well as social excellence. Both negative and positive aspects are evaluated in a network supply chain over a multi-period time horizon positioning manufacturer, suppliers, retailers, and the relationship of all the nodes are analyzed in a tier for each aspect. The results showed that stronger the relationship, stronger is the chain performance (Cruz & Liu, 2011). Therefore, we can infer that for a successful citrus supply chain network, efficiency along with best suited relationship among the chain regulators is also essential.

In recent research forward logistics is explored under multi-period criteria, multi-objective reverse logistics is designed and analyzed over a multi-period time horizon for effective decision making in the long run. The objectives formulated for the study includes minimization of cost economic intent and maximization of green environmental intent through "fuzzy EDAS" method (Ghorabaee, et al., 2017). On the other hand, "NSGA-II" Pareto-based algorithms focused on maximizing total profits, minimizing the total supply risks as well as minimizing the carbon emissions, while the output "Taguchi" approach was used to qualify the solutions found for the problems under research (Kumar, et al., 2017). A multi-period research made use of "Lagrangian Relaxation Method", focusing on inventory routing problems for deterministic perishables in a supply chain (Rafie-Majd, Pasandideh, & Naderi, 2018), while another multi-period research that focused on the distribution network of a single product within specific time frame and with fix demand rate is studied. The goal of research being total cost minimization for supply chain however, the citrus demand rate changes along the period where it is subjected to rise during the initiation of the season, while declines drastically till the end of its significant period considered along each different perishable product.

3.6 Multi-Objective Optimization

Several research published till date are based on multi-objective criteria, where most of them focus on the sustainability of the supply chain that incorporates economic, environmental, and social benefits for the success of overall supply and demand. Basic supply chain for manufacturing industries consists of manufacturers, retailers, and suppliers, where the prime objectives for attaining an optimized chain consists of maximizing the net profits, minimizing excessive costs, minimizing the carbon content in the air that possibly arises due to manufacturing practices and transportation (Cruz & Wakolbinger, 2008).

Since the production and distribution of perishable items needs extensive care and controlled measures, it is more subjected to sustainability risks. The objectives followed to optimize production planning for perishable items while considering fixed shelf life are total cost minimization and maximizing the remaining fractional life of the perishable item, and for flexible shelf life of the products comprises minimizing production cost only along with maximizing fractional remaining shelf life of perishable products (Amorim, Gunther, & Lobo, 2012). Researchers in the past have been concerned about supply and demand patterns along with price interface in the system dynamics of perishable fruits and vegetables. For the purpose, objectives devised for the study basically covered minimizing excessive prices and maximizing wholesaler's markup (Teimoury, et al., 2013).

Whether the perishable product follows a deterministic shelf life or a non-deterministic shelf life, is a fruit, a vegetable, meat, or dairy product, most of the studies found clues to chain optimization via cost minimization and carbon emission minimization. There are lesser-known studies that worked on lead time minimization or on reducing the loss, while making supply chain pace efficaciously (Soysal, Ruwaard, & VanderVorst, Modelling food logistics networks with emission considerations: The case of an international beef supply chain, 2014). Similarly, optimized supply chain network designs are created for perishable foods to ensure efficiency and greater performance by each of the end node present in the chain. Likewise, in other multi-objective researches, total cost minimization and minimizing the negative environmental effect were the objectives to integrating sustainability in a perishable food supply chain (Govindan, et al., 2014).

Cost and Carbon emission are now a very common objective that is interlinked to most of the supply chains. Researchers came across "TOPSIS", a multi-criteria approach for decision making regarding routing problems that provides accomplishment of tradeoff between cost and carbon dioxide emission (Validi, Bhattacharya, & Byrne, A case analysis of a sustainable food supply chain distribution system—A multi-objective approach, 2014). Furthermore, few more studies conducted for sustainable supply chain includes the common objectives of cost minimization and carbon dioxide minimization, while also adding on the mixed integer linear programming for quality maximization using "NSGA-II, Meta heuristic" approach for finding an optimal solution for hub location problems (Musavi & Amiri, 2017).

Food traveling through an extensive distribution network either from truck or through air via airplane does face quality loss due to perishability. Achieving less cost structure with equally reduced carbon emissions, along with best efficient mechanism, is a goal for almost all the fresh food industries worldwide (Bortolini, et al., 2016). One of the basic issues that parallels with perishable foods is their deterministic or random shelf life. The fluctuations of demand alongside sustained shelf life are a boundless challenge, especially for the case of reverse logistics. Researchers have deployed "fuzzy EDAS" method to minimize cost and maximize green supply chain methods to deal with uncertainties in reverse logistics

(Ghorabaee, et al., 2017). Similarly, the risks and opportunities are dealt in the organized supply chain by maximizing the social responsibility while trying to minimize the carbon content in the air (Kumar, et al., 2017).

3.7 Carbon Emission

One of the growing environmental issues is the continuous addition of carbon emissions in the air. Carbon emissions has now become a global problem, while many countries are striving hard to reduce the harmful gas from environment, developing different carbon control policies and trying to balance urbanization accordingly (Adams & Acheampong, 2019).

Biogenic emissions from plants play a major role in reducing carbon from the environment and are thus recognized as the ozone and photochemical producers (Fares , et al., 2011). Despite benefits, agricultural practices, addition of fertilizers, use of machines for harvesting, loading, and unloading adds excessive carbon in the air compared to the amount reduced by plants around the globe. Another study conducted optimized citrus fruit crates in a closed loop supply chain, having economic as well as environmental goals (Liao, et al., 2020). The study primarily focused on the waste caused in the environment by citrus fruits crates, that cause damage to environment. While present study incorporates numerous other facts as well that adds up to the prevailing damage such as carbon emissions during post-harvest practices, fruit spoilage in the entire network, emissions during transportation etc.

Developing a sustainable supply chain network is extremely important for all the emerging industries. To enable achieving sustainability and growth in the industries, researches modeled a perishable supply chain network with fuzzy constraints, having reduction of carbon emissions as a major economic contribution, and solved the problem using HGA and HHS (Dai, Aqlan, Zheng, & Gao, 2018). Similarly, to address the challenge for rising demand and high quality of perishable food, a multi-objective model was designed to enhance suitability in decision making as well (Yakavenka, et al., 2020). Two-echelon problem with time windows was solved by a hybrid approach MHVP, where reducing cost caused by carbon footprint was included as major research goal (Govindan, et al., 2014). Results obtained from both studies indicated that hybrid methods provided better solutions and optimized chains with time windows can prove fruitful in reducing environmental damage, also benefiting the economy overall.

As discussed above, demand for perishable products is consistently rising in the markets and has now shifted towards a competitive edge where every market intermediary tries to reach the market early with maximum freshness in the perishable. The chain is equally subjected to different challenges and thus, requires sustainability in regard to costs, carbon emissions, as well as product freshness (Liu, et al., 2021). Along with other factors, enablers of food supply chain have crucial importance in reducing the carbon footprint. Practical insight to stakeholders for overall food supply chain performance improvement shows that food waste and carbon footprint can be reduced side-by-side with effective decision making (Parashar, Sood, & Agrawal, 2020). The transition of traditional supply chain to processed supply chain, also changes the amount of greenhouse gas emissions. In traditional supply, farmers from afar area reach markets on their own and thus causes increase in costs, carbon emissions, and low profits (Nasr, et al., 2021). MILP model is designed for location-inventory-routing problem for reduction of total distribution cost and environmental outlook. Fresh farm products are rather stored in warehouse where supplier gets to decide for inventory routing and reduction of overall costs (Onggo, et al., 2019).

3.8 Research Gap

The loading, transportation, unloading, and bizarre market conditions causes' loss of fruit in terms of quantity as well as quality, while increasing costs at each level of chain flow, and increased delays due to which the fruit reaches market with minimum shelf life left before it starts deteriorating. There has been limited research in the network supply chain for citrus, especially when considering farms and their production statistics, processing plants with related tradeoff between cost and quality, and market structure at national level. Little or no research is conducted on improving the transportation mechanisms to make the chain more efficient and cost effective, to save citrus from losing its quality, and on reducing excessive delays that serves as a prime reason for spoiled perishable fruits available in market.

As supported by literature review, there are several researches where focus is to optimize objective functions for different supply chains, considering delivery time minimization from hub or warehouse storage areas (Basirati, Jokar, & Hassannayebi, 2020). Present study is different in the sense that the network node is not storing fruit quantities but are selling points for the received quantities where fruit is placed over shelves and face exponential deterioration.

To summarize the literature according to the topic of research selected is presented below in the form of a table, where different research work in similar filed are compared from the present focus of study.

Table 3.1

Typology of the past research and contribution of present study

Research	Multi-Period	Multi-Objective	Seasonal Demand	Perishable Products	Objectives	Solution Methods
(Cruz & Liu, 2011)	✓	✓			Total Profits Maximization + Risk minimization	Meta Heuristics
(Amorim, Gunther, & Lobo, 2012)		✓		✓	Cost minimization + Fractional shelf-life maximization	Integrated Mathematical Model
(Muluneh & Srinivasa Rao, 2012)			✓	✓	Cost Minimization	Weibull Decay, Sensitivity Analysis
(Teimoury, et al., 2013)		✓		✓	Price variation + Price mean minimization + wholesalers markup maximization	System dynamics modeling approach
(Govindan, et al., 2014)		✓		✓	Cost + Environmental Impact Minimization	Multi-objective Hybrid, MHPV
(Soysal, Ruwaard, & VanderVorst, 2014)		✓		✓	Logistic cost + Gas emissions minimization	MOLP with Epsilon Constraint Method
(Validi, Bhattacharya, & Byrne, 2014)		✓		✓	Cost + Delivery time + CO_2 emission minimization	Genetic Algorithm resolved via NSGA-II
(Wu, Shen, & Zhu, 2015)	✓			✓	Total Cost Minimization	MINLP by Greedy Heuristics
(Bortolini, et al., 2016)		✓		✓	Cost + Delivery time + CO_2 emission minimization	Multi-objective programming, Exact Approach
(Rabbania, Geranmayeh, & Haghjoo, 2016)				✓	Total Cost Minimization	Genetic Algorithm resolved via GAMS
(Wang, et al., 2016)		✓	✓	✓	Total Cost Minimization + Freshness Maximization	STVNS – Genetic Algorithms

(Shaabani & Kamalabadi, 2016)	✓			✓	Cost Minimization	PBSA solved by CPLEX
(Ghorabaee, Amiri, Olfat, & Firouzabadi, 2017)	✓	✓			Total cost minimization + Total greenness maximization	MINLP – Fuzzy EDAS & Fuzzy MODM Method
(Kumar, et al., 2017)	✓	✓			Total Profits Maximization + Risk & Disruption + CO_2 emission minimization	MINLP by NSGA-II using Taguchi Approach
(Musavi & Amiri, 2017)		✓		✓	Cost + quality max + CO_2 emission minimization	Meta Heuristics solved via NSGA-II
(Esmaeili & Sahraeian, 2018)		✓		✓	Total Travel Cost + Customer Waiting Time + CO_2 emission minimization	MINLP/ MILP solved by NSGA-II
(Rafie-Majd, Pasandideh, & Naderi, 2018)	✓			✓	Total Cost minimization	Lagrangian Relaxation Method
(Savadkoohi, Mousazadeh, & Torabi, 2018)	✓			✓	Total Cost minimization	Possibilistic programming via Fuzzy UAM & LAM
(Onggo, et al., 2019)	✓		✓	✓	Cost Minimization	MILP – Simheuristic Algorithm
(Basirati, Jokar, & Hassannayebi, 2019)		✓			Total Cost + Distance minimization	AUGECON by MOICA
(Biuki, Kazemi, & Alinezhad, 2020)		✓		✓	Cost + Environmental Impact minimization + Job Creation maximization	MIP by Meta Heuristics
(Zulvia , Kuo, & Nugroho, 2020)		✓		✓	Capacity + Diversity + Performance Maximization	MOGE Algorithms, Meta Heuristics
(Chan, et al., 2020)	✓	✓		✓	Total expense + Lead time + CO_2 emission minimization + quality maximization	MO-GLNPSO
Present Research Study	✓	✓	✓	✓	Waste Minimization + CO_2 emission minimization + Cost minimization	AUGECON Method with Lexicographic Optimization

The conducted research study focuses on multi-objectives along multi-period study for optimization, as discussed in the next chapter 4 – Mathematical Modelling discussing both traditional citrus supply chain as case I and processed citrus supply chain as case II of the research study.

CHAPTER 4: Mathematical Modelling

Based on the literature review, supply and demand network in Pakistan, and the research gap, two cases are formulated. One of it is the traditional citrus supply chain of Pakistan and the other is the value-added citrus supply chain of Pakistan. The model for Case I consists of three elementary levels of chain: Citrus Farms, Markets, and Retailers as shown in Figure 4.1. The research will follow mathematical modeling by considering three main objective functions of 'Fruit Waste Minimization', 'Carbon Emissions Minimization', and 'Cost Minimization', along with the constraints that follows each objective functions. The mathematical formulae are presented below along with an overview of constraints, parameters and decision variables that are worked on to optimize the supply chain of citrus fruit to make it more sustainable and efficient.

4.1 Case I: Traditional/Non-branded Citrus Supply Chain

For case I, following model is created that discusses present perspective of the markets with non-branded citrus supply to markets and then to retailers, proposing the direction of optimization. To address the challenges in traditional / non-branded citrus supply chain in Pakistan, this research includes the development of mathematical model on the bases of following assumptions,

- Capacity of citrus fruit grown at each farm is known in tonnes.
- Number of citrus farms and fruit/vegetable markets are known, while number of retailers may vary.
- Retailers' buying quantity is directly proportional to demand/ consumption patterns. Contractors are involved in the purchase of entire citrus quantity from farms, in form of one or more pickings.
- Packing in wooden crates as well as the logistic services are done by contractors from farms to markets are also provided by them, given the fluctuation of commercial and fuel rates.
- The multi-period time span considered in accordance with variable seasonal demand arising from retailers as consumer demand, is over three months i.e., November, December and January.

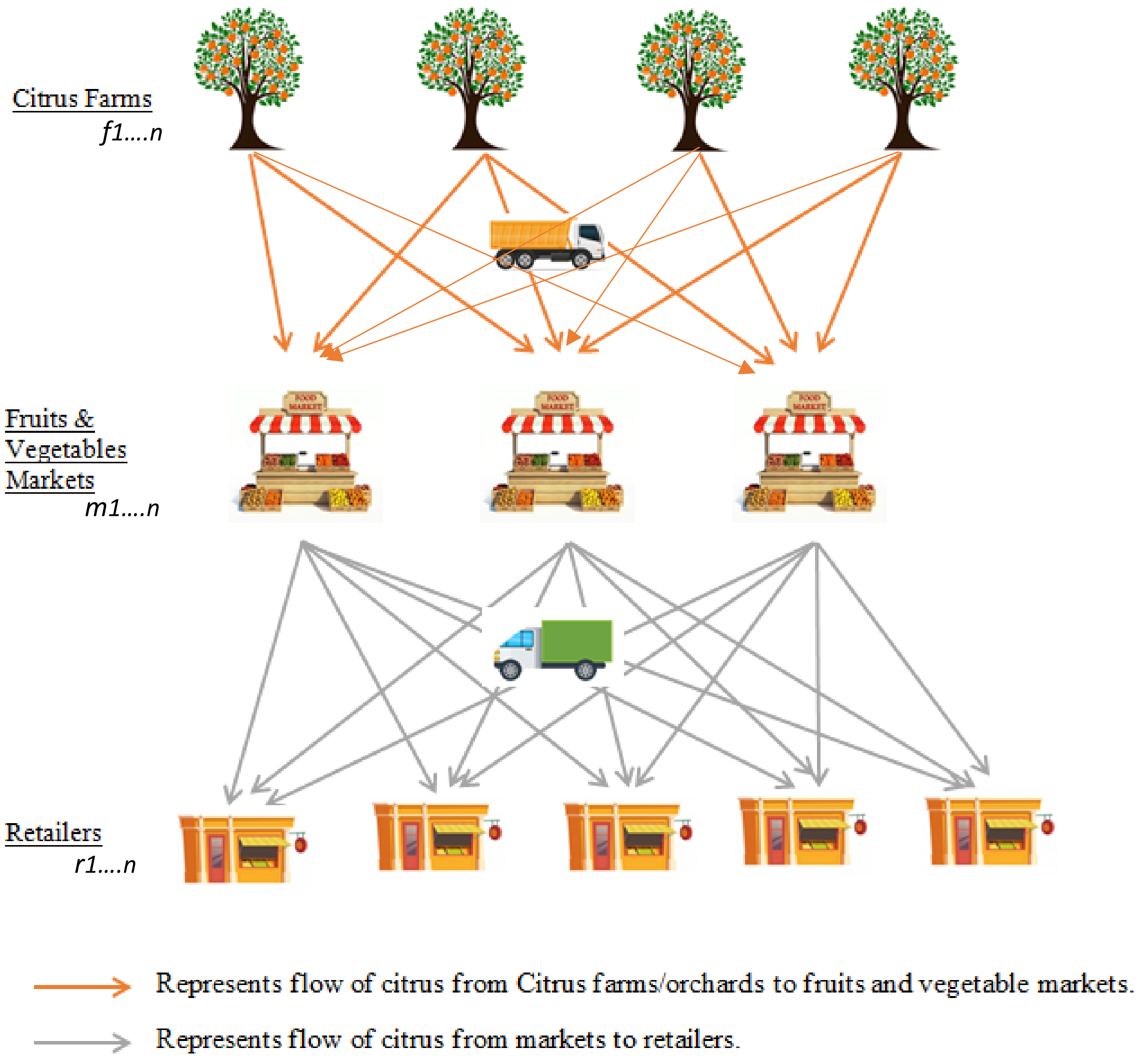

Figure 4.1. Traditional citrus supply chain model

The mathematical model is carved to reach the goal of minimizing fruit waste so as to work through measures to reduce the quantity wasted each season and saving fruits from further damage as well as minimizing carbon dioxide assisting chain partners in controlling excessive unnecessary exertions and minimizing costs that incur along the supply chain extending from the supply of fruit till the fulfillment of market demand while enhancing overall economic share and environmental responsibility.

Notations

Sets

f	citrus farms	$f = 1, 2, 3, \ldots .F$
m	fruit and vegetable markets	$m = 1, 2, 3, \ldots .M$

r	retailers	$r = 1, 2, 3, \ldots .R$
t	time-period	$t = 1, 2, 3, \ldots .T$

Parameters

P_f	production capacity of citrus fruit at farms 'f' (tonnes)
C_f	production cost of citrus fruit at farms 'f' (\$/tonne)
LC_f	loading cost of citrus at farms 'f' (\$/tonne)
LC_m	loading cost of citrus at market 'm' (\$/tonne)
UC_m	unloading cost of citrus at market 'm' (\$/tonne)
UC_r	unloading cost of citrus at retailer 'r' (\$/tonne)
MC	market commission charged per quantity brought to market 'm' from farm 'f' (\$/tonne)
V_{fm}	vehicle capacity that transports citrus from farm 'f' to market 'm' (tonnes)
V_{mr}	vehicle capacity that transports citrus from market 'm' to retailer 'r' (tonnes)
$\tilde{x}_m$	deterioration rate constant at market 'm' where, $0 < x < 1$
$\tilde{t}_m$	deterioration time-period at market 'm'
d_{fm}	distance of travel between farm 'f' and market 'm' (km)
d_{mr}	distance of travel between market 'm' and retailer 'r' (km)
D_{mt}	market demand 'm' at period 't' (tonnes)
D_{rt}	retailer demand 'r' at period 't' (tonnes)
F_{fmr}	transportation cost from farm 'f' to market 'm' and from market 'm' to retailer 'r' (\$/km)
γ_{ft}	quantity of carbon dioxide emission at farm 'f' in period 't' (kg of CO_2/ton)
γ_{mt}	quantity of carbon dioxide emission at market 'm' in period 't' (kg of CO_2/ton)
γ^{t}_{fmr}	quantity of carbon dioxide emission during transportation from farm 'f' to market 'm', to retailer 'r' in period 't' (kg of CO_2/ton)
φ^{t}_{fm}	total carbon emission during transportation of citrus from farm 'f' to market 'm' in period 't' (kg of CO_2/ton)
φ^{t}_{mr}	total carbon emission during transportation of citrus from market 'm' to retailer 'r' in period 't' (kg of CO_2/ton)
J^{t}_{fm}	total transportation cost from farm 'f' to market 'm' in period 't' (\$)
J^{t}_{mr}	total transportation cost from market 'm' to retailer 'r' in period 't' (\$)

T_{fm} loss of fruit during transportation from farm '*f*' to market '*m*' (tonnes)

T_{mr} loss of fruit during transportation from market '*m*' to retailer '*r*' (tonnes)

Decision Variables

q_{ft} post-harvest quantity of citrus at farm '*f*' in period '*t*' (tonnes)

Q^{t}_{fm} quantity of citrus transported from farm '*f*' to market '*m*' in period '*t*' (tonnes)

Q^{t}_{mr} quantity of citrus transported from market '*m*' to retailer '*r*' in period '*t*' (tonnes)

Y^{t}_{mr} $\left\{\begin{matrix} 1 \text{ if retailer 'r' selects market 'm'} \\ 0 \text{ otherwise} \end{matrix}\right\}$

ω_{ft} auxiliary variable for quantity loss of citrus at citrus farm '*f*' in period '*t*' (tonnes)

ω_{mt} auxiliary variable for quantity loss of citrus at market '*m*' in period '*t*' (tonnes)

ω_{rt} auxiliary variable for quantity loss of citrus at retailer '*r*' in period '*t*' (tonnes)

4.1.1 Objective Function 1: Fruit Waste Minimization

The first objective function apprehends the basic goal of research that is the loss of citrus fruits quantity by varied reasons. The goal is to minimize the causes due to which citrus is exposed to losses in terms of quantity as well as quality. Quantity evaluation is a challenging factor to be measured therefore, mathematical equations it is coined as the sum of loss of citrus at citrus farms, at markets, and at retailers, decay due to the short shelf-life, also during transportation to and from market, where the fruit is practically thrown away as low-quality waste that becomes unfit for consumption. It can be presented as objective in eq 1,

$$Min Z_1 = \sum_{f=1}^{F} \omega_{ft} + \sum_{m=1}^{M} \omega_{mt} + \sum_{r=1}^{R} \omega_{rt} \quad (1)$$

In the above equation, ω_{ft} is the auxiliary decision variable that refers to the quantity loss at farms evaluated by taking the difference of quantity produced and the quantity of fruit transported from farms to markets, assuming that there exist no other sales at farm level. Similarly, ω_{mt} refers to the quantity loss at markets that is evaluated using exponential decay function as the fruit is subjected to deterioration and is thrown away as waste. There may also exist other factors that destroy quality of fruit such as inappropriate transportation and packaging etc. Since retailer reaches market with the consumer demand, the difference of fruit brought from markets as demanded and the quantity brought gives quantity loss at retailer ω_{rt} stating to the quantity unpurchased by the customers and leftover at shelf that is finally exposed to fruit waste.

4.1.2 Objective Function 2: Carbon Emission Minimization

Second objective function is concerned with improving green environment and reducing harmful gases in air, especially carbon dioxide, which is now a major growing global concern. The objective function can be written in eq 2 as,

$$Min Z_2 = \sum_{f=1}^{F}\left(\gamma_{ft} \times q_{ft}\right) + \sum_{m=1}^{M}\left(\gamma_{mt} \times Q_{fm}^{t}\right) + \sum_{f=1}^{F}\sum_{m=1}^{M}\varphi_{fm}^{t} + \sum_{m=1}^{M}\sum_{r=1}^{R}\varphi_{mr}^{t} \tag{2}$$

Carbon Emission Minimization comprises the product of carbon dioxide emitted at farms due to post-harvesting activities, spoilage of fruit, use of fertilizers etc. and quantity of fruit harvested on each farm or orchard (FAOSTAT, 2022). The function also includes the carbon emitted at markets due to spoilage of fruit quantities (Bell & Horvath, 2020), carbon emissions during transportation of fruits from farms to markets, as well as from markets to retailers within seasonal time-period (Lin, et al., 2019).

4.1.3 Objective Function 3: Cost Minimization

Third objective function covers all the costs in a supply chain from citrus farm 'f' to the market 'm', and then finally till the retailers' 'r' present in the entire network. The costs added in the function are,

- Farm level costs that include all production costs C_f incurred by growers and loading cost LC_f.
- Transportation cost incurred in supplying citrus from farms to markets J_{fm}^{t}.
- Market level costs such as unloading costs at market UC_f, and market commission costs that is considered along other costs paid at markets MC .
- Transportation cost incurred in supplying citrus from markets to retailers J_{mr}^{t}.

- Retail level costs such as loading cost at markets LC_m, and unloading costs at retailers UC_m.

Therefore, the objective function for Cost Minimization can be written in eq 3 as,

$$Min Z_3 = \sum_{f=1}^{F}\sum_{t=1}^{T}\left[\left(C_f + LC_f\right)\times q_{ft}\right] + \sum_{f=1}^{F}\sum_{m=1}^{M}\sum_{t=1}^{T}\left(J^t_{fm}\right) + \sum_{m=1}^{M}\left[\left(UC_m + MC\right)\times Q^t_{fm}\right] + \sum_{m=1}^{M}\sum_{r=1}^{R}\sum_{t=1}^{T}\left(J^t_{mr}\right) + \sum_{r=1}^{R}\left[\left(LC_m + UC_r\right)\times Q^t_{mr}\right] \quad (3)$$

The details of each of the costs are explained below.

1. Production Cost C_f is the cost incurred against all harvesting and post harvesting activities. These includes costs due to cultivating activities, cost of nursery raising, cost of manure and fertilizers, cost of irrigation, harvesting cost such as land revenues and other taxes, picking and packing costs which is a fixed amount paid to labor per crate.
2. Loading Cost LC_f and LC_m occurs when the fruit is loaded on the vehicle. The need of infrastructure or manpower to handle and load tonnes of citrus is fulfilled by paying significant amount. The amount is paid at farms by contractors and at market by retailers.
3. Unloading Cost UC_f and UC_m occurs when the fruit is unloaded from the vehicle at destination. This amount is paid at markets by market contractors and at retail shops by retailers.
4. Total Transportation Cost J^t_{fm} and J^t_{mr} is incurred along each distance covered for transporting tonnes of citrus from one node of the network to another. These include all fixed transportation costs as well as the variable transportation costs.
5. Market Commission MC is the cost paid by each contractor after reaching the market. It is the fixed cost charged per crate, over tonnes of fruit quantity brought to market along with fixed market entry cost.

4.1.4 Constraints for Modeling

The model includes evaluations and interpretations based on the supply side, demand side, and transportation mechanism involved in a complete supply chain. Constraints are carefully designed to set along with the above-mentioned objective functions. Following are the constraints that follow basic goals of the research along with explanation regarding each.

i. Farm Capacity Constraints

The Citrus Supply chain begins from the agriculture areas where citrus is produced in accordance with the area capacity of production. The produced quantity is less than or equal to the production capacity of a specific farm, represented below as constraint in eq 4. Similarly, the quantity transported from farm 'f' to markets 'm' is less than or equal to the produced quantity as it may be subjected to post-harvest losses (Ahmad, Mehdi, Ghafoor, & Anwar, 2018), as constraint in eq 5.

$$q_{ft} \leq P_f \qquad \forall_f \tag{4}$$

$$\sum_{f=1}^{F}\sum_{m=1}^{M} Q_{fm}^{t} \leq \sum_{f=1}^{F} q_{ft} \qquad \forall_t \tag{5}$$

ii. Transshipment Constraints

The quantity of citrus transported from farms to markets is less than the total capacity produced over a specific farm area and is measured in tonnes, as evident from constraint in eq 5. Similarly, the total quantity of citrus transported to retailers is less than the quantity received by markets mainly due to loss of fruit at market and because of fruit deterioration with time. It can be written in constraint as eq 6.

$$\sum_{r=1}^{R} Q_{mr}^{t} \leq \sum_{f=1}^{F} Q_{fm}^{t} \qquad \forall_f ; \forall_m \tag{6}$$

The storage at market is not conducted practically and is considered as sales duration in which fruit is also subjected to deterioration and is evaluated by exponential decay function, discussed later in this section. After the loaded vehicles of citrus reach markets, auction is conducted for the entire trucks that can be of different loaded quantities. The winner of the auction is responsible for the distribution of fruits among buyers, mostly for bulk purchases. The retailers buy tonnes of citrus quantities that are based on the shelf storage capacity at their retail shops. The other prime factor that affects retailers' bulk buying is the amount of demand laid forward by consumers.

iii. Demand of Citrus

The demand raises according to the consumption trends of end consumers. The received demand is fulfilled by the markets that in turn receive fruit from the citrus farms. In citrus supply chain, it is evident that the basic demand is forecasted by the retailers' which is variable in nature as it depends on price, taste, buying preferences, etc. (Taylor & Andrew , 2006). Variable demand is different from uncertain demand because of its dependence on certain commodity instances that are responsible in stimulating or withdrawing customer buying behavior, while uncertainty depends on the exact true value of the commodity itself and is quantified by using probability (Begg, Bratvold, & Welsh, 2014; Durham & Eales, 2010).

Hence, we can infer that the demand of citrus is initiated by end node of supply chain which extends in the upward direction to the production site, responsible for the fulfillment of overall consumer demand (Sharif, Farooq, & Malik, 2005; Grillo, Alemany, Ortiz, & Fuertes-Miquel, 2017), whereby the demand is immediate and elastic. Citrus fruits are consumed raw, processed, bought by juice production companies to extract juice and pulp, and bought in bulk by other flavor producing industries therefore, assumed to possess greater consumption demand. Since citrus fruit seasonality is the prime study focus, only seasonal time is considered while shaping demand for the model.

The case assumed here is that the market demand combined with retailer demand is less than or equal to the total quantity transported; hence there exists no shortage in the supply chain during early seasonal time but starts increasing later due to greater consumer demands. The quantity that flows from market to retailer is less than the demand brought. A binary variable is introduced alongside demand and supply in constraint in eq 7 that enables the retailer '*r*' to identify and select closest market '*m*' which has the capacity to fulfill maximum consumer demand, called 'Retailer Segmentation'. To meet the unfulfilled demand, retailer visits other markets that may not be the closest serving, increasing the travel distance as well as costs in the supply chain.

$$\sum_{m=1}^{M}\sum_{t=1}^{T} Q^{t}_{mr} \leq \sum_{r=1}^{R} D_{rt} \times Y^{t}_{mr} \qquad \forall_{r} \tag{7}$$

Since the demand that reaches each individual market is the summed quantity of demand received from each of the individual retailer, the total demand received by farms is the summed demand arising from all the markets in a fresh fruit supply chain, which can be coined as constraint in eq 8,

$$\sum_{f=1}^{F}\sum_{t=1}^{T} Q^{t}_{fm} = \sum_{m=1}^{M} D_{mt} \qquad \forall_{r} \tag{8}$$

iv. <u>Transportation Costs</u>

The kind of transportation vehicle used, and the costs incurred have gained enough importance in multiple researches whether the product under focus is perishable fresh item or heavy weather resistant material. The transportation costs are generally found to rise alongside delicate product supply and are hence higher for perishable items (Yu, Wang, & Liang, 2011;

Castro, Coronado, & Lozano, 2017). The delays and unforeseen events also cause increase in total cost structure due to spoilage of perishables (Musavi & Amiri, 2017). constraints in eq 9 and in eq 10 depict total transportation costs incurred in a complete citrus supply chain.

$$J^{t}_{fm} = \left[\left(F_{fmr} \times d_{fm} \right) \times \frac{Q^{t}_{fm}}{V_{fm}} \right] \qquad \forall_{m} \tag{9}$$

$$J^{t}_{mr} = \left[\left(F_{fmr} \times d_{mr} \right) \times \frac{Q^{t}_{mr}}{V_{mr}} \right] \qquad \forall_{f} \tag{10}$$

Total Transportation Cost includes all the fixed costs and variable costs that projects during transportation and are pre-decided with contractor. The costs are calculated in accordance with the distance covered by each vehicle required to pick and transport complete quantity of citrus from the area of production to markets and further from markets to retailers.

v. Carbon Emission Constraints

Carbon Emissions have gained enough importance in many researches, aiming at optimizing different supply chains (Bortolini, Faccio, Gamberi, & Pilati, 2016; Kumar, et al., 2017), improving environment by converting biomass to biofuel (Ahmed & Sarkar, Impact of carbon emissions in a sustainable supply chain management for a second generation biofuel, 2018), and enhancing sustainability (Validi, Bhattacharya, & Byrne, 2014; Musavi & Amiri, 2017). The carbon's emitted by vehicles during transportation of citrus quantities from farms to markets is coined as constraint in eq 11, and that by vehicles during transportation of citrus quantities from markets to retailers is shown as constraint in eq 12.

$$\varphi^{t}_{fm} \le \sum_{f=1}^{F} \sum_{m=1}^{M} \left[\left(\frac{Q^{t}_{fm}}{V_{fm}} \times d_{fm} \right) \times \gamma^{t}_{fmr} \right] \qquad \forall_{r} ; \forall_{t} \tag{11}$$

$$\varphi^{t}_{mr} \le \sum_{m=1}^{M} \sum_{r=1}^{R} \left[\left(\frac{Q^{t}_{mr}}{V_{mr}} \times d_{mr} \right) \times \gamma^{t}_{fmr} \right] \qquad \forall_{f} ; \forall_{t} \tag{12}$$

The total carbon dioxide emission in the above constraint can be evaluated by calculating total number of trips required to transport complete quantities of citrus from one node of the chain to another, along with the product of amount of carbon emitted during per km transportation of fruits. The constraint allows calculation of total carbon emitted in the supply network while also highlighting the direction of optimizing distance covered by the vehicle.

vi. Quantity Loss of fruit

The loss of fruit occurs due to varied reasons such as post-harvest damages, inappropriate handling, theft issues, and unexpected accidents, but also due to quality deteriorating attributes such as disease, and damage because of weather conditions or because of pressure during long route travels etc. The quantity of citrus lost at farm can be evaluated by considering random variable for uniform distribution for marketable surplus – the quantity available at farm for transportation, usually in the form of pickings, and the citrus quantity packed and sent to market. It can be formulated as constraint in eq 13.

$$\omega_{ft} \leq \alpha_f \times q_{ft} + \alpha_f \times \sum_{f=1}^{F}\sum_{t=1}^{T}\left(Q_{fm}^{t}\right) \qquad \forall_m;\forall_t \tag{13}$$

According to Ahmad, Mehdi, Ghafoor, & Anwar, 2018, post-harvest losses for the case of kinnow in Pakistan are about 20-40%. The loss of citrus at markets can be evaluated by taking the rate of decay at which the fruit is subjected to loss with passing time-period at market as deteriorated unpurchased quantity at shelves.

$$\omega_{mt} \leq \alpha_m \times \left[\frac{\left(Q_{fm}^{t}\right)}{\tilde{x}_m \cdot \dfrac{\tilde{t}_m}{T}}\right] + T_{fm} \qquad \forall_f;\forall_r \tag{14}$$

The loss of fruit due to decay is expressed by exponential decay function where fruit deteriorates by rate constant $\tilde{x}$ (Yang, et al., 2020; Singh & Singh, 2011), during random time period $\tilde{t}$ divided over total time period T in constraint in eq 14. *a* in eq 13-15 is the variable for uniform distribution of quantity. The value of *a* is analyzed data following uniform distribution and an expected value is used to tackle variable fruit demand. The difference of quantity at market and the quantity transported to retailer or bought by retailer caters the loss of fruit at market, including the loss due to decay over time-period and random variable for uniform distribution. Similarly, for the case of fruit waste at retailer, fruit is subjected to loss every time it is stored or displayed over shelves and the quantity of fruit left at the end of the time-period unpurchased by customers is taken as loss at retailer, as shown in constraint in eq 15.

$$\omega_{rt} = \left[\left(D_{rt} \times Y_{mr}^{t}\right) - \alpha_r \times \sum_{r=1}^{R}\sum_{t=1}^{T} Q_{mr}^{t}\right] + T_{mr} \qquad \forall_m;\forall_l \tag{15}$$

4.2 Case II: Processed/Branded Citrus Supply Chain

For case II, following model as shown in Figure 4.3, is created that consists of four levels of chain: Citrus Farms, Processing Plants, Markets, and Retailers, discussing the value chain of fruits with branded citrus supply to markets and then to retailers. To address the challenges in value added/ branded citrus supply chain in Pakistan, this research includes the development of mathematical model on the bases of following assumptions,

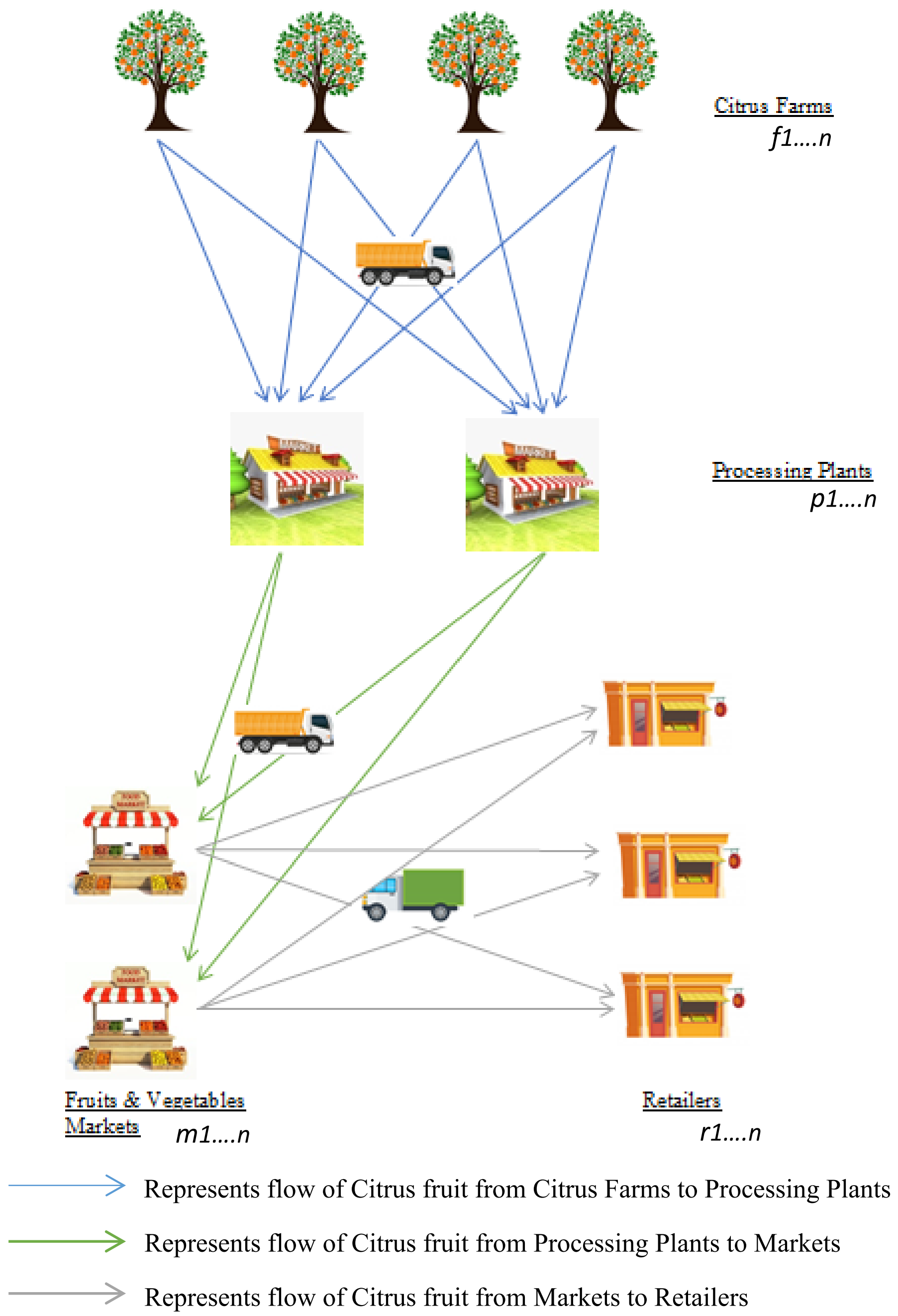

Figure 4.2. Processed citrus supply chain model

- Capacity of citrus fruit grown at each farm is known in tonnes.
- Number of citrus farms, processing plants, and fruit/vegetable markets are known, while number of retailers may vary.
- Retailers' buying quantity is directly proportional to demand/ consumption patterns. Contractors are involved in the purchase of entire citrus quantity from farms, in form of one or more pickings.
- Packing in wooden crates as well as the logistic services are done by contractors from farms to plants and then to markets are also provided by them, given the fluctuation of commercial and fuel rates.
- The multi-period time span considered in accordance with variable seasonal demand arising from retailers as consumer demand, is over three months i.e., November, December and January.

Case II is also formulated to follow the mathematical modeling to reach the goal of minimizing fruit waste and take measures in reducing the quantity wasted each season by improving quality and adding value via processing activities of processing plants, saving fruits from further damage as well as assisting chain partners in adjusting unnecessary efforts. Carbon Emission Minimization, and finally minimizing costs that incur along the supply chain extending from the supply of fruit from farms till the fulfillment of consumer demand while enhancing overall economic share and social responsibility.

The mathematical formulae are presented below along with an overview of constraints, parameters and decision variables that are worked on to optimize the value-added supply chain of citrus fruit.

Notations

Sets:

f	citrus farms	$f = 1,2,3,\ldots.F$
p	processing plants	$p = 1,2,3,\ldots.P$
m	fruit and vegetable markets	$m = 1,2,3,\ldots.M$
r	retailers	$r = 1,2,3,\ldots.R$
t	time-period	$t = 1,2,3,....T$

Parameters:

P_f	production capacity of citrus fruit at farms 'f' (tonnes)
C_f	production cost of citrus fruit at farms 'f' (\$/tonne)

LC_f	loading cost of citrus at farms '*f*' ($/tonne)
LC_p	loading cost of citrus at plant '*p'* ($/tonne)
LC_m	loading cost of citrus at market '*m*' ($/tonne)
PC_p	packaging cost at plant '*p*' ($/tonne)
UC_p	unloading cost of citrus at plant '*p*' ($/tonne)
UC_m	unloading cost of citrus at market '*m*' ($/tonne)
UC_r	unloading cost of citrus at retailer '*r*' ($/tonne)
G_p	cost of processing at plant '*p*' ($/tonne)
MC	market commission charged per quantity brought to market '*m*' from plant '*p*' ($/tonne)
V_{fp}	vehicle capacity that transports citrus from farm '*f*' to plants '*p*' (tonnes)
V_{pm}	vehicle capacity that transports citrus from plants '*p*' to market '*m*' (tonnes)
V_{mr}	vehicle capacity that transports citrus from market '*m*' to retailer '*r*' (tonnes)
$\tilde{x}_p$	deterioration rate constant at plants '*p*' where, $0< x<1$
$\tilde{x}_m$	deterioration rate constant at market '*m*' where, $0< x<1$
$\tilde{t}_p$	deterioration time-period at plants '*p*'
$\tilde{t}_m$	deterioration time-period at market '*m*'
d_{fp}	distance of travel between farm '*f*' and plants '*p*' (km)
d_{pm}	distance of travel between plants '*p*' and market '*m*' (km)
d_{mr}	distance of travel between market '*m*' and retailer '*r*' (km)
D_{pt}	processing plant demand '*p*' at period '*t*' (tonnes)
D_{mt}	market demand '*m*' at period '*t*' (tonnes)
D_{rt}	retailer demand '*r*' at period '*t*' (tonnes)
F_{fpmr}	transportation cost from farm '*f*' to plants '*p*', to market '*m*' and from market '*m*' to retailer '*r*' ($/km)
γ_{ft}	quantity of carbon dioxide emission at farm '*f*' in period '*t*' (kg of co_2/ton)
γ_{pt}	quantity of carbon dioxide emission at market '*m*' in period '*t*' (kg of co_2/ton)
γ_{mt}	quantity of carbon dioxide emission at plants '*p*' in period '*t*' (kg of co_2/ton)
γ^{t}_{fpmr}	quantity of carbon dioxide emission during transportation from farm '*f*' to market '*m*', to plants '*p*', and to retailer '*r*' in period '*t*' (kg of co_2/ton)
φ^{t}_{fp}	total carbon emission during transportation of citrus from farm '*f*' to plants '*p*' in period '*t*' (kg of co_2/ton)

φ^{t}_{pm}	total carbon emission during transportation of citrus from plants '*p*' to market '*m*' in period '*t*' (kg of co_2/ton)
φ^{t}_{mr}	total carbon emission during transportation of citrus from market '*m*' to retailer '*r*' in period '*t*' (kg of co_2/ton)
J^{t}_{fp}	total transportation cost from farm '*f*' to plants '*p*' in period '*t*' ($)
J^{t}_{pm}	total transportation cost from plants '*p*' to market '*m*' in period '*t*' ($)
J^{t}_{mr}	total transportation cost from market '*m*' to retailer '*r*' in period '*t*' ($)
T_{fp}	loss of fruit during transportation from farm '*f*' to plants '*p*' (tonnes)
T_{pm}	loss of fruit during transportation from plants '*p*' to market '*m*' (tonnes)
T_{mr}	loss of fruit during transportation from market '*m*' to retailer '*r*' (tonnes)

Decision Variables:

q_{ft}	post-harvest quantity of citrus at farm '*f*' in period '*t*' (tonnes)
Q^{t}_{fp}	quantity of citrus transported from farm '*f*' to processing plant '*p*' in period '*t*' (tonnes)
Q^{t}_{pm}	quantity of citrus transported from processing plant '*p*' to market '*m*' in period '*t*' (tonnes)
Q^{t}_{mr}	quantity of citrus transported from market '*m*' to retailer '*r*' in period '*t*' (tonnes)
Y^{t}_{mr}	$\begin{Bmatrix} \text{1 if retailer 'r' selects market 'm'} \\ \text{0 otherwise} \end{Bmatrix}$
ω_{ft}	auxiliary variable for quantity loss of citrus at citrus farm '*f*' in period '*t*' (tonnes)
ω_{pt}	auxiliary variable for quantity loss of citrus at processing plant '*p*' in period '*t*' (tonnes)
ω_{mt}	auxiliary variable for quantity loss of citrus at market '*m*' in period '*t*' (tonnes)
ω_{rt}	auxiliary variable for quantity loss of citrus at retailer '*r*' in period '*t*' (tonnes)

4.2.1 Objective Function 1: Fruit Waste Minimization

The first objective function evaluates the basic goal of research that is the loss of citrus fruits quantity by varied reasons such as decay due to the short shelf life, during transportation etc. where the fruit is practically thrown away as low-quality waste that becomes unfit for consumption. The goal is to minimize the causes due to which citrus is exposed to losses therefore it is coined as the sum of loss of citrus at citrus farms, at processing plants, at markets, and at retailers. It can be presented as objective in eq 1,

$$Min Z_1 = \sum_{f=1}^{F} \omega_{ft} + \sum_{p=1}^{P} \omega_{pt} + \sum_{m=1}^{M} \omega_{mt} + \sum_{r=1}^{R} \omega_{rt} \tag{1}$$

In the above equation, ω_{ft} is the auxiliary variable and refers to the quantity loss at farms evaluated by taking the difference of quantity produced and the quantity of fruit transported from farms to markets, assuming that there exist no other sales at farm level. Similarly, ω_{pt} is the quantity loss at plants due to varied reasons such as inappropriate handling and decay of un-waxed fruit etc., calculated by considering the difference of received and transported quantities of fruit, assuming no extra sales over plants. ω_{mt} refers to the quantity loss at markets that is evaluated using exponential decay function as the fruit is subjected to deterioration and is thrown away as waste. There may also exist other factors that destroy quality of fruit such as inappropriate transportation and packaging etc. Since retailer reaches market with the consumer demand, the difference of fruit brought from markets as demanded and the quantity brought gives quantity loss at retailer ω_{rt}, stating to the quantity unpurchased by the customers and leftover at shelf that is finally exposed to fruit waste.

4.2.2 Objective Function 2: Carbon Emission Minimization

Second objective function evaluates carbon emission minimization to supply citrus starting from one node of chain to the other in accordance with the carbon emitted by vehicle carrying citrus quantities to all the levels of the model. The function can be written as objective in eq 2, where carbon is emitted at farms due to post-harvest activities, fertilizers, deforestation etc., at plants during processing activities (Iriarte, et. al, 2021), and at markets due to spoilage of fruits is also considered alongside carbon emission during transporting citrus quantities from farm to plants, from plants to markets and from markets to retailers.

$$\begin{aligned} Min Z_2 = {} & \sum_{f=1}^{F} \left(\gamma_{ft} \times q_{ft} \right) + \sum_{p=1}^{P} \left(\gamma_{pt} \times Q^{t}_{fp} \right) + \sum_{m=1}^{M} \left(\gamma_{mt} \times Q^{t}_{pm} \right) + \\ & \sum_{f=1}^{F} \sum_{p=1}^{P} \varphi^{t}_{fp} + \sum_{p=1}^{P} \sum_{m=1}^{M} \varphi^{t}_{pm} + \sum_{m=1}^{M} \sum_{r=1}^{R} \varphi^{t}_{mr} \end{aligned} \tag{2}$$

4.2.3 Objective Function 3: Cost Minimization

Third objective function is about optimizing excessive costs in a supply chain from citrus farm 'f' to processing plant 'p', from plant to the markets' 'm', and then finally till the retailers' 'r' present in the entire network. Therefore, the objective function for Cost Minimization can be written as objective in eq 3,

$$Min Z_3 = \sum_{f=1}^{F}\sum_{t=1}^{T}\left[\left(C_f + LC_f\right)\times q_{ft}\right] + \sum_{f=1}^{F}\sum_{p=1}^{P}\sum_{t=1}^{T}\left(J^t_{fp}\right) + \sum_{p=1}^{P}\left[\left(UC_p + G_p + PC_p + LC_p\right)\times Q^t_{fp}\right] + \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{t=1}^{T}\left(J^t_{pm}\right) + \sum_{m=1}^{M}\left[\left(UC_m + MC\right)\times Q^t_{pm}\right] + \sum_{m=1}^{M}\sum_{r=1}^{R}\sum_{t=1}^{T}\left(J^t_{mr}\right) + \sum_{r=1}^{R}\left[\left(LC_m + UC_r\right)\times Q^t_{mr}\right] \tag{3}$$

The details of each of the costs are explained earlier in case I, except for the costs that incur at processing plant which includes,

1) Unloading cost UC_p paid to labor for unloading tonnes of citrus at processing plant.
2) Processing cost G_p where activities include sorting of citrus fruit, washing, waxing, and temporarily storing at cold storage that requires temperature of 4°C.
3) Picking and packing cost PC_p incurs at grading the processed fruits in sizes and qualities, and finally packing in wooden crates for supply to markets.
4) Loading Cost LC_p incurred at loading crates of processed fruit in trucks for transportation towards markets.

4.2.4 Constraints for Modeling

Constraints are designed in accordance with the model including supply and demand across all four nodes of the chain, to set along with the above-mentioned objective functions. Following are the constraints to mathematical modeling.

i. Farm Capacity Constraints

As evident, the citrus supply chain begins from the farms where citrus is produced conferring with the farm capacity of production, represented below as constraint in eq 4, while the quantity transported to processing plant is less than or equal to the quantity of fruit produced as it has the omission of wasted fruit quantity due to post harvest losses at farms, as written in constraint in eq 5.

$$q_{ft} \le P_f \qquad \forall_f \tag{4}$$

$$\sum_{f=1}^{F}\sum_{p=1}^{P} Q^t_{fp} \le \sum_{f=1}^{F} q_{ft} \qquad \forall_t \tag{5}$$

ii. Transshipment Constraints

The processing factories are designed in such a way that it processes fruits for three categories at the same time such as for export, for national supply, and for juice and flavoring companies. The constraint in eq 5 represents the quantity flow towards plants that is less than or equal to the produced quantity at farms. The quantity transported from plants to markets is less than or equal to the quantity transported from farms, due to loss of fruit during transportation, during processing, grading/ packing, and because of sales of fruit to other buyers outside markets, represented in constraint in eq 6.

Similarly, the quantity that travels from markets to retailers is less than or equal to the received quantity by markets due to varied quantity losses, represented in constraint in eq 7.

$$\sum_{p=1}^{P} Q_{pm}^{t} \leq \sum_{f=1}^{F} Q_{fp}^{t} \qquad \forall_f ; \forall_t \qquad (6)$$

$$\sum_{m=1}^{M} Q_{mr}^{t} \leq \sum_{p=1}^{P} Q_{pm}^{t} \qquad \forall_p ; \forall_t \qquad (7)$$

iii. Demand of Citrus

The case assumed here is that the market demand combined with retailer demand is less than the quantity transported, primarily due to increased processed consumption demand (USDA, 2021); hence there exists shortage in the supply chain. The quantity that flows from market to retailer is less than or equal to the demand brought. Binary variable introduced alongside demand and supply in constraint in eq 8 enables the retailer '*r*' to identify and select market 'm' which has the capacity to fulfill maximum consumer demand, called 'Retailer Segmentation'.

$$\sum_{m=1}^{M} \sum_{r=1}^{R} Q_{mr}^{t} \leq \sum_{r=1}^{R} D_{rt} \times Y_{mr}^{t} \qquad \forall_t \qquad (8)$$

Summed demand received by markets is less than or equal to the quantity received by markets from plants, as represented below in constraint in eq 9, while summed demand collected from markets and received by processing plants for value added citrus is formulated in constraint in eq 10.

$$\sum_{p=1}^{P}\sum_{m=1}^{M} Q^{t}_{pm} \leq \sum_{m=1}^{M} D_{mt} \qquad \forall_t \qquad (9)$$

$$\sum_{f=1}^{F}\sum_{p=1}^{P} Q^{t}_{fp} \leq \sum_{p=1}^{P} D_{pt} \qquad \forall_t \qquad (10)$$

iv. Transportation Costs

The transportation costs along the supply chain are generally found higher for perishable items (Yu, Wang, & Liang, 2011; Castro, Coronado, & Lozano, 2017). Constraints in eq 11-13 represent total transportation for the network in case II as,

$$J^{t}_{fp} = \left[\left(F_{fpmr} \times d_{fp} \right) \times \frac{Q^{t}_{fp}}{V_{fp}} \right] \qquad \forall_m ; \forall_r \qquad (11)$$

$$J^{t}_{pm} = \left[\left(F_{fpmr} \times d_{pm} \right) \times \frac{Q^{t}_{pm}}{V_{pm}} \right] \qquad \forall_f ; \forall_r \qquad (12)$$

$$J^{t}_{mr} = \left[\left(F_{fpmr} \times d_{mr} \right) \times \frac{Q^{t}_{mr}}{V_{mr}} \right] \qquad \forall_f ; \forall_p \qquad (13)$$

Total Transportation Cost includes all the fixed costs and variable costs and is calculated in accordance with the distance covered by each vehicle in a route required to pick and transport complete quantity of citrus from the area of production to processing plant, from plant to markets and further from markets to retailers.

v. Carbon Emission Constraints

The carbon dioxide emission can be calculated by taking number of trips required to transport citrus quantities to all levels of supply network, along with carbon emitted by vehicle in transporting citrus quantities. It can be formulated as constraints in eq 14-16 as,

$$\varphi^{t}_{fp} \leq \sum_{f=1}^{F}\sum_{p=1}^{P} \left[\left(\frac{Q^{t}_{fp}}{V_{fp}} \times d_{fp} \right) \times \gamma^{t}_{fpmr} \right] \qquad \forall_m ; \forall_t \qquad (14)$$

$$\varphi^{t}_{pm} \leq \sum_{p=1}^{P}\sum_{m=1}^{M} \left[\left(\frac{Q^{t}_{pm}}{V_{pm}} \times d_{pm} \right) \times \gamma^{t}_{fpmr} \right] \qquad \forall_f ; \forall_t \qquad (15)$$

$$\varphi_{mr}^{t} \leq \sum_{m=1}^{M}\sum_{r=1}^{R}\left[\left(\frac{Q_{mr}^{t}}{V_{mr}} \times d_{mr}\right) \times \gamma_{fpmr}^{t}\right] \qquad \forall_p ; \forall_t \tag{16}$$

vi. <u>Quantity Loss of fruit</u>

The loss of fruit occurs due to varied reasons such as post-harvest damages, inappropriate handling, theft issues, and unexpected accidents, but also due to quality deteriorating attributes such as disease, and damage because of weather conditions or because of pressure during long route travels etc. The quantity of citrus lost at farm can be evaluated by using constraint in eq 17 while quantity of citrus lost at processing plant as constraint in eq 18.

$$\omega_{ft} \leq \alpha_f \times q_{ft} + \alpha_f \times \sum_{f=1}^{F}\sum_{t=1}^{T}\left(Q_{fp}^{t}\right) \qquad \forall_p ; \forall_t \tag{17}$$

$$\omega_{pt} \leq \alpha_p \times \left[\frac{Q_{fp}^{t}}{\tilde{x}_p \cdot \frac{\tilde{t}_p}{T}}\right] + T_{fp} \qquad \forall_m ; \forall_t \tag{18}$$

Since the shelf life of fruit is unaffected in plant due to washing and waxing activities and due to cold storages, yet fruit deterioration function is deployed at plants for delays and for fruit at storage before subjected to waxing. Similarly, for deterioration at markets and loss evaluation is shown as constraint in eq 19.

$$\omega_{mt} \leq \alpha_m \times \left[\frac{Q_{pm}^{t}}{\tilde{x}_m \cdot \frac{\tilde{t}_m}{T}}\right] + T_{pm} \qquad \forall_p ; \forall_t \tag{19}$$

Fruit waste at retailer is subjected to loss every time it is stored or displayed over shelves and the quantity of fruit left at the end of the time-period unpurchased by customers is taken as loss at retailer, as shown in constraint in eq 20.

$$\omega_{rt} = \left[\left(D_{rt} \times Y_{mr}^{t}\right) - \alpha_r \times \sum_{r=1}^{R}\sum_{t=1}^{T} Q_{mr}^{t}\right] + T_{mr} \qquad \forall_f ; \forall_p \tag{20}$$

The mathematical model developed with its constraints and objective functions are analyzed and optimized by "Augmented Epsilon Constraint Method" using "Lexicographic Optimization", as discussed in the next section 5.

CHAPTER 5: Solution Methodology

Methodology comprises of an organized series of methods that validates the way in which research is carried out. Following are the illustrated five steps of methodology for the present research.

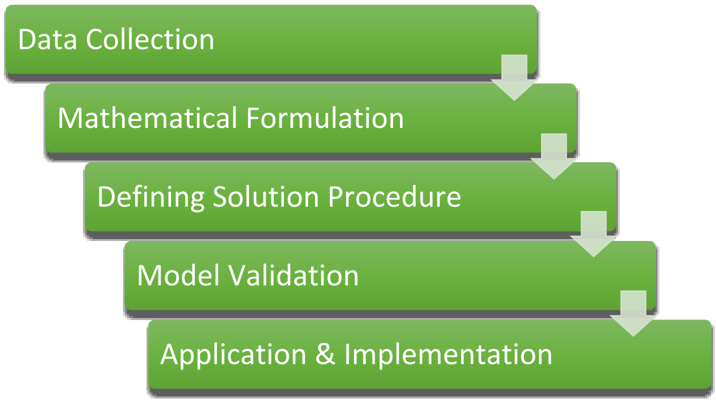

Figure 5.1. Organized methodology steps

The proposed mathematical model is tested and validated with significant optimization method and results drawn according to collected data. Application of the results are discussed, and implementation are suggested in the end as the last step. The solution method selected for solving mathematical problem is the generations method, that makes use of computational software "Augmented Epsilon Constraint Method". All feasible solutions are arranged in payoff table that gives a whole picture of possible pareto optimal solutions and enables the decision maker to select the best preferred solution which supports desired optimization to research problem.

5.1 Augmented Epsilon Constraint Method with Lexicographic Optimization

The methodology used is "Augmented Epsilon Constraint Method with Lexicographic Optimization". Augmented epsilon constraint method is an effective method for multi-objective mathematical programming since it provides greater pareto optimal solution and also conveys more information to the decision makers by which they can make effective decisions (Mavrotas, 2009). This method is chosen because of its ability to transform multi-objective approach into single objective by considering one of the objective functions as the main objective of research while other objectives as constraints to the main one. It is an efficient and satisfactory solution method because it evades the redundant iterations that may lead solution to infeasibility and is being widely applied over multi-objective research areas such as engineering, agriculture, resource industries, and economics etc.

Areas of study that have successfully used lexicographic augmented epsilon constraint method are mostly related to energy resources, while location-routing problems in the case of manufactured perishables products have reached best optimal solution. Such as,

- Both voltage and dynamic security aspects of electricity power systems (Aghaei, Amjady, & Shayanfar, 2011), and effective decision-making frameworks in energy markets for electricity retailer (Nezhad, Ahmadi, Javadi, & Janghorbani, 2015) are devised into multi-objective research, deploying augmented epsilon constraint method with lexicographic optimization.
- Heat and power scheduling over short term multi-objective framework where the system is optimized using the same method and the objectives are directed towards economic and environmental aspects (Ahmadi, Ahmadi, & Nezhad, 2014), while same is applied in the multi-objective optimization case of hydrothermal generation (Nezhad, Javadi, & Rahimi, 2014).
- Reverse osmosis network for seawater desalination. Modeling comprises of introduction of three energy recovery device options and is solved via augmented epsilon constraint method with lexicographic optimization and fuzzy decision-making techniques (Du , et al., 2014).
- Augmented epsilon constraint is used along "NSGA-II" for performance comparison in the location-routing research of bi-objective distribution of perishable products (Khalili-Damghani, Abtahi, & Ghasemi, 2015). It is used to study closed-loop supply chains alongside transportation routing problem in order to maximize the quality of product returns (Masoudipour, Jafari, Amirian, & Sahraeian, 2019) and for hazardous waste routing problem with the objectives of cost and risk minimization (Yu & Solvang, 2016). Similarly, supply chain sustainability management in paper industry is also studied with augmented epsilon constraint method (Vafaeenezhada, Tavakkoli-Moghaddam, & Cheikhrouhou, 2019).
- To assist production planning managers, staff scheduling problem is solved through augmented epsilon constraint method to maximize work performance of employees (Sadjadi , Heidari, & Esboei, 2014).

"Augmented Epsilon Constraint Method with Lexicographic Optimization" for the Agri-fresh perishables, specifically in the case of citrus supply chain, perhaps gives the research study its unique contextual contribution. Since the mathematical model formulated has many variables along with related data input values, therefore such complex model is solved using computer aided tools.

5.2 Payoff Table

In the presence of different possible outcomes and objectives, payoff table is a useful way of representing research objectives as well as analyzing them with the most effective approach. The payoff table created by using "Lexicographic Optimization Method" simply represents number of objectives on the left side that are to be solved as solution for mathematical problems, while research category or area focusing target objective is mentioned at the top of the table. Lexicographic method is a type of elementary method for solving multi-attribute decision making problems. The attributes or the categories designed for study are ranked according to their significance on research conducted. The mathematical modeling for presently designed supply chain research has three main objectives, research problems ***(P)***. This can be demonstrated as constraints in eq 21-23,

$$Min Z_1 = x_1 \tag{21}$$

$$Min Z_2 = x_2 \tag{22}$$

$$Min Z_3 = x_3 \tag{23}$$

Converting these research problems to "Augmented ε-Constraint" method as constraint in eq 24-26,

$$Z_1 = Min\, f_1(x_1) \tag{24}$$

$$Z_2 = Min\, f_2(x_2) \tag{25}$$

$$Z_3 = Min\, f_3(x_3) \tag{26}$$

The first objective is Fruit Waste Minimization, second objective is Carbon Emission Minimization, and the third is of Cost Minimization. Transforming the research problem ***(P)*** to problem ***(P`)***, to get ε-Constraint equivalents ε_1 and ε_2, the above is shown in eq 27,

$$\begin{aligned} & Z_1 = Min\, f_1(x) \\ & \text{s.t.} \\ & \quad f_2(x) \le \varepsilon_1 \\ & \quad f_3(x) \le \varepsilon_2 \\ & \quad \vdots \\ & \quad \text{\& other constraints} \end{aligned} \tag{27}$$

Surplus and slacks has a very small value that is almost close to zero. According to literature and past practices, the value ranges between 10^{-3} and 10^{-6} (Mavrotas, 2009). The payoff table according to set priorities for research study is represented below.

Table 5.1

Payoff table for lexicographic method, citrus supply chain (Ahmed & Sarkar, 2019)

Optimization Problems	**Objective Function values for**		
	Fruit Waste	Carbon Emission	Cost
Problem 1	**Min = FW** s.t. (all constraints) **Calculate:** (a, b, c) f_1^1 = FW (a, b, c)	f_2^1 = CE (a, b, c)	f_3^1 = C (a, b, c)
Problem 2	f_1^2 = FW (a*, b*, c*)	**Min = CE** s.t. (all constraints) FW = $f_1^1 + \delta_1$ **Calculate:** (a*, b*, c*) f_2^2 = CE (a*, b*, c*)	f_3^2 = C (a*, b*, c*)
Problem 3	f_1^3 = FW (a`, b`, c`)	f_2^3 = CE (a`, b`, c`)	**Min = C** s.t. (all constraints) FW = $f_1^2 + \delta_1$ CE = $f_2^2 + \delta_2$ **Calculate:** (a`, b`, c`) $f_3^3$ = C (a`, b`, c`)

5.3 Solution Algorithm and Flow Chart

A step-by-step flow chart for the solution of research objectives by augmented epsilon constraint method is represented below as Figure 5.2. "Augmented Epsilon Constraint Method" is marked for it effective results because it changes the feasible solution while being able to produce results in the direction of non-extreme efficient solution which is never possible with other methods such as weighted sum method and goal programming method etc., where scaling is not possible for optimization solutions. The flow chart begins with designing mathematical model and constructing objectives for the study. The objective functions are prioritized and evaluated in payoff table, as discussed above, according to lexicographic method. The research problem is then transformed by using augmented epsilon method where delta epsilon values are also evaluated. The iteration counters enable identifying feasible solution as optimal solution for the research problem.

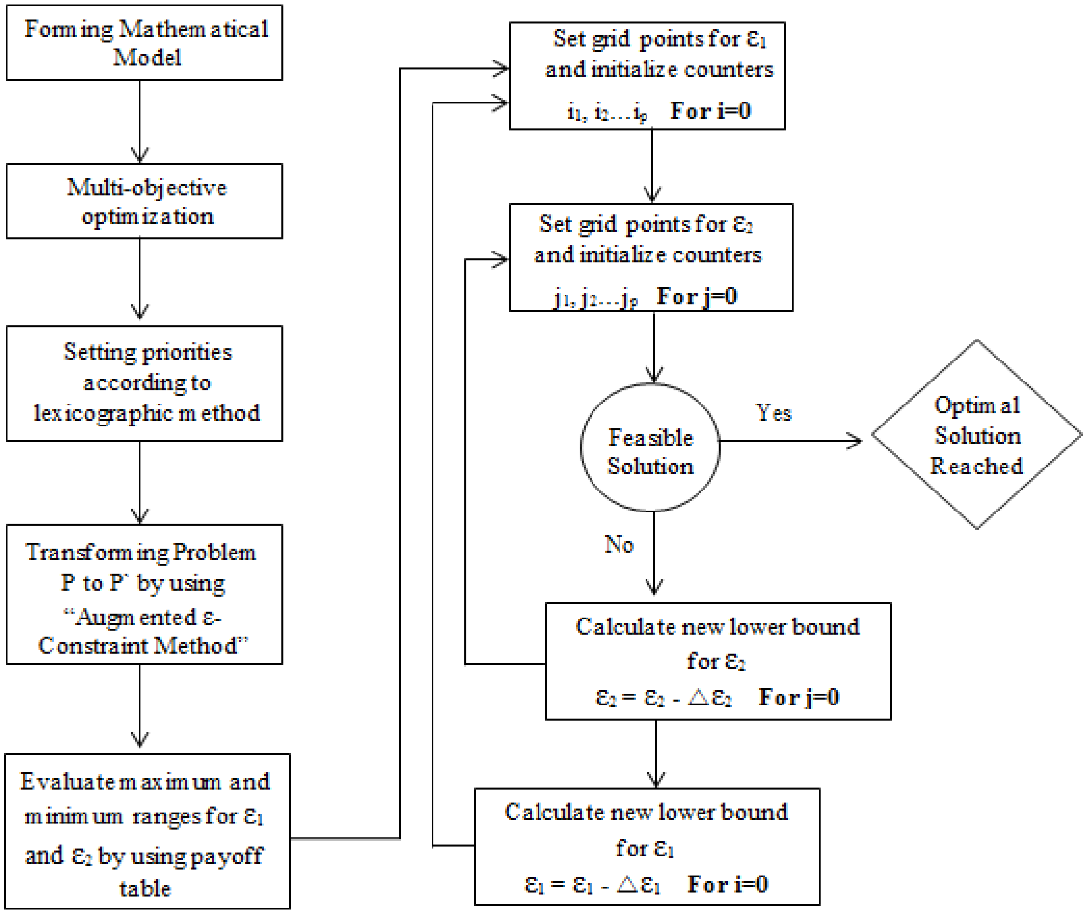

Fig 5.2 Flow chart of augmented epsilon constraint method solution algorithm (Ahmadi, Ahmadi, & Nezhad, 2014; Aghaei, Amjady, & Shayanfar, 2011)

CHAPTER 6: Results and Discussion

The optimization of mathematical model for this research is approached by using MATLAB, which is software over which the model variables, constraints and functions are constructed as well as each of their values are coded or linked from MS EXCEL sheets to achieve an optimized solution to analyze and interpret the model according to attained results. The above proposed augmented epsilon constraint method with lexicographic optimization is highly attuned with MATLAB, following efficient feasible solution with approximately zero coding errors.

When using generations method for optimization, there are large number of constraints and greater number of variables are often difficult to solve and require computer aided tools to find an optimized solution to the problem. MATLAB on the other hand excels in solving mathematical problems with efficiency and reduced programming errors. Writing codes, inserting values against each notation, running and finally analysis of the results is made easy for the user that can be done quickly, enabling several iterations in the matter of seconds. Several researchers have used the software as an optimization tool for solving complex multi-objective mathematical modeling problems. Therefore, due to its network optimization excellence, it is also used for the multi-objective and multi-period optimization of citrus supply chains.

6.1 Data Collection

The data has been carefully selected from all the stakeholders of the chains in accordance with availability and from latest publications. The city Sargodha from Punjab, Pakistan is picked for farm supply because of being the prime citrus growing area. The data of production capacity, cost of production, prices, etc. are all gathered from "Agriculture Marketing Information Service (AMIS, 2021), Punjab, Pakistan" and from "Crop Reporting Service (CRS, 2020), Punjab, Pakistan", as shown of Table A1 in Appendix. Since the study extends across the province, three large markets are selected from Punjab, located in cities Sargodha, Faisalabad, and Islamabad, while market statistics are collected from market functionaries and evaluated using average values. Similarly, processing plants are selected from Punjab and information such as detailed processing activities and their related costs are collected, as shown in Table A2 of Appendix.

Retailers are also selected from various locations in Punjab at random bases and retailing information including cost structures, demand, and probable unsold citrus quantities by the end of seasonal time from individual retailers is collected. Additionally, the contractors are approached via framers' contacts for related data information vital for research. Different travelling distances for traditional citrus supply chain are sourced from GOOGLE EARTH application are shown in Table A3 and Table A4 of Appendix, and for processed citrus supply chain are shown in Table A5 and Table A6 of Appendix. The kind of vehicle considered transporting tonnes of fruit from farm to markets, then from market to retailer in the form of bulk is a rigid road truck with fuel consumption of 3.0 liters per km (Sahin, et. al, 2009). Since road trucks' engine run on diesel, therefore, consume high-speed diesel that is currently Rs. 110.24 per liter (SHELL, 2021), while becomes \$0.63 (\$/km) as per international currency (XE Currency Converter, 2021), as shown in Table A7, Table A8, Table A9 and Table A10 of Appendix.

6.2 Optimization Results for Case – I

Payoff table is created according to the flow chart of lexicographic optimization as shown in Figure 5.2. The results obtained are tabulated in the payoff table according to the set priorities. Objectives of the research are selected according to the importance and preference of each in the research. Waste is the prime issue in prevailing perishable supply chain therefore, Fruit Waste Minimization is selected as the first objective to be solved Carbon Emission Minimization being the second objective and Cost Minimization as the third objective for the study. Table 6.1 shows the pareto optimal alternatives for traditional citrus supply chain with non-branded citrus products. The Epsilon values are further evaluated by using and following the flow chart of 'Augmented Epsilon Constraint Method' solution algorithm, according to which minimum and maximum ranges of epsilon and delta epsilon values are calculated (as in Table A11 of appendix), followed by iterations that make it possible for the researcher to find an optimal solution for the research study.

Table 6.1

Payoff table with pareto optimal alternatives (non-branded)

	Waste Minimization	Carbon Emission Minimization	Cost Minimization
Problem 1	405	2,540.9	4,942,668
Problem 2	390	2,468.9	4,939,845
Problem 3	396	2,474.9	4,933,267

6.3 Optimization Results for Case – II

Similarly, another payoff table is created for the optimal values obtained from the results of case-II i.e., processed citrus supply chain with branded citrus products, according to the flow chart of lexicographic optimization as shown in Figure 5.2. The objectives are also selected on the bases of proposed priorities and are evaluated on the bases of assigned weights to the alternative optimal values as entered in the payoff table shown below as Table 6.2. Minimum and maximum ranges of epsilon and delta epsilon values are also calculated as shown in Table A12 of appendix, followed by iterations that enables finding an optimal solution for the research study.

Table 6.2

Payoff table with pareto optimal alternatives (branded)

	Waste Minimization	Carbon Emission Minimization	Cost Minimization
Problem 1	337.5	2,709.3	5,915,526
Problem 2	327	2,582.6	5,916,800
Problem 3	331.5	2,663.3	5,915,700

6.4 Comparative Discussion

6.4.1. Results of Traditional Supply Chain

The multi-period, and multi-objective traditional citrus supply chain optimization of citrus fruits within seasonal demand and retailer segmentation is solved using computer aided tools, following Augmented Epsilon Constraint Method with Lexicographic optimization. The solution for each of the case is reached by coding individual objectives along with their related constraints, brought together in the form of payoff table and evaluated for the research problem under focus. The payoff table give a complete picture of all possible pareto optimal alternative solutions and makes it convenient for the researcher or the decision maker to achieve the best outcome and preferred optimization.

The optimal solution obtained from the method indicates supply chain optimization laying a huge impact on reduced carbon emissions, cost as well as saving fruit from excessive loss. The optimal cost in traditional supply chain is $ 4,941,493 that incurs during the transportation of citrus with 2,504.9 kg CO_2, saving fruit waste during transportation and by deterioration with a total of 372 tonnes. The results are also shown graphically as the pareto curve in figure 5, which shows the optimal solution for fruit waste minimization, carbon emissions minimization, and cost minimization for the supply chain.

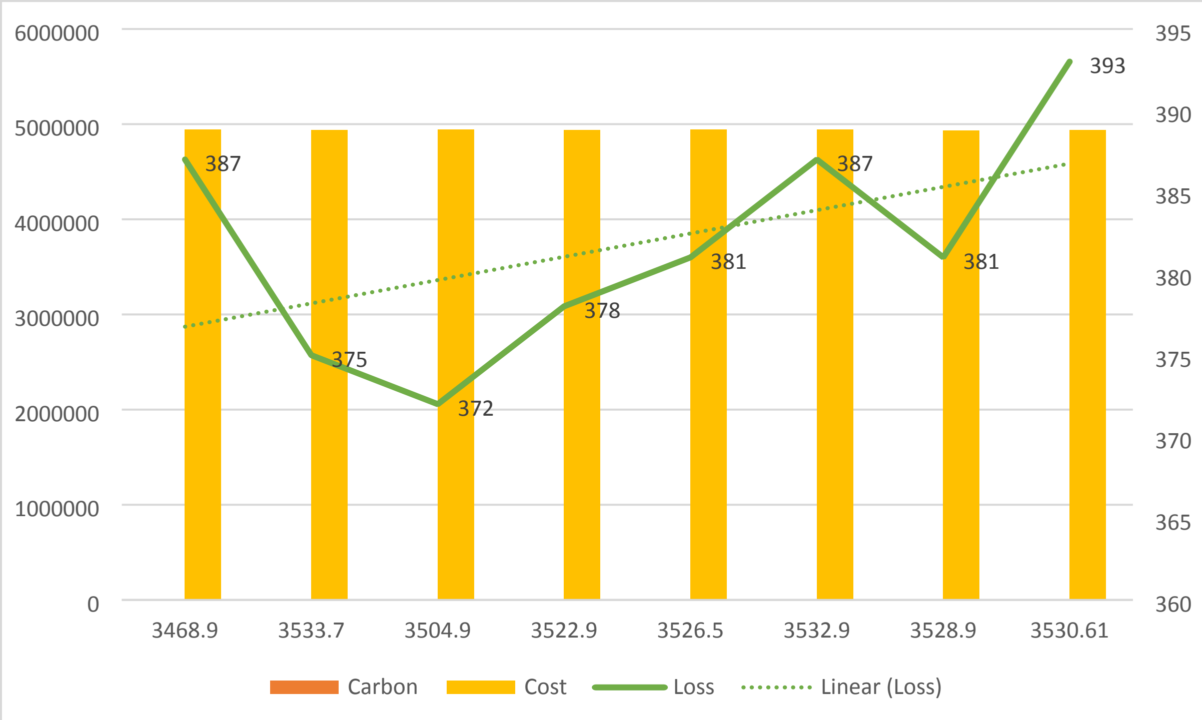

Figure 6.1. Graphical pareto optimal solution for traditional citrus supply chain

As evident from the answers presented in the graph above, there are significant rises of the graphical line pointing in the increased carbon emissions as well as increased cost structure for the entire chain however at the optimal region, all the objective functions are inclined to minimize waste, carbon emissions and cost. Citrus quantity shipped from farms to markets in traditional supply chain is shown in figure 6.2. The quantities between nodes are tabulated in Table A13 of the appendix, transported through shortest possible distance, as represented in Table A3 and Table A4 of the appendix. It can be seen clearly from the bar graph that each of the market receive citrus in accordance with its seasonal capacity where the fruit is picked when ripen, packed and transported to markets.

The first time-period is the initial phase of season, second time-period comprises of the seasonal bloom in which maximum fruit quantity is transported to the markets, and the third time-period is considered as the end of season where there is no more fruit on the trees at farm and the retailer demand is fulfilled from the quantity available in the markets. The retailer segmentation allows retailers to reach the closest serving markets for the fulfilment of demand, while other markets are visited for the unfulfilled consumer demand and for greater quantities that are not satisfied by the closest serving market. Time-period 3 is specifically responsible for pulling the retailers to explore other markets to satisfy consumer demand.

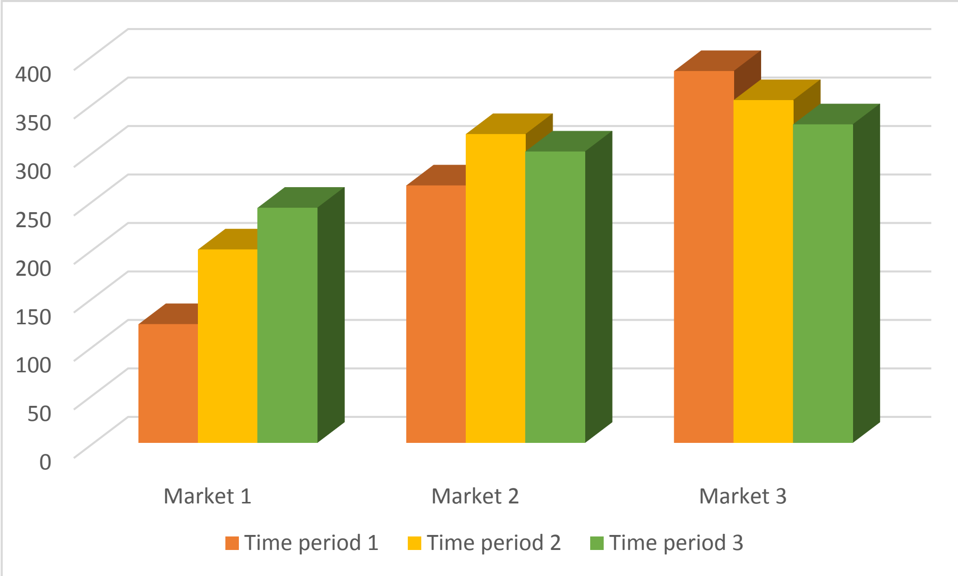

Figure 6.2. Quantities of citrus transported during seasonal time-period

6.4.2. Results of Processed Supply Chain

The processed citrus supply chain with multi-period, and multi-objective optimization within seasonal demand and retailer segmentation is solved using computer aided tools, following methodology augmented epsilon constraint method with lexicographic optimization. As that of traditional citrus supply chain, optimal solution obtained from the method specifies that it has a positive impact on reducing overall supply chain costs, reducing environmental damage along with the reduction of excessive fruit loss, especially during transportation.

The optimal cost in processed supply chain is $ 5,916,250 that incurs during the transportation of citrus at the optimal carbon emissions of 2,667.1 kg CO_2, saving fruit waste during transportation and by deterioration with a total of 312 tonnes. The graphical pareto curve is drawn on the bases of obtained results as shown in figure 6.3 with the optimal solution for fruit waste minimization, carbon emissions minimization, and cost minimization for the processed supply chain. The graph shows a steady rise in the fruit waste, also combined with increased carbon emissions as well as higher costs for the chain. Therefore, the optimal region is obtained at the very beginning of the graphical line where all the objective functions are inclined to minimize fruit waste, carbon emissions and cost.

As shown, the graph clarifies significant rises of the graphical line pointing in the increased loss of fruit, carbon emissions as well as cost for the entire chain. Citrus quantity is transported from farms to processing plants, from processing plants to markets, and then from markets to retailers covering mentioned distances as represented in Table A4, Table A5 and Table A6 of the appendix. The bar graph shown in figure 6.4 and figure 6.5 shows the optimized transportation of citrus quantities in processed supply chain, and the quantity shipped among the nodes is tabulated in Table A14 and Table A15 of the appendix.

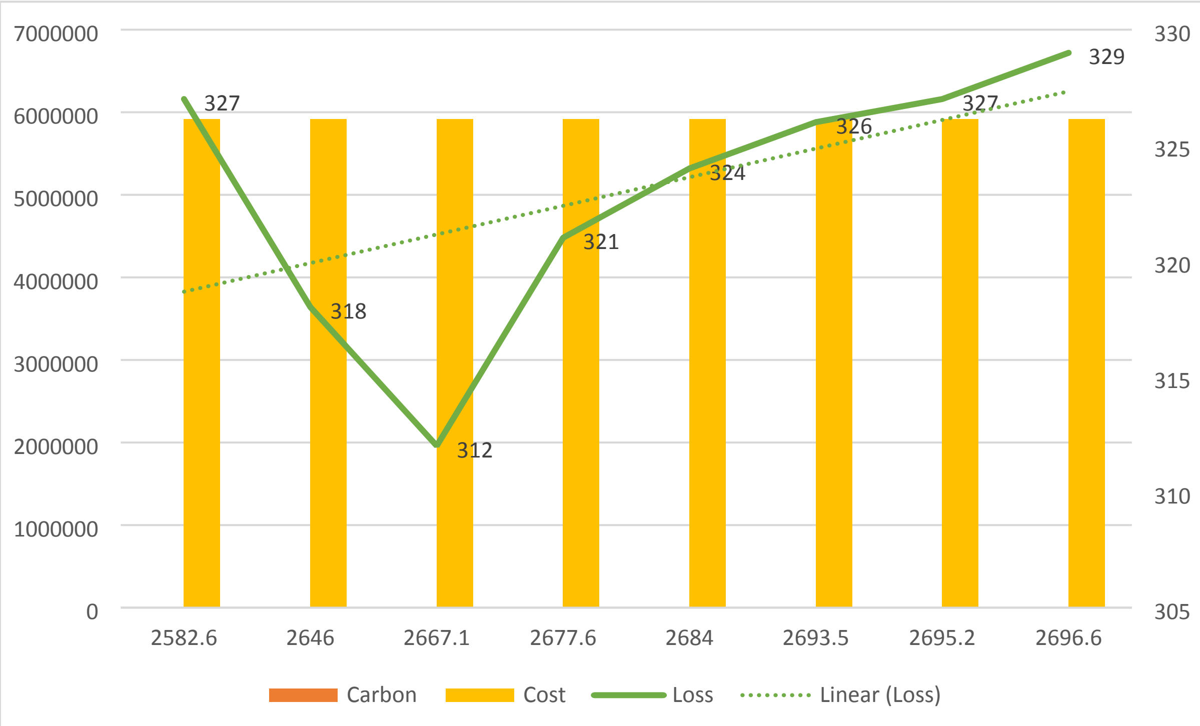

Figure 6.3. Graphical pareto optimal solution for processed citrus supply chain

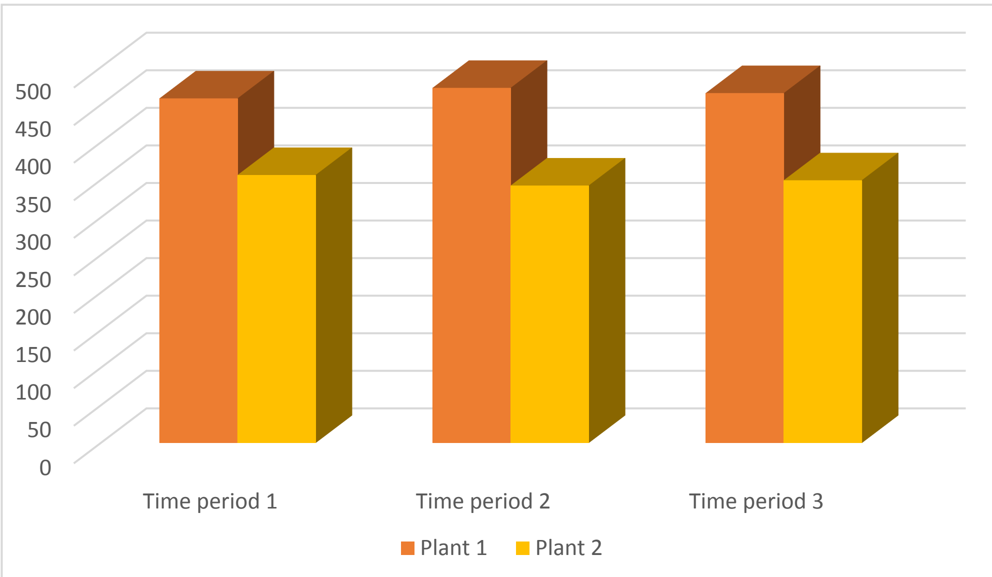

Figure 6.4. Quantities of citrus received by plants during seasonal time-period

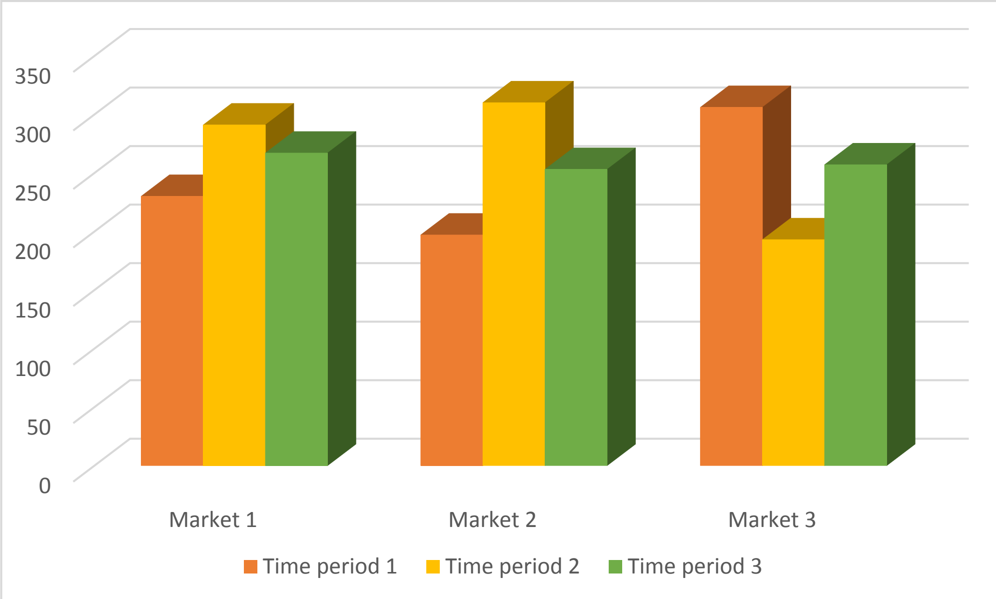

Figure 6.5. Quantities of citrus received by markets during seasonal time-period

The bar graph in figure 6.4 clearly depicts that the processing plants receive citrus quantities from all the farms since they hold huge capacities for processing tonnes of citrus. Processing plants then transport citrus quantities to markets on the bases of received market demand as shown in figure 6.5. Retailer segmentation in processed supply chain allows retailers to reach the closest serving markets for the processed citrus fruit demand and more markets are approached for the unfulfilled consumer demand for greater unfulfilled quantities.

6.4.3. Comparison of supply chains

Quantity transported and optimal solutions for both citrus supply chains i.e., traditional and processed, shows possibility for improvements by enhancing efficiency and supply chain performance. A comparison between both the chains are structured in a way that enables analyzing the two citrus supply chains more clearly, such as deterioration of fresh/ non-branded citrus fruit as well as processed/ branded citrus fruit and tabulation of loss of fruit in a supply chain. Although processed supply chain allows citrus fruits to remain fresh for a longer duration facilitating generous consumption and demand, yet it costs higher than the non-branded supply chain. Similarly, due to extended supply network that involves transportation of fruit from farms to plants, from plants to markets, and finally from markets to retailers also increases the release of carbon emissions.

The fruit deterioration function (Yang, et. al, 2020; Singh & Singh, 2011) used in mathematical modeling for the calculations of spoilage of fruit caused by transportation inefficiencies, exposure to temperature, inappropriate handling, and as unpurchased leftover quantities at shelf, is an add-on to the decay of fruit because of progressive seasonal time. Following figure 6.6 shows the fruit deterioration of citrus in a season for non-branded citrus fruits.

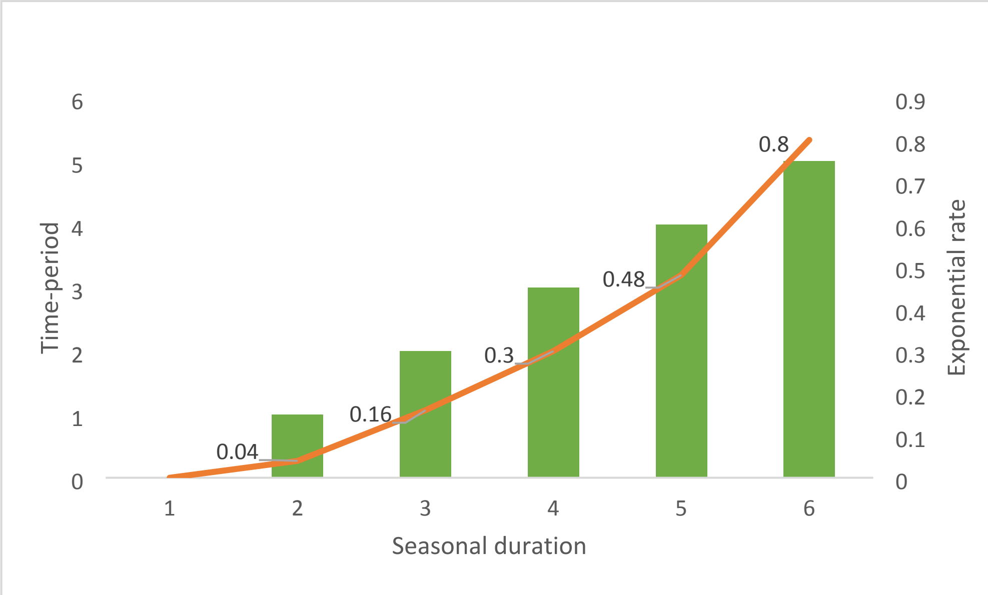

Figure 6.6. Rate of fruit deterioration for non-branded citrus supply chain

While figure 6.7 shows the fruit deterioration in a season for branded and processed citrus fruits, where the graphical line is slightly lower as compared to that of non-branded, primarily because of the sorting, cleaning, and cautious packaging of fruit.

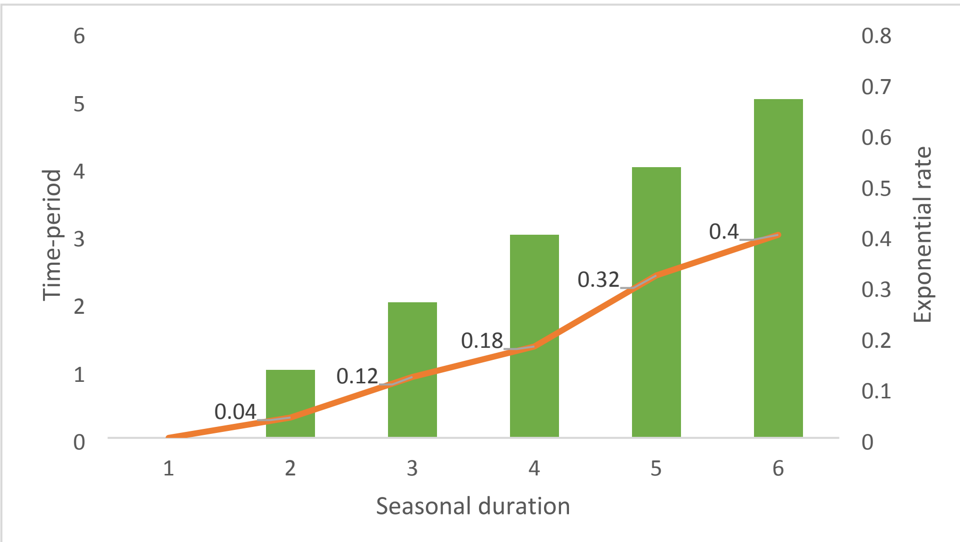

Figure 6.7. Rate of fruit deterioration for branded citrus supply chain

The loss of fruit is shown in figure 6.8 for traditional supply chain where each of the factor is evaluated in a pie chat that contributes to the fruit waste. It clearly shows that major fruit loss happens during transportation, mainly due to long travelling distance that adds to speedy deterioration of fruit, logistics inefficiencies, and inappropriate infrastructure. Other major loss is calculated at the retailer's end, where spoiled as well as unsold quantities are thrown away as no longer consumable wasted fruits.

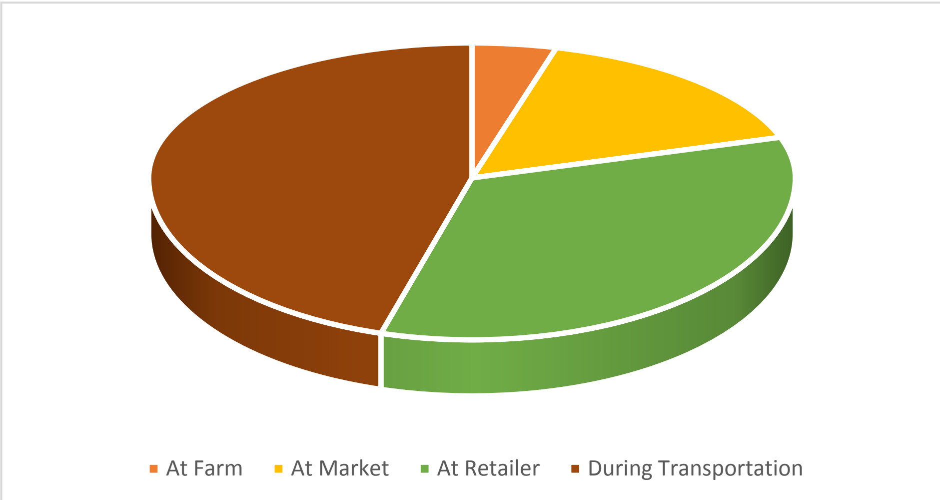

Figure 6.8. Fruit waste in traditional citrus supply chain

Similarly, the loss of fruit shown in figure 6.9 tabulates for processed citrus supply chain. The pie chart clarifies again that major fruit loss happens during transportation as well as at the retailer's end. However, the loss at markets is less than the loss in traditional citrus supply chain but adds fruit loss at plants mainly caused due to sorting, grading and processing of fruit.

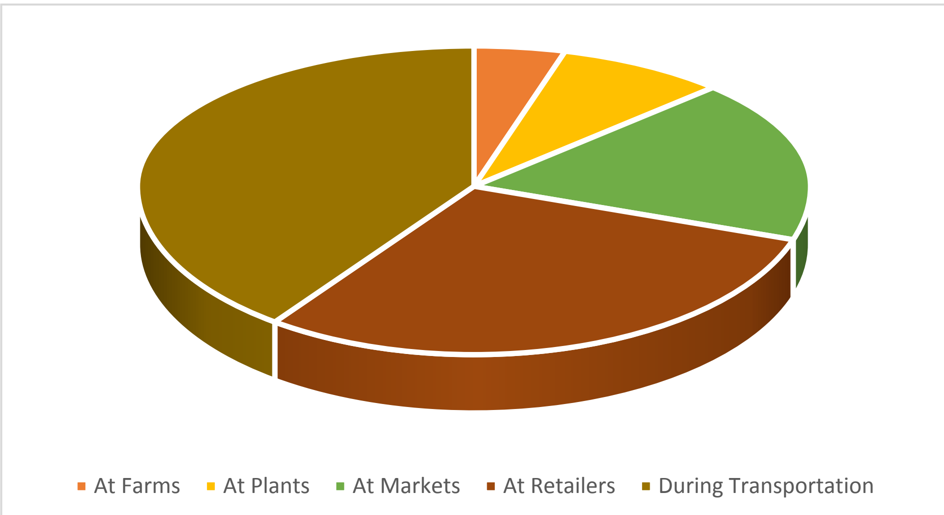

Figure 6.9. Fruit waste in processed citrus supply chain

6.4.4. Sensitivity Analysis

Sensitivity analysis is performed for all the key parameters of both chains individually for each of the objectives, as shown in Table 6.3. The percentage changes range from positive half to negative half, which represents considerable effect of change in parameters over the objective function values.

Table 6.3

Sensitivity analysis for traditional citrus supply chain

Parameter	% Change	Waste (tonnes) % Change	CO_2 (kg) % Change	Cost ($) % Change
P_f	+50	+0.07	-0.90	+2.44
	+25	+0.08	-1.5	+1.13
	-25	-0.05	+9.82	-0.87
	-50	-0.07	+19.87	-0.75
C_f	+50	N.E.	N.E.	+5.31
	+25	N.E.	N.E.	+2.66
	-25	N.E.	N.E.	-2.66
	-50	N.E.	N.E.	-5.29
V_{fm}	+50	-0.96	-2.60	-3.28
	+25	-0.42	-1.56	-2.09
	-25	+1.12	+2.60	+1.10
	-50	+1.68	+7.80	+4.07
V_{mr}	+50	-0.72	-2.00	-2.08
	+25	-0.34	-1.05	-1.67
	-25	+1.08	+1.96	+2.01
	-50	+1.46	+4.88	+2.63
$\tilde{x}_m$	+50	-0.03	N.E.	N.E.
	+25	-0.02	N.E.	N.E.
	-25	+0.12	N.E.	N.E.
	-50	+0.13	N.E.	N.E.
$\tilde{t}_m$	+50	+1.10	N.E.	N.E.
	+25	+0.60	N.E.	N.E.
	-25	-0.10	N.E.	N.E.
	-50	-0.80	N.E.	N.E.

N.E. refers to 'No Effect'

According to the table,

- Production quantities P_f at farms has a direct influence on all the objective functions, mainly because increase in produced quantities also increases cost of production, packing, loading and unloading costs etc. The number of trips and number of vehicles also increase to transport fruit from area of production to markets, adding carbons to air. There is significant increase and decrease of fruit waste that parallels with percentage changes as it is effects post-harvest losses and losses during transportation.
- The change of cost of production C_f however, influences the cost minimization as the increase and decrease of cost is mainly concerned with the cost structures of the supply

chain, as shown in the table +50% increase and -50% decrease lays huge cost differences.

- Similarly, increase and decrease of percentage values in vehicle carrying capacities V_{fm} and V_{mr} has a major effect on all the objective functions. The change of values is rather surprising as +25% and +50% shows that there is less fruit waste, a smaller number of vehicles that travel extra distance in transporting tonnes of fruit quantities from one node of the chain to the other causing less carbon emissions, as well as cost reduction saving extra transportation expenses and vice versa.
- Deterioration rate constant $\tilde{x}_m$ along with time-period $\tilde{t}_m$ has an impact on the waste minimization objective function only because of the direct link of rate constant with the spoilage of fruit at market, contributing to total fruit waste of citrus supply chain.

Sensitivity analysis for processed citrus supply chain is shown in Table 6.4 where the percentage changes in key parameters represent considerable effect of change in the objective function values. According to the formulated table,

- Production quantities P_f at farms for processed supply chain also has a direct influence on all the objective functions. Cost minimization is greatly affected by ±50% change in parameter value mainly because of the changes in cost of production, packing, loading and unloading costs etc. While there is minimal effect on the carbon emissions minimization and fruit waste minimization.
- Cost of production C_f and cost of processing activities G_p has no effect on waste minimization and carbon emissions minimization objectives while it impacts cost minimization greatly, because the +50% increase and -50% decrease of cost is connected with the overall cost structures of the processed supply chain.
- Vehicle carrying capacities V_{fp}, V_{pm} and V_{mr} has a major effect on all the objective functions. The table shows that 25% and 50% changes bring out huge changes to the cost structures where it saves extra costs on increased vehicle capacities, saves excessive carbon emissions by travelling trips over large distances, also saving fruit from spoilage during transportation.
- Deterioration rate constants $\tilde{x}_p$ and $\tilde{x}_m$ long with time-periods $\tilde{t}_p$ and $\tilde{t}_m$ basically impacts fruit waste minimization objective function as the rate constant is responsible for evaluating the amount of spoilage to citrus fruits with the passage of time at both

processing plants as well as at markets, contributing to total fruit waste of citrus supply chain.

Table 6.4

Sensitivity analysis of processed citrus supply chain

Parameter	% Change	Waste (tonnes) % Change	CO_2 (kg) % Change	Cost ($) % Change
P_f	+50	+0.13	+1.26	+12.2
	+25	+0.07	+0.63	+3.2
	-25	-0.04	-1.03	-4.33
	-50	-0.01	-1.37	-6.37
C_f	+50	N.E.	N.E.	+11.34
	+25	N.E.	N.E.	+5.67
	-25	N.E.	N.E.	-5.67
	-50	N.E.	N.E.	-11.34
G_p	+50	N.E.	N.E.	+1.26
	+25	N.E.	N.E.	+0.63
	-25	N.E.	N.E.	-0.63
	-50	N.E.	N.E.	-1.26
V_{fp}	+50	-0.11	-7.50	-12.2
	+25	-0.04	-4.50	-3.20
	-25	+0.02	+7.49	+4.33
	-50	+0.07	+12.5	+6.37
V_{pm}	+50	-0.9	-6.08	-9.0
	+25	-0.06	-2.20	-5.70
	-25	+0.04	+3.91	+5.11
	-50	+0.5	+5.8	+9.13
V_{mr}	+50	-0.76	-4.55	-8.76
	+25	-1.24	-1.82	-6.10
	-25	+1.43	+2.16	+6.28
	-50	+0.66	+4.75	+7.54
$\tilde{x}_m$	+50	-1.14	N.E.	N.E.
	+25	-1.12	N.E.	N.E.
	-25	+1.10	N.E.	N.E.
	-50	+1.16	N.E.	N.E.
$\tilde{x}_p$	+50	-1.18	N.E.	N.E.
	+25	-1.12	N.E.	N.E.
	-25	+1.13	N.E.	N.E.
	-50	+1.16	N.E.	N.E.
$\tilde{t}_m$	+50	+1.30	N.E.	N.E.
	+25	+1.16	N.E.	N.E.
	-25	-0.40	N.E.	N.E.
	-50	-0.50	N.E.	N.E.
$\tilde{t}_p$	+50	+1.21	N.E.	N.E.
	+25	+1.08	N.E.	N.E.
	-25	-0.90	N.E.	N.E.
	-50	-1.10	N.E.	N.E.

6.4.5. Methodology Comparison

‘Augmented Epsilon Constraint Method with Lexicographic Optimization’ is compared with ‘Goal Programming – Weighted Sum Method’ by employing similar data set, objective functions and constraints to find comparable results authentication as well as to know that which of the two methodologies provide finest optimal answers for the research problem. The optimal solution obtained from the weighted sum method for traditional citrus supply chain indicated $ 4,998,375 cost during the transport of citrus at the optimal carbon emissions of 2,540.9 kg CO_2, saving fruit waste during transportation and by deterioration with a total of 417.8 tonnes. The results are tabulated below in table 6.5 that provides a clear understanding of the results obtained by both methodologies indicating 'Augmented Epsilon Constraint Method with Lexicographic Optimization' has a better approach to minimizing fruit waste, costs and carbon emissions as compared to 'Goal Programming – Weighted Sum Method'.

Similarly, the optimal solution obtained from the weighted sum method for processed citrus supply chain indicated $ 5,920,268 cost during the transport of citrus at the optimal carbon emissions minimization of 2,820.1 kg CO_2, saving fruit waste during transportation and by deterioration with a total of 447 tonnes. The results tabulated below in table 6.6 explains both methodologies and highlights 'Augmented Epsilon Constraint Method with Lexicographic Optimization' is a better performing approach as compared to 'Goal Programming – Weighted Sum Method'. The gap analysis of objectives from both methodologies reveals that AUGMECON – Lexicographic Optimization is the best applicable methodology that gives the finest pareto optimal answers for solution. The formula used for gap analysis is:

$$\frac{\text{Best Value} - \text{Minimum of Range}}{\text{Maximum} - \text{Minimum of Range}}$$

Table 6.5

Methodology comparison for traditional citrus supply chain

Methodologies/ Results	AUGMECON	Goal Programming
Waste Minimization	372	417.8
Carbon Emission Minimization	2,504.9	2,540.9
Cost Minimization	4,941,493	4,998,375

Table 6.6

Methodology Comparison for Processed Citrus Supply Chain

Methodologies/ Results	AUGMECON	Goal Programming
Waste Minimization	312	447
Carbon Emission Minimization	2,667.1	2,820.1
Cost Minimization	5,916,250	5,920,268

CHAPTER 7: Conclusion, Contributions and Managerial Implications

This research conducted was basically intended to optimize citrus supply chain to avoid delays, minimize excessive costs along all branches of the chain, and reach an optimal solution that helps minimizing fruit waste, promoting increased consumption at national levels, and reducing environmental damage by minimizing carbon emissions. Generally past researches have focused on perishables with deterministic shelf-life, especially at national levels, most of the researches conducted targets the market structure constraints (Sharif, Farooq, & Malik, 2005), involvement of greater number of intermediaries (Shahzad, 2017), value chains (Ahmad, Mehdi, Ghafoor, & Anwar, 2018), and profit distribution among growers (Shah, Khan, Khan, Idrees, & Haq, 2010). Hence the research was limited to financial and marketing aspect of agriculture only. Citrus being the backbone of all available fruits in Pakistan needs special attention as it is among the top fruits that are greatly consumed as well as exported internationally.

7.1 Conclusion

Multi-period citrus supply chains were developed with both traditional and processed perspectives and optimized by using mathematical modeling. This research article enhances understanding the kinds of citrus supply chains operational in the country, also enabling the stakeholders of the chains to perform better, as addressed by optimized decision variables. The research was designed with the aim of reducing fruit waste and promoting efficient availability through transportation of fruit within the seasonal time duration so it can reach the end consumers in its maximum freshness, while also saving excessive costs. The result discussed in chapter 6 shows the difference of traditional citrus supply chain and processed citrus supply chain. The results for each of the objective functions of the chains are plotted in a way that shows performance of the chains and makes it easier to assess the best performing supply chain.

According to the above represented graphs as well as the results shown and discussed, it is observed that various aspects of traditional supply chain performs better than the processed supply chain. There are several factors by which traditional supply chain attains a higher performance level, primarily because the citrus fruit is transported to a lesser number of supply nodes and does not travel to an additional node of the chain i.e., processing plants. The extra traveling distance towards plants as well as from plants to markets also increases the overall cost structures mainly including transportation costs, extra loading/ unloading costs, and processing costs, also increases the carbon emissions with additional transportation as well as due to processing activities.

Similarly, the fruit loss for traditional supply chain is accounted as post-harvest waste at farms, deteriorated fruit waste at markets and at retailers, and finally fruit waste during transportation along the entire chain. The waste is entirely subjected to landfill because it is completely unsuitable consumption. While in the case of processed supply chain, the loss is accounted as post-harvest waste at farms, less deteriorated fruit waste at markets as well as at retailers, and finally fruit waste during transportation along the entire chain. There is less fruit waste in processed supply chain due to fruit cleaning, processing and thin laying of wax which extends the shelf-life fruit, and safe packaging that also limits spoilage of fruit during transportation and at retailers'. The waste at farms, markets, retailers and during travelling is subjected to landfill because it is inappropriate for consumption, but it is less landfill at plants. 15% of the fresh fruits disregarded during sorting and cleaning activities is purchased by small flavoring industries where food colors, jams, jellies, and molasses are produced as byproducts.

7.2 Contribution to the body of knowledge

The research conducted has highlighted various areas that can be helpful for new researches conducted in the field. It contributes to existing literature of Agri-fresh perishables with a combination of multi-period study, seasonal demand and retailer segmentation. It is evident from the comparative results of the current study that consumers prefer to buy products with significant quality and tend to reject buying deteriorated fruits or fruits with low freshness. There are several researches where the focus of mathematical modeling is to optimize objective functions for different supply chains, even considering delivery time minimization from hub or warehouse storage areas.

Present study is different in the sense that the market's network node is not storing fruit quantities but is selling point for the received quantities where fruit is placed over shelves and face exponential deterioration. Moreover, another contribution to the present research is the use of "Augmented Epsilon Constraint Method with Lexicographic Optimization" for Agri-fresh perishable supply chain. Most of the past researches made use of this methodology for resources and energy problems optimization. Augmented Epsilon is a generation method that enables the decision-maker to come up with best preferable posteriori decisions where a complete picture of all possible pareto optimal solutions is tabulated in payoff table, using lexicographic optimization.

7.3 Managerial Implications

There are few managerial implications derived as an outcome of the conducted research. The multi-period study allows the third-party contractors, responsible for the transport of citrus fruit from the area of production to the end consumer, to select route with shortest possible distance for transportation of citrus quantities, within seasonal time limit to conserve fruit freshness. The study aids in the consumer demand forecasting not only on the bases of fruit consumption quantities but on the type of fruit preferred as being fresh or processed. Similarly, it enables retailers to carefully forecast citrus demand to be bought from the market, considering significant quantities of fresh or processed citrus fruit as per consumer demand. Besides, it lets the retailer to select market that is nearest to the retailers' location and has the capacity to sell fresh or processed fruit quantities as demanded by retailer. This study will also be helpful for new market entrants in analyzing citrus supply chains operating in country, as well as for the existing market functionaries, contractors and retailers to cut short on excessive costs as well as improve seasonal supply efficiency.

7.4 Limitations and Future Research directions

Despite unique findings of this research, few of the limitations in the research model includes considering the data used for optimizing the model which is only related to one of the citrus fruit types (Kinnow). Moreover, this study is restricted to only one province-Punjab of Pakistan because of its higher production capacity and availability of functional processing plants. Therefore, other provinces with smaller production capacities can also be considered with their respective market structures, demand, and availability of fruit in accordance with seasonal time. A third case can also be studied where either farmers' supply directly to the marts or farmers supply citrus to processing plants, and from processing plants it is distributed directly to the cash & carry's, marts, or large stores.

Similarly, other fruit and vegetable types can be studied under same perspective and within their respective seasonal durations example sensitive fruits, strawberries and raspberries etc. can be studied with multi-period optimization. The present study can also be researched further with multi-route or vehicle routing aspect. Lastly, by including other objective functions such as quality maximization, lead time minimization, and social responsiveness maximization etc. can yield more optimized results to the food supply chains, contributing to increased consumption and quality with less fruits waste, pointing towards economic, social and environmental benefits.

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Appendices

Appendix A: Data tables for supply chains

Table A1

Farm and market parameters

Farm No.	Area (acres)	Production (tonnes)	Cost of Production ($ 270 per tonne)	No. of crates	Packing Cost ($)	Market Commission ($)
1	10	80	21,600	4000	2169	169
2	18	144	38,880	7200	3904	304
3	55	450	121,500	22500	12199	949
4	25	200	54,000	10000	5422	422

Table A2

Parameters of processing plants

Picking and Packing Cost ($ 11 per ton)	Processing Cost ($ 42 per ton)	No. of crates (1 crate of 15 kg's)	Packing Cost ($0.36 per crate)
880	3360	5330	1919
1584	6084	9600	3456
4950	18900	30000	10800
2200	8400	13330	4799

Table A3

Distance between farms and markets for traditional supply chain

	Farm 1	Farm 2	Farm 3	Farm 4
Sargodha	32	8	35	32
Faisalabad	87	105	91	87
Islamabad	269	248	267	269

Table A4

Distance between markets and retailers for traditional supply chain

	Retailer 1	Retailer 2	Retailer 3	Retailer 4	Retailer 5
Sargodha	95	260	115	30	244
Faisalabad	21	385	63	131	344
Islamabad	319	22	320	207	27

Table A5

Distance between farms and plants for processed supply chain

	Farm 1	Farm 2	Farm 3	Farm 4
Plant 1	58	55	55	60
Plant 2	53	28	49	53

Table A6
Distance between plants and markets for processed supply chain

	Plant 1	Plant 2
Sargodha	27	21
Faisalabad	150	155
Islamabad	211	217

Table A7

Cost of transportation between farms and markets for traditional supply chain ($/km)

	Farm 1	Farm 2	Farm 3	Farm 4
Sargodha	20.16	5.04	22.05	20.16
Faisalabad	21.42	4.41	25.2	23.94
Islamabad	54.81	66.15	57.33	54.81

Table A8

Cost of transportation between markets and retailers for traditional supply chain ($/km)

	Retailer 1	Retailer 2	Retailer 3	Retailer 4	Retailer 5
Sargodha	59.85	163.8	72.45	18.9	153.72
Faisalabad	13.23	225.54	39.69	82.53	216.72
Islamabad	200.97	13.86	201.6	130.41	17.01

Table A9

Cost of transportation between farms and plants for processed supply chain ($/km)

	Farm 1	Farm 2	Farm 3	Farm 4
Plant 1	36.54	34.65	34.65	37.8
Plant 2	33.39	17.64	30.87	33.39

Table A10
Cost of transportation between plants and markets for processed supply chain ($/km)

	Plant 1	Plant 2
Sargodha	17.01	13.23
Faisalabad	94.5	97.65
Islamabad	132.93	136.71

Table A11

Ranges and delta epsilon evaluation (non-branded)

Δε1	Δε2	ε1	ε2
72.0	9401.0	2468.90	4933267
36.0	4700.5	2504.90	4937968
24.0	3133.7	2516.90	4939534
18.0	2350.3	2522.90	4940318
14.4	1880.2	2526.50	4940788
12.0	1566.8	2528.90	4941101
10.3	1343.0	2530.61	4941325
9.0	1175.1	2531.90	4941493
8.0	1044.6	2532.90	4941623
7.2	940.1	2533.70	4941728

Table A12

Ranges and delta epsilon evaluation (branded)

Δε1	Δε2	ε1	ε2
126.7	1100.0	2582.6	5915700
63.4	550.0	2646.0	5916250
42.2	366.7	2667.1	5916433
31.7	275.0	2677.6	5916525
25.3	220.0	2684.0	5916580
21.1	183.3	2688.2	5916617
18.1	157.1	2691.2	5916643
15.8	137.5	2693.5	5916663
14.1	122.2	2695.2	5916678
12.7	110.0	2696.6	5916690

Table A13

Quantity transported between farms and markets (case-I)

Quantity Shipped	Market 1	Market 2	Market 3	
Farm 1	122	0	0	Time Period 1
Farm 2	0	207	76	
Farm 3	0	158	107	
Farm 4	0	0	200	
Farm 1	0	78	0	Time Period 2
Farm 2	0	0	0	
Farm 3	104	240	175	
Farm 4	95	0	178	
Farm 1	0	0	0	Time Period 3
Farm 2	0	94	0	
Farm 3	132	206	328	
Farm 4	110	0	0	

Table A14

Quantity transported between farms and plants (case-II)

Quantity Shipped	Plant 1	Plant 2	
Farm 1	0	142	Time Period 1
Farm 2	166	0	
Farm 3	292	0	
Farm 4	0	214	
Farm 1	0	70	Time Period 2
Farm 2	80	167	
Farm 3	234	0	
Farm 4	158	105	
Farm 1	76	0	Time Period 3
Farm 2	0	207	
Farm 3	282	142	
Farm 4	107	0	

Table A14

Quantity transported between plants and markets (case-II)

Quantity Shipped	Market 1	Market 2	Market 3	
Plant 1	230	0	149	Time Period 1
Plant 2	0	197	157	
Plant 1	89	310	52	Time Period 2
Plant 2	202	0	141	
Plant 1	267	144	0	Time Period 3
Plant 2	0	109	257	

Appendix B: MATLAB modeling for Traditional Supply Chain (Case-I)

Case 1: A

```
Prob=optimproblem('ObjectiveSense','minimize')
```

Sets:

```
farms=4;
markets=3;
retailers=5;
periods=3;
```

Decision Variables:

```
%Quantity Produced
qi=optimvar('qi',farms,1,periods,'Type','integer','LowerBound',0,'UpperBound',
1000000);
%Quantity Shipped btw farms and markets
Qij=optimvar('Qij',farms,markets,periods,'Type','integer','LowerBound',0,'Uppe
rBound',1000000);
%Quantity Shipped btw markets and retailers
Qjk=optimvar('Qjk',retailers,markets,periods,'Type','integer','LowerBound',0,'
UpperBound',100000);
%Binary Variable for retailer segmentation
Yk=optimvar('Yk',retailers,1,periods,'Type','integer','LowerBound',0,'UpperBou
nd',1);
%Loss at farm
Li=optimvar('Li',farms,1,periods,'Type','continuous','LowerBound',0,'UpperBoun
d',100000);
%Loss at market
Lm=optimvar('Lm',markets,1,periods,'Type','continuous','LowerBound',0,'UpperBo
und',100000);
%Loss at retailer
Lr=optimvar('Lr',retailers,1,periods,'Type','continuous','LowerBound',0,'Upper
Bound',100000);
```

Parameters:

```
%Vehicle cost for f to m (Sahin,2009)
Fj=zeros(farms,markets,periods);
Fj(:,:,1)=0.63;
Fj(:,:,2)=Fj(:,:,1);
Fj(:,:,3)=Fj(:,:,2);
%Vehicle cost for m to r (Sahin,2009)
Fk=zeros(retailers,markets,periods);
Fk(:,:,1)=0.63;
Fk(:,:,2)=Fk(:,:,1);
Fk(:,:,3)=Fk(:,:,2);
%Production cost at farm
production_cost=zeros(farms,1,periods);
production_cost(:,:,1)=[21600 38880 121500 54000];
production_cost(:,:,2)=[21600 38880 121500 54000];
production_cost(:,:,3)=[21600 38880 121500 54000];
% distances between farms and markets
dij=zeros(farms,markets,periods);
```

```
dij(:,:,1)=[32 87 269;8 105 248;35 91 267;32 87 269]; % distance between farms
and market (Route 1)
dij(:,:,2)=dij(:,:,1);
dij(:,:,3)=dij(:,:,2);
% distances between markets and retailers
djk=zeros(retailers,markets,periods);
djk(:,:,1)=[95 21 319;260 358 22;115 63 320;30 131 207;244 344 27]; % distance
between retailers and market
djk(:,:,2)=djk(:,:,1);
djk(:,:,3)=djk(:,:,2);
% Transportation cost from farms to markets ($/km)
Veh_cap=12;
V2=8;
%Demand at retailer and markets for citrus quantities
Dk=zeros(retailers,1,periods);
Dk(:,:,1)=[110 190 150 160 180];
Dk(:,:,2)=Dk(:,:,1);
Dk(:,:,3)=Dk(:,:,2);
Dm=zeros(farms,1,periods);
Dm(:,:,1)=[210 200 220 240];
Dm(:,:,2)=Dm(:,:,1);
Dm(:,:,3)=Dm(:,:,2);
%Transportation Cost Constraints
TCost1_con=Cij==(dij.*Fj.*Qij/Veh_cap);
TCost2_con=Cjk==(djk.*Fk.*Qjk/V2);
%Loss of fruit during transportation
Tfml=zeros(farms,markets,periods);
Tfml(:,:,1)=2;
Tfml(:,:,2)=Tfml(:,:,1);
Tfml(:,:,3)=Tfml(:,:,2);
Trml=zeros(retailers,markets,periods);
Trml(:,:,1)=3;
Trml(:,:,2)=Trml(:,:,1);
Trml(:,:,3)=Trml(:,:,2);

%carbon emitted during transportation from f to m

ctfm=zeros(farms,markets,periods);
ctfm(:,:,1)=0.05;
ctfm(:,:,2)=ctfm(:,:,1);
ctfm(:,:,3)=ctfm(:,:,2);
%carbon emitted during transportation from m to r
ctmr=zeros(markets,retailers,periods);
ctmr(:,:,1)=0.05;
ctmr(:,:,2)=ctmr(:,:,1);
ctmr(:,:,3)=ctmr(:,:,2);
%carbon emission at farm
cef=zeros(farms,1,periods);
cef(:,:,1)=0.12;
cef(:,:,2)=cef(:,:,1);
cef(:,:,3)=cef(:,:,2);
%carbon emission at market
cem=zeros(markets,1,periods);
cem(:,:,1)=0.21;
```

```
cem(:,:,2)=cem(:,:,1);
cem(:,:,3)=cem(:,:,2);
cefm=zeros(plants,markets,periods);
cefm(:,:,1)=[ 3     4     5
              3     6     2];
cefm(:,:,2)=cefm(:,:,1);
cefm(:,:,3)=cefm(:,:,2);
cemr=zeros(markets,retailers,periods);
cemr(:,:,1)=[ 3     4     6     4     3
              6     3     5     3     4
              3     4     5     3     5];
cemr(:,:,2)=cemr(:,:,1);
cemr(:,:,3)=cemr(:,:,2);

% Farms, Markets, and Retailer costs
%Picking and packing cost at farm
pcf=zeros(farms,1,periods);
pcf(:,:,1)=[2169 3940 12199 5422];
pcf(:,:,2)=pcf(:,:,1);
pcf(:,:,3)=pcf(:,:,2);
%Loading cost at farm
lcf=zeros(farms,1,periods);
lcf(:,:,1)=[125 121 146 134];
lcf(:,:,2)=lcf(:,:,1);
lcf(:,:,3)=lcf(:,:,2);
%Unloading cost from f to m
ucm=zeros(farms,1,periods);
ucm(:,:,1)=[120 217 678 301];
ucm(:,:,2)=ucm(:,:,1);
ucm(:,:,3)=ucm(:,:,2);
%Market Commission paid by each loaded truck
MC=zeros(farms,1,periods);
MC(:,:,1)=[169 304 949 422];
MC(:,:,2)=MC(:,:,1);
MC(:,:,3)=MC(:,:,2);
%Loading cost from m to r
lcr=zeros(retailers,1,periods);
lcr(:,:,1)=[60 65 80 90 85];
lcr(:,:,2)=lcr(:,:,1);
lcr(:,:,3)=lcr(:,:,2);
%Unoading cost at r
ucr=zeros(retailers,1,periods);
ucr(:,:,1)=[30 65 60 35 40];
ucr(:,:,2)=ucr(:,:,1);
ucr(:,:,3)=ucr(:,:,2);
```

Objective Functions

```
Prob.Objective=sum(sum(sum(Li))+sum(sum(Lm))+sum(sum(Lr)));

Prob.Objective=sum(sum(sum(sum(cef.*qi)))+sum(cem).*sum(sum(Qij,1),2)+sum(sum(
sum(cefm)))+sum(sum(sum(cemr))));

Prob.Objective=sum(sum(sum(production_cost+lcf.*qi))+sum(sum(ucm+MC.*sum(Qij,2
)))+sum(sum(lcr+ucr.*sum(Qjk,2)))+sum(sum(Cij))+sum(sum(Cjk)));
```

Constraints

```
%Production Constraints
Pi=zeros(farms,1,periods);
Pi(:,:,1)=[80 144 450 200];
Pi(:,:,2)=[80 144 450 200];
Pi(:,:,3)=[80 144 450 200];
Production_Con=qi<=Pi;
Supply_Con=sum(sum(Qij))<=sum(qi);
%Transshipment Constraints
Trans_Con=sum(sum(Qjk))<=sum(sum(Qij));
%Demand Constraints
Demand1_Con=sum(sum(Qjk))<=sum(Dk.*Yk);
Demand2_Con=sum(sum(Qij))==sum(Dm);
%Loss Constraints
af=0.13;
am=0.10;
ar=0.04;
tm=2;
xm=0.30;
Loss1_Con=Li<=af.*sum(sum(qi))-af.*sum(sum(Qij,4),2);
Loss2_Con=Lm<=am.*(sum(sum(sum(Qij)))./(xm.*(tm./periods))+sum(sum(sum(Tfml))
);
Loss3_Con=sum(Lr)==sum(Dk.*Yk)-ar.*sum(sum(sum(Qjk)))+sum(sum(sum(Trml)));
%Carbon Emission Constraints
Carbon1_Con=sum(sum(cefm))<=(sum(sum(sum(Qij.*dij)))/Veh_cap).*sum(sum(ctfm));
Carbon2_Con=sum(sum(cemr))<=(sum(sum(sum(Qjk.*djk),2))/V2).*sum(sum(ctmr));
%Optimization Constraints
Prob.Constraints.Production_Con=Production_Con;
Prob.Constraints.Supply_Con=Supply_Con;
Prob.Constraints.Trans_Con=Trans_Con;
Prob.Constraints.Demand1_Con=Demand1_Con;
Prob.Constraints.Demand2_Con=Demand2_Con;
Prob.Constraints.TCost1_con=TCost1_con;
Prob.Constraints.TCost2_con=TCost2_con;
Prob.Constraints.Loss1_Con=Loss1_Con;
Prob.Constraints.Loss2_Con=Loss2_Con;
Prob.Constraints.Loss3_Con=Loss3_Con;
Prob.Constraints.Carbon1_Con=Carbon1_Con;
Prob.Constraints.Carbon2_Con=Carbon2_Con;

[x1, fval1]=solve(Prob)
```

Appendix C: MATLAB modeling for Processed Supply Chain (Case-II)

Case 2:

```
Prob=optimproblem('ObjectiveSense','minimize')
```

Sets:

```
farms=4;
plants=2;
markets=3;
retailers=5;
periods=3;
```

Decision Variables:

```
%Quantity Produced
qi=optimvar('qi',farms,1,periods,'Type','integer','LowerBound',0,'UpperBound',
1000000);
%Quantity Shipped btw farms and plants
Qip=optimvar('Qip',farms,plants,periods,'Type','integer','LowerBound',0,'Upper
Bound',1000000);
%Quantity Shipped btw plants and markets
Qpj=optimvar('Qpj',markets,plants,periods,'Type','integer','LowerBound',0,'Upp
erBound',100000);
%Quantity Shipped btw markets and retailers
Qjk=optimvar('Qjk',markets,retailers,periods,'Type','integer','LowerBound',0,'
UpperBound',100000);
%Binary Variable for retailer segmentation
Yk=optimvar('Yk',retailers,1,periods,'Type','integer','LowerBound',0,'UpperBou
nd',1);
%Loss at farm
Li=optimvar('Li',farms,1,periods,'Type','continuous','LowerBound',0,'UpperBoun
d',100000);
%Loss at plants
Lp=optimvar('Lp',plants,1,periods,'Type','continuous','LowerBound',0,'UpperBou
nd',100000);
%Loss at market
Lm=optimvar('Lm',markets,1,periods,'Type','continuous','LowerBound',0,'UpperBo
und',100000);
%Loss at retailer
Lr=optimvar('Lr',retailers,1,periods,'Type','continuous','LowerBound',0,'Upper
Bound',100000);
```

Parameters:

```
%Vehicle cost for f to p (Sahin,2009)
Fp=zeros(farms,plants,periods);
Fp(:,:,1)=0.63;
Fp(:,:,2)=Fp(:,:,1);
Fp(:,:,3)=Fp(:,:,2);
%Vehicle cost for p to m (Sahin,2009)
Fj=zeros(markets,plants,periods);
Fj(:,:,1)=0.63;
Fj(:,:,2)=Fj(:,:,1);
Fj(:,:,3)=Fj(:,:,2);
%Vehicle cost for m to r (Sahin,2009)
Fk=zeros(markets,retailers,periods);
Fk(:,:,1)=0.63;
Fk(:,:,2)=Fk(:,:,1);
Fk(:,:,3)=Fk(:,:,2);
%Production cost at farm
production_cost=zeros(farms,1,periods);
production_cost(:,:,1)=[21600 38880 121500 54000];
production_cost(:,:,2)=[21600 38880 121500 54000];
production_cost(:,:,3)=[21600 38880 121500 54000];
% distances between farms and plants
dip=zeros(farms,plants,periods);
```

```
dip(:,:,1)=[58 53;55 28;55 49;60 53]; % distance between farms and market
(Route 1)
dip(:,:,2)=dip(:,:,1);
dip(:,:,3)=dip(:,:,2);
% distances between plants and markets
dpj=zeros(markets,plants,periods);
dpj(:,:,1)=[27 21;150 155;211 217]; % distance between farms and market (Route
1)
dpj(:,:,2)=dpj(:,:,1);
dpj(:,:,3)=dpj(:,:,2);
% distances between markets and retailers
djk=zeros(markets,retailers,periods);
djk(:,:,1)=[95 260 115 30 244;21 358 63 131 344;319 22 320 207 27]; % distance
between retailers and market
djk(:,:,2)=djk(:,:,1);
djk(:,:,3)=djk(:,:,2);
% Transportation cost from farms to markets ($/km)
Veh_cap=12;
V2=8;
%Demand at retailer and markets for citrus quantities
Dp=zeros(plants,1,periods);
Dp(:,:,1)=[430 443];
Dp(:,:,2)=Dp(:,:,1);
Dp(:,:,3)=Dp(:,:,2);
Dk=zeros(retailers,1,periods);
Dk(:,:,1)=[110 190 150 160 180];
Dk(:,:,2)=Dk(:,:,1);
Dk(:,:,3)=Dk(:,:,2);
Dm=zeros(markets,1,periods);
Dm(:,:,1)=[270 266 290];
Dm(:,:,2)=Dm(:,:,1);
Dm(:,:,3)=Dm(:,:,2);
%Transportation Cost Constraints
TCost1_con=Cip==(dip.*Fp.*Qip/Veh_cap);
TCost2_con=Cpj==(dpj.*Fj.*Qpj/Veh_cap);
TCost3_con=Cjk==(djk.*Fk.*Qjk/V2);
%Loss of fruit during transportation
% Tfpl=randi([1 2],farms,plants,periods);
Tfpl=zeros(farms,plants,periods);
Tfpl(:,:,1)=1;
Tfpl(:,:,2)=Tfpl(:,:,1);
Tfpl(:,:,3)=Tfpl(:,:,2);
% Tpml=randi([1 2],markets,plants,periods);
Tpml=zeros(markets,plants,periods);
Tpml(:,:,1)=2;
Tpml(:,:,2)=Tpml(:,:,1);
Tpml(:,:,3)=Tpml(:,:,2);
% Trml=randi([2 3],markets,retailers,periods);
Trml=zeros(markets,retailers,periods);
Trml(:,:,1)=2.5;
Trml(:,:,2)=Trml(:,:,1);
Trml(:,:,3)=Trml(:,:,2);

%carbon emitted during transportation from f to p
```

```
ctfp=zeros(farms,plants,periods);
ctfp(:,:,1)= 0.05;
ctfp(:,:,2)=ctfp(:,:,1);
ctfp(:,:,3)=ctfp(:,:,2);
%carbon emitted during transportation from p to m
ctpm=zeros(markets,plants,periods);
ctpm(:,:,1)= 0.05;
ctpm(:,:,2)=ctpm(:,:,1);
ctpm(:,:,3)=ctpm(:,:,2);
%carbon emitted during transportation from m to r
ctmr=zeros(markets,retailers,periods);
ctmr(:,:,1)= 0.05;
ctmr(:,:,2)=ctmr(:,:,1);
ctmr(:,:,3)=ctmr(:,:,2);
%carbon emission at farm
cef=zeros(farms,1,periods);
cef(:,:,1)=0.12;
cef(:,:,2)=cef(:,:,1);
cef(:,:,3)=cef(:,:,2);
%carbon emission at plants
cep=zeros(plants,1,periods);
cep(:,:,1)=0.32;
cep(:,:,2)=cep(:,:,1);
cep(:,:,3)=cep(:,:,2);
%carbon emission at market
cem=zeros(markets,1,periods);
cem(:,:,1)=0.26;
cem(:,:,2)=cem(:,:,1);
cem(:,:,3)=cem(:,:,2);
cefp=zeros(farms,plants,periods);
cefp(:,:,1)=[6     5
             5     9
             8     6
             5     9];
cefp(:,:,2)=cefp(:,:,1);
cefp(:,:,3)=cefp(:,:,2);
cepm=zeros(plants,markets,periods);
cepm(:,:,1)=[ 7     9     5
              8     6     7];
cepm(:,:,2)=cepm(:,:,1);
cepm(:,:,3)=cepm(:,:,2);
cemr=zeros(markets,retailers,periods);
cemr(:,:,1)=[ 7     9     6     8     8
              6     7     5     7     9
              8     9     5     7     5];
cemr(:,:,2)=cemr(:,:,1);
cemr(:,:,3)=cemr(:,:,2);

%Loading cost at farm
lcf=zeros(farms,1,periods);
lcf(:,:,1)=[125 121 146 134];
lcf(:,:,2)=lcf(:,:,1);
lcf(:,:,3)=lcf(:,:,2);
%Unloading cost from f to p
```

```
ucp=zeros(farms,1,periods);
ucp(:,:,1)=[120 217 678 301];
ucp(:,:,2)=ucp(:,:,1);
ucp(:,:,3)=ucp(:,:,2);
%Processing cost at plant
Gp=zeros(plants,1,periods);
Gp(:,:,1)=[9444 27300];
Gp(:,:,2)=Gp(:,:,1);
Gp(:,:,3)=Gp(:,:,2);
%Packaging cost at plant
Pp=zeros(plants,1,periods);
Pp(:,:,1)=[5830 3784];
Pp(:,:,2)=Pp(:,:,1);
Pp(:,:,3)=Pp(:,:,2);
%loading cost from p to m
lcp=zeros(plants,1,periods);
lcp(:,:,1)=[86 75];
lcp(:,:,2)=lcp(:,:,1);
lcp(:,:,3)=lcp(:,:,2);
%Unloading cost from p to m
ucm=zeros(plants,1,periods);
ucm(:,:,1)=[690 420];
ucm(:,:,2)=ucm(:,:,1);
ucm(:,:,3)=ucm(:,:,2);
%Market Commission paid by each loaded truck
MC=zeros(plants,1,periods);
MC(:,:,1)=[269 342];
MC(:,:,2)=MC(:,:,1);
MC(:,:,3)=MC(:,:,2);
%Loading cost from m to r
lcr=zeros(retailers,1,periods);
lcr(:,:,1)=[60 65 80 90 85];
lcr(:,:,2)=lcr(:,:,1);
lcr(:,:,3)=lcr(:,:,2);
%Unoading cost at r
ucr=zeros(retailers,1,periods);
ucr(:,:,1)=[30 65 60 35 40];
ucr(:,:,2)=ucr(:,:,1);
ucr(:,:,3)=ucr(:,:,2);
```

Objective Functions

```
Prob.Objective=sum(sum(Li))+sum(sum(Lp))+sum(sum(Lm))+sum(sum(Lr));

Prob.Objective=sum(sum(sum(sum(cef.*qi)))+sum(cep).*sum(sum(Qpj),2)+sum(cem).*
sum(sum(Qjk),2)+sum(sum(sum(cefp)))+sum(sum(sum(cepm)))+sum(sum(sum(cemr))));

Prob.Objective=sum(sum(sum(production_cost+lcf+ucp.*qi))+sum(sum(Gp+Pp+lcp+ucm
+MC).*sum(sum(Qpj)))+sum(sum(lcr+ucr).*sum(sum(Qjk,2)))+sum(sum(Cip))+sum(sum(
Cpj))+sum(sum(Cjk)));
```

Constraints

```
%Production Constraints
Pi=zeros(farms,1,periods);
Pi(:,:,1)=[80 144 450 200];
Pi(:,:,2)=[80 144 450 200];
```

```
Pi(:,:,3)=[80 144 450 200];
Production_Con=qi<=Pi;
Supply_Con=sum(sum(Qip))<=sum(qi);
%Transshipment Constraints
Trans_Con=sum(sum(Qpj))<=sum(sum(Qip));
Trans2_Con=sum(sum(Qjk))<=sum(sum(Qpj));
%Demand Constraints
Demand1_Con=sum(sum(Qjk))<=sum(Dk.*Yk);
Demand2_Con=sum(sum(Qpj))<=sum(Dp);
Demand3_Con=sum(sum(Qip))<=sum(Dm);
%Loss Constraints
af=0.13;
ap=0.10;
am=0.06;
ar=0.04;
tp=2;
tm=2;
xp=0.25;
xm=0.30;
Loss1_Con=sum(Li)<=af.*sum(sum(qi))-af.*sum(sum(Qip),2);
Loss2_Con=Lp<=ap.*(sum(sum(sum(Qip))).//(xp.*(tp./periods)))+sum(sum(sum(Tfpl))
)
Loss3_Con=Lm<=am.*(sum(sum(sum(Qpj))).//(xm.*(tm./periods)))+sum(sum(sum(Tpml))
);
Loss4_Con=sum(Lr)==sum(Dk.*Yk)-ar.*sum(sum(sum(Qjk)))+sum(sum(sum(Trml)));
%Carbon Emission Constraints
Carbon1_Con=sum(sum(cefp))<=(sum(sum(sum(Qip.*dip)))/Veh_cap).*sum(sum(ctfp));
Carbon2_Con=sum(sum(cepm))<=(sum(sum(sum(Qpj.*dpj)))/Veh_cap).*sum(sum(ctpm));
Carbon3_Con=sum(sum(cemr))<=(sum(sum(sum(Qjk.*djk)))/V2).*sum(sum(ctmr));
%Optimization Constraints
Prob.Constraints.Production_Con=Production_Con;
Prob.Constraints.Supply_Con=Supply_Con;
Prob.Constraints.Trans_Con=Trans_Con;
Prob.Constraints.Trans2_Con=Trans2_Con;
Prob.Constraints.Demand1_Con=Demand1_Con;
Prob.Constraints.Demand2_Con=Demand2_Con;
Prob.Constraints.Demand3_Con=Demand3_Con;
Prob.Constraints.TCost1_con=TCost1_con;
Prob.Constraints.TCost2_con=TCost2_con;
Prob.Constraints.TCost3_con=TCost3_con;
Prob.Constraints.Loss1_Con=Loss1_Con;
Prob.Constraints.Loss2_Con=Loss2_Con;
Prob.Constraints.Loss3_Con=Loss3_Con;
Prob.Constraints.Loss4_Con=Loss4_Con;
Prob.Constraints.Carbon1_Con=Carbon1_Con;
Prob.Constraints.Carbon2_Con=Carbon2_Con;
Prob.Constraints.Carbon3_Con=Carbon3_Con;

[x2, fval2]=solve(Prob)
```