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Optimization of Perishable Resources in an uncertain Environment using Mathematical Model

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Abstract
The paper examined optimization of perishable resources in an uncertain environment using mathematical model. The mathematical model was used to provide a systematical approach via which perishable goods can be preserved with their economic value not affected. To this end, two research questions were formulated to guide the study. Several related literature were reviewed and the basic features of the mathematical model were examined as well. The study employed the quantitative research method that made use of secondary data to analyse the research question formulated in the study. This is based on the mathematical model design and its use to explain perishable resources optimization in uncertain supply chain environment. This also comprised of using extant literature from the review to support the subsisting model proposition in order to make valid conclusions. The study found that reducing costs and increasing the level of service (satisfaction) are the most important factors in today's market competition. In this regard, in the framework of a comprehensive systematic approach, supply chain management considers the coordination between the members in order to reduce costs and increase the level of service in providing a product or service to the customers. In this system, the total costs of the facility are a special priority. Efforts have been made to model and optimize the supply chain design. The study revealed that a change in demand would lead to a change in the level of profitability, and the optimal demand would be reached when the production amounts of the factory are the same as the sales. It was recommended that the mathematical model can be used for optimizing customer demand maximization functions can be added to target functions by using strategic planning and maximizing customer satisfaction
Keywords: Optimization, Perishable resource, uncertain environment, Mathematical model, Maximization

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I. Introduction

Agricultural Food Supply Chains (AFCS) are responsible for bringing agricultural products from the farm to the fork. Since these supply chains (SC) comprise the largest manufacturing sector in the world, especially Europe and contribute to the economy with 4.25 million employees and a turnover over €1 trillion, it is critical to develop effective and efficient models and methods to support AFSC decision-making processes and to optimise AFSC performance (Amorim et al. 2016, FoodDrink Europe 2016). Such performance is strongly influenced by factors such as uncertainty sources (e.g. weather, diseases, pests) and product characteristics (e.g. perishability), which differentiate AFSC from other industrial supply chains. Therefore, generic decision-making models and methods for designing and operating SC cannot be easily extrapolated to the agricultural food sector since they do not represent real AFSC performance.

Reduction in raw materials, increase in pollutants and the extent of pollution caused by them have been important issues for organizations in recent decades. In addition, failure to observe ethical responsibilities will lead to increased costs and thus reduced profitability. Sustainable supply chain management is rooted in sustainability and includes an extensive approach to supply chain management. Sustainability in the supply chain means pushing the supply chain to focus on social, economic and environmental aspects, and addressing the existing problems in the traditional supply chain. Sustainable supply chain includes all logistics costs from an economic point of view, reducing the amount of contaminants released from an environmental point of view, and reviewing social responsibility from a social point of view.

The supply chain for perishable products includes products with a durable shelf life and limited production, the management of which requires making right decisions (Katsaliaki et al. 2014). Rapid food spoilage leads to a loss in the volume of many foods and more pressure on FSCs; it also reduces the quality, profitability and sustainability of food. Some of the food losses that occur after harvesting and in the supply chain transportation are inevitable. According to FAO reports, 20–60% of the total production in all countries and one-third of food products for human consumption in the world (about 1.3 billion tons per year) are lost after harvesting.

A first step, and one of the most critical ones for optimising AFSC performance, is to adequately design them as tactical and operational decisions, as well as their impact on overall SC performance, and this will depend on their configuration (Baghalian, Rezapour, & Farahani 2013). Tsolakis et al. (2014) point out that despite the significance of SC configuration decisions and a number of studies that address them in the general SC management context, the relevant agri-food literature on this topic is limited. This is probably due to the difficulties imposed by the structure and complexity of an entire agrifood chain's relationships, and to incoming uncertainties that characterise this particular network type.

In their review of operational research models applied to fresh fruit supply chain, Soto-Silva et al. (2016) state that there is a gap of models to design and manage such SC. These authors note that practically all models consider a constant price over time without taking into account fruit seasonality or loss in the product's value due to product deterioration. They point out the need for tools that incorporate fresh fruit supply chain characteristics, such as shelf life, quality deterioration, waste, and prices that depend on time and product freshness. They also indicate that given the uncertainty and risk that surround the fresh fruit sector, it is necessary to develop models that include these characteristics.

Since inherent sources of uncertainty in AFSC have a negative impact on their performance and sustainability, several authors (Ahumada & Villalobos 2009; Akkerman, Farahani, & Grunow 2010; Borodin et al. 2016; Lucas & Chhajed 2004; Tsolakis et al. 2014) state the need to develop AFSC design models that contemplate the effect of existing uncertainty sources and product perishability throughout the chain. In order to formulate such models, it is necessary to define AFSC's characteristics, uncertainty sources, decisions and mathematical programming approach that can be addressed and employed when designing AFSC and establish the state of the art of such items to know current research and to detect existing gaps in the literature. This study therefore aims to utilize the mathematical model to analyse how perishable resources can be optimized under uncertain environment. To achieve the above objective, the study formulated specific objectives to guide the study such as:

1. Determine the characteristics and uncertainties of mathematical modelling approach.
2. Determine how mathematical model can be used to optimize perishable resources.

Research Question

The research basically is guided by one research question which constitute the main aim of the investigation.
How can mathematical model be used to optimize perishable resources under uncertain environment.

II. Literature Review

An overview of Agricultural food supply chain characteristics

This dimension is composed of four categories: 1) Subsector, where the agri-food sector is subdivided into subsectors; 2) Supply chain stages showing the existing AFSC stages; 3) number of products where the different products produced by Agricultural food supply chain were identified; 4) product characteristics, where the characteristics inherent of agri-food products were identified.

Subsector

Many products can be obtained from AFSC, such as rice, beef, carrots or apples. These SC products are different in terms of the needed productive processes, product characteristics and legislation, which makes their management and design very different. For this reason, it is necessary to classify the agri-food sector into subsectors. This study proposes distinguishing between: 1) crop-based AFSC and 2) animal-based AFSC as their products and productive processes vastly differ. In addition, it is interesting to subdivide the crop-based AFSC into: 1.a) highly perishable AFSC (vegetables and fruits), and 1.b) slightly perishable AFSC (cereals, tubs, nuts) (Ahumada & Villalobos, 2009). This takes us to the next stage which is the supply chain stages.

Supply Chain Stages

According to Chopra and Meindl (2007), supply chain can be divided into five stages:

- Supplier
- Processor.
- Distributor.
- Retailer.
- Customer.

In this sector, farmers are considered the suppliers of SC, although they have, in turn, their own suppliers (e.g. seed or fertilizer companies). They all perform add-value activities with products, such as packaging in fresh fruit SC, or slaughtering, cutting up and packaging in beef SC, and are considered processors. Distributors are responsible for storing and distributing products to retailers, who sell the finished product to end customers. Finally, customers represent the market's final demand.

Number of Products

AFSC can be designed to manage one product or more, which makes SC management more complicated when more products are simultaneously managed. However, given product seasonality in some agri-food subsectors (e.g. vegetables and fruits), it is interesting to design AFSC capable of simultaneously managing more than one product variety (e.g. different varieties of apples) or even different products (e.g. spinach, lettuce and cauliflower).

Product Characteristics

Agri-food products are characterised mainly by their perishability, represented by considering products' remaining shelf life until they become inedible for humans and/or by contemplating a product deterioration rate that depends on time and/or environmental factors (e.g. temperature or humidity). Other characteristics of agri-food products are the food quality and food safety requirements imposed by end customers and/or governments. Food quality is measured by a product's physical attributes (e.g. taste, texture, colour) and customers' perceptions of them, while food safety can be measured as a binary variable to determine if a product is allowed for consumption or not to prevent illnesses caused by contaminated products (Akkerman, Farahani, & Grunow 2010). Finally, agri-food products are also characterised by heterogeneity between units of the same product in physical attributes and perishability terms. For example, two apples harvested at the same time from one same tree, or two similarly fed chickens of similar age, can present different physical attributes (weight, colour, taste, texture, etc.) and distinct deterioration rates. In some cases, product characteristics can be interrelated and considered equivalents, but this does not occur in all AFSC types. For example, some authors claim that product quality is linked directly to its freshness, whereas others state that product quality and freshness can be considered differentiated characteristics according to AFSC (Grillo et al. 2017). Therefore, depending on the specific case for which the AFSC design model is developed, researchers and practitioners can decide to either consider these characteristics separately or, on the contrary, integrate some of them in order to lessen the model's complexity.

Application of Mathematical Model for the Optimisation of Perishable Resources

In order to design a sustainable supply chain based on post-harvest losses and harvest timing equilibrium, a sustainable two-way optimization model was presented by An and Ouyang in which a food company maximizes its profit and minimizes the post-harvest waste by expanding process facilities and purchases, price determination, a group of non-cooperative early distributor farmers, harvesting time, transportation, storage and market decisions which have been considered as product uncertainty and market equilibrium (An & Ouyang, 2016).

Given the evolution of the agricultural sector and the new challenges facing it, effective management of agricultural supply chains is an attractive topic for research. Therefore, uncertainty management in the supply chain for the agricultural crops is important in researches on the latest advances in operational research methods to manage the uncertainty that occurs in supply chain management issues (Borodin et al., 2016).

In another study, in order to achieve multi-objective optimization for the design of a sustainable supply chain network with respect to distribution channels, a new method for designing SCN with multiple distribution channels (MDCSCN) was presented. By providing direct products and services to customers by available facilities, as a substitution for the conventional products and services, this model benefits them. Sustainable objectives, such as reducing economic costs, increasing customer coverage, and mitigating environmental impacts, contribute to MDCSN design. A multi-objective artificial bee colony (MOABC) Algorithm for solving the MDCSCN model, which integrates the priority paradigm coding mechanism, Pareto optimization and the swarm intelligence of the bee colony, was provided. The concept of sustainable development would be taken into consideration when it can reduce economic costs for chain companies, increase the flexibility of customer orders and reduce environmental impacts (Zhang et al., 2016).

Because of competition, customer pressure and legal issues, corporate executives need to focus, during decision making, on aspects of sustainability of value creation, including a new set of challenges. Companies are striving to develop products of a specific quality with minimal cost. Today, the environmental and social performance of products beyond its entire life cycle should be taken into account. From an environmental point of view, product design should result in products that are characterized by reduced material severity, lower input of toxic materials, biodegradability, durability, ease of recovery and lower energy consumption during the life cycle. Supply chain design is a mutual planning issue that involves all value chain processes of the core company with interfaces for supplier–consumer that illustrate the resources and flow of materials (Stindt, 2017). To optimize the fresh food logistics, an optimization model was proposed with three types of decision-making in gardening, which deal with the purchase, transportation and storage of fresh produce (Soto-Silva et al., 2017). The management of unsophisticated food in retail stores is very difficult due to the short life span of products and their spoilage. Many elements, such as price, shelf space allocation and quality that can affect the rate of consumption, should be considered when designing step for the retail chain perishable food. Xiao and Yang designed a retail chain for perishable foods and provided a mathematical model for a single-item retail chain, and determined the pricing strategy, shelf space allocation, and quantity assignment to maximize the overall profitability of the retailer with the use of tracer technologies (Xiao & Yang, 2016).

In the contemporary business world, focus is not only on reducing costs and increasing profits, but also on achieving sustainability and balance between social responsibility, environmental protection and economic prosperity. These factors lead to sustainability; therefore, a preventive model in the food supply chain can be useful (Sgarbossa & Russo 2017).In recent years, food safety incidents have occurred in many countries, and issues related to the quality of food and safety have become more socially appealing. Due to the concern about the quality sustainability of the food supply chain, many companies have developed a real-time data mining system to ensure the quality of the products in the supply chain. For food safety and quality issues, the food chain precautionary system helps in the analysis of the food safety risk and minimization of the production and distribution of poor quality or non-safe products. Precaution also helps in improving the quality of food due to ensuring the sustainability of the supply chain quality. Therefore, Wang and Yue introduced a data mining food safety precautionary system for a sustainable supply chain (Wang & Yue 2017).

Research Method

The study employed the quantitative research method that made use of secondary data to analyse the research question formulated in the study. This is based on the mathematical model design and its use to explain perishable resources optimization in uncertain supply chain environment. This also comprised of using extant literature from the review to support the subsisting model proposition in order to make valid conclusions. The research mathematical model is presented below. Considering the problem statement, the assumption considered in the design process of the mathematical model as well as the proposed model solution is as follows:

The number of retailers is known.

- The demand for retailer l for the period p specified with d⌋p is a specific variable, and retailers' demands are independent of each other.
- There are different vehicles with different capacities that should be considered.
- Every retailer/open top distribution center is visited at a maximum of once per period.
- Soft time windows are included.
- There is more than one vehicle for each route.
- If a retailer or open top distribution center needs service, there should be more than one vehicle for servicing.
- The time period is considered as 1 day.
- The capacity of manufacturers and distribution centers is limited.
- At all stages, vehicles are available from the morning and the maximum availability time for each vehicle is less than or equivalent to working time per day.
- Distribution centers meet retailers' demand, and manufacturers can meet the orders of distribution centers.
- Retailers and distribution centers can order more than they need (they also have the permission for storage).
- One type of product is considered.
- In retail and distribution centers, no return can be made.
- The time and cost of dispatching the vehicle are known.
- Travel cost and unit distance are specified.
- The cost of maintenance is known.
- The service time is specified for each retailer.
- The speed of the vehicle is known.
- Products should be ordered in such a way that none expires in the warehouse.
- The first round of work should start and end at the same open top production unit.
- The second round should start and end at the same center of the open top distribution center.
- Manufacturers cannot directly sell products to retailers.

$$\begin{aligned}\text{Min } F_1 = &\sum_{m\in M}\text{OC}_m \sum_{m\in M} z_{me} + \sum_{m\in M}\sum_{e\in Tech}\text{SC}_{me} z_{me} + \sum_{d\in D}\text{OC}_d y_d \\ &+ \sum_{p\in P}\left(\sum_{k\in K}\sum_{m_k\in M_K}\sum_{i,j\in N_1} c_{ij} x_{ijp}^{m_k k} + \sum_{k\in K}\sum_{m_k\in M_k}\sum_{i,j\in N_2} c_{ij} r_{ijp}^{m_K K}\right. \\ &+ \sum_{m\in Me}\sum_{\in \text{Tech}}\text{VC}_{mep} h_{mep} + \sum_{d\in D}\text{VC}_{dp}\left(\sum_{l\in L}\beta_{dlp}\left(\sum_{k\in K}\sum_{m_k\in M_K}\eta_{lp}^{m_k k}\right)\right) \\ &+ \sum_{m\in M}\sum_{d\in D}\sum_{k\in K}\sum_{m_k\in M_K}\text{FVF}_k x_{mdp}^{m_k k} + \sum_{d\in D}\sum_{l\in L}\sum_{k\in K}\sum_{m_k\in M_K}\text{FVS}_k r_{dlp}^{m_k k} \\ &\left. + \sum_{d\in D}\text{Pd}_{dp}\left(ud_{dp}\right) + \sum_{l\in L}\text{Pr}_{lp}\left(ur_{lp}\right) + \sum_{d\in D}\text{HC}_{dp} I_{dp} + \sum_{l\in L}\text{HC}_{lp} I_{LP}\right)\end{aligned} \quad (1)$$

The 1 objective function reduces the overall variable and fixed costs of supply chain design. The first part is the fixed cost of opening a production unit, and the second is the fixed cost of association with the consolidation and learning of technology. The third part is about the fixed cost of opening distribution centers. It is important to know that the above corrections are related to the first stage of a two-stage model that includes decisions that need to be made before identifying the demands and vehicle routes in different periods or the fixed costs of the opening. The remaining parts are related to the second stage. They show variable costs, and these decisions are made after demands have been periodically determined. Parts four and five are transportation costs for the first and second periods. The sixth and seventh sections represent variable costs in manufacturing units and distribution centers. The next two parts are the fixed costs of each round of the first and second periods. The next two are the fine of distortion of the time window and the final two parts of the cost of inventory of distribution centers and retailers.

$$\begin{aligned}\text{Min } F_2 = &\sum_{m\in M}\sum_{e\in \text{Tech}}\text{EO}_{me} z_{me} + \sum_{d\in D}\text{EO}_d y_d \\ &+ \sum_{p\in P}\left(\sum_{k\in K}\sum_{m_k\in M_k}\sum_{i,j\in N_1}\text{ET}_{ij} x_{ijp}^{m_k k} + \sum_{k\in K}\sum_{m_k\in M_K}\sum_{i,j\in N_2}\text{ET}_{ij} r_{ijp}^{m_K K}\right. \quad (2) \\ &\left. + \sum_{d\in D}\text{VE}_{dp}\left(\sum_{l\in L}\beta_{dlp}\left(\sum_{k\in K}\sum_{m_k\in M_K}\eta_{lp}^{m_k k}\right)\right) + \sum_{m\in M}\sum_{e\in \text{Tech}}\text{VE}_{mep} h_{mep}\right)\end{aligned}$$

The 2 objective function measures the overall environmental impact over the network. The first two parts are the environmental impacts related to the opening services of manufacturing units and distribution centers. The next two in the second phase are the environmental impacts associated with the marine transportation of products from production units to distribution centers in the first round and from distribution centers to retailers in the second. Finally, the two final sums are variable environmental impacts that arise from executive activities in production and distribution centers

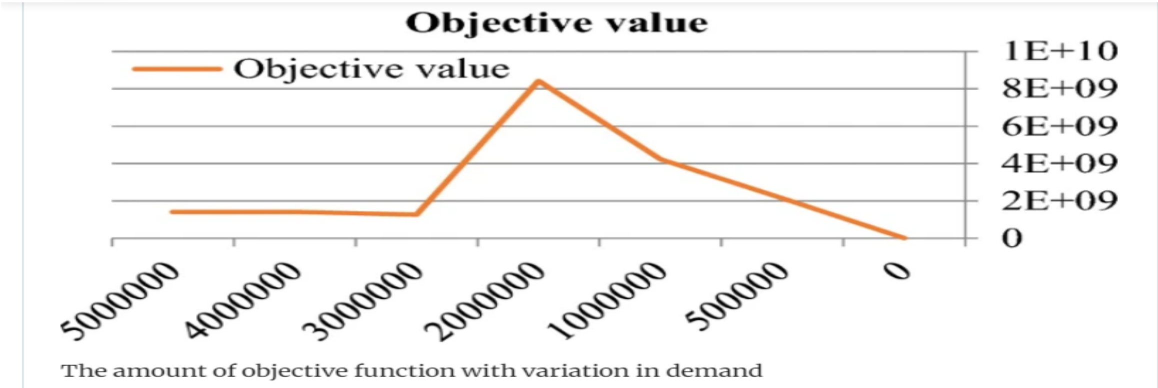
$$\text{Max } F_3 = \sum d_{lp} \cdot A_{ip}^{q} - \sum\sum\sum\sum\left[\left(B_{ip} \cdot \text{VC}_{mep}\right) + \left(\delta_{dp}^{m_k} \cdot S_{cme}\right)\right] \quad (3)$$

$$\text{Max } F_4 = \sum_{s} pb_e\left[\alpha\left(\sum_{m}\sum_{e}\text{EO}_{me}\right) + (1-\alpha)\left(\sum_{c}\sum_{m}\sum_{e} S_{cme}\right)\right] \quad (4)$$

The 3 objective function indicates the maximum profitability of the supply chain according to the freshness of the products. This function consists of two parts; the first part expresses the demand based on the products' freshness, and the second part expresses the cost of production (constant and variable) based on product quality. The 4 objective function also indicates the maximum level of satisfaction with the use of technology due to its use in the production process based on the amount of pollutants and the construction costs.

Case Study

The case study was adopted from a work that has similar parameters especially as it relates to the analysis of using mathematical model for the optimization of perishable resources. In this case study, the manufacturing group B.A was investigated. In this study, distribution of all types of ready-made foods of meat products to distribution centers was considered. This product should be consumed within 6 months from the time of production.



As suggested in the mathematical modeling section (Sect. 3), the proposed model is a reverse logistical chain network model of the sustainable production system of perishable goods, which is used in this section. In this study, due to the sensitivity of meat products, it is considered to be a difficult type.

Research data Analysis

Since the company produces a diverse range of products like cooked foods, including chicken nugget, chicken and mushroom nugget, potato croquette, Krakow; semi-cooked foods, including hamburger, chicken burger, vegetable omelet, little omelets, ; and raw foods, including chicken kebab, Lari kebab, in various volumes, in this research, the supply chain of fried foods (chicken nuggets) was examined.

Storage conditions: 18° below zero
Warehousing conditions: 18° below zero, inside the carton and plastic pallet
Package weight: 250 g
Bulk packaging weight: 2 kg
Number in the package: 9 pcs
The full list of additives and packaging materials together with the amount of consumption per ton of nuggets is shown in Table 1

Table 1 Additive consumption and inventory of the first period
From: A reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization

Type of material	**Unit**	**Consumption/ton**
Active carbon	kg	0.12
Anti oxidants	kg	0.08
Acid citric	kg	0.44
Phosphoric acid	kg	0.6
Beta carotene	kg	0.025
Propylene glycol	kg	0.63
Liquid soda	kg	5.5
Catalyst nickel	kg	1.6
Aromatics	kg	0.75
Monodiglyceride	kg	3
Lecithin	kg	1.5
Potassium sorbate	kg	1
NaCl	kg	3
Cartons	–	100
Nylon	kg	2.7
Adhesives	-	0.18

Source: Adapted from Moghaddam1, Javadi & Molana (2018) work on a reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization

Company planning is usually announced to all of the manufacturing departments at the beginning of the year as a forecast for the whole year by the planning unit and with the cooperation of the trading department with regard to the capacity of the manufacturing equipment. During the year, the planning director, production manager and the commercial manager accurately determine the amount of the monthly production. In the meat industry, production of oil drop is allowed to be between 2 and 5%, and it is 3% for this company. The company produces about 4500 to 5000 nuggets per month. The demand for nuggets is in an average of 200–250 t/m, which is about 5.5% of the total factory production.
Changes in demand are an effective factor in maximizing target functions. Table 2 shows how much change in demand affects the target functions.

D **(demand)**	**Objective function**
0	− 121,378
500,000	2,143,146,000
1,000,000	4,234,710,000
2,000,000	8,417,837,000
3,000,000	1,260,096,000
4,000,000	1,409,690,000
5,000,000	1,409,690,000

Source: Adapted from Moghaddam1, Javadi & Molana (2018) work on a reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization
As shown in Table 2, demand changes lead to changes in the objective function, that is, with increase in the amount of demand, the company's profit also increases, and it is clear that when the demand does not exist, the amount of the objective function is negated. Therefore, the amount of optimized demand is created when the factory production is the same as the sales.
Table 3 describes the values of the four objective functions introduced in this study. As shown in the table, the two first objectives are minimized and the two following objectives are maximized; therefore, in sensitivity analysis for the first two functions that are minimized, the minimum and maximum values are displaced. Also, the model responses are ensured for (the feasibility of) all constraints, meaning that the optimal values obtained for all constraints are true.

Objective function	**Minimum**	**Optimized value of the objective function**	**Maximum**
Objective 1	2,500,756,000	3,750,009,781	1,570,000,000
Objective 2	3,700,840,000	3,205,685,000	1,764,375,000
Objective 3	2,746,874,000	3,746,870,000	4,005,874,000
Objective 4	89%	95%	95%

Source: Adapted from Moghaddam1, Javadi & Molana (2018) work on a reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization

III. Conclusion

Reducing costs and increasing the level of service (satisfaction) are the most important factors in today's market competition. In this regard, in the framework of a comprehensive systematic approach, supply chain management considers the coordination between the members in order to reduce costs and increase the level of service in providing a product or service to the customers. In this system, the total costs of the facility are a special priority. Efforts have been made to model and optimize the supply chain design. But there are a few research projects that target the design of supply chain networks comprehensively (taking into account both strategic and tactical issues simultaneously). Many of these attempts use definitive methods, while in the real world, definitive assumption is unreasonable. Therefore, it is necessary to consider uncertainty in investigations and decisions. On the other hand, taking into account the reduction of environmental impacts, considering the importance of the environment and pollution prevention is of great significance. Environmental damage is one of the most intangible costs that the entire community is its beneficiary.

In the sustainable supply chain, the effects of a chain on the environment are also addressed, and this, together with the inclusion of uncertainty and the study of the supply chain for perishable goods, forms an efficient collection that is addressed in this study. In this paper, introducing two objective functions to minimize the cost of supply chain design and environmental impacts and two functions to maximize profitability and satisfaction with the use of technology, all aspects of a supply chain for perishable goods are considered. The proposed model of this research has been implemented for the B.A. food production company. This unit uses up-to-date equipment for production. The results of the study indicate the effect of demand on the objective functions. By analyzing the sensitivity to demand, it was found that a change in demand would lead to a change in the level of profitability, and the optimal demand would be reached when the production amounts of the factory are the same as the sales. In this paper, proper objective functions for each of the two objectives were introduced with appropriate constraints that consider all aspects. Further research can be done to investigate other issues. For example, customer demand maximization functions can be added to target functions by using strategic planning and maximizing customer satisfaction. For example, customer demand maximization functions by strategic planning and maximizing customer satisfaction can be added to objective functions. Fuzzy numbers can also be used instead of crisp numbers.

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