# The Supply Chain Management for Perishables Products : A Literature Review

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## Abstract

*In recent years, food loss has emerged as a global concern, with research indicating that between 20% to 60% of total production is lost within the food supply chain. Consequently, both researchers and practitioners have increasingly directed their attention towards maximizing the availability of food products for society. As a result, researchers have employed various operations research tools to optimize the food supply chain and facilitate decision-making processes. This paper aims to provide a literature review of modeling and optimization approaches in perishable supply chain management, with a specific focus on minimizing losses throughout the supply chain. Our primary emphasis is on perishable foods, and we analyze selected research papers based on their objectives, employed models, and solution approaches. Through our research analysis, we identify potential avenues for future research in the field of perishable products supply chains, with the overarching goal of reducing losses along the entire supply chain.*

***Key words :*** *optimisation, supply chain, perishable products.*

## I. Introduction

Supply Chain Management (SCM), a widely explored subject in research literature, transcends the confines of multiple academic disciplines. While SCM has been defined in various ways through diverse viewpoints, a widely accepted definition is that SCM involves the coordination of information, financial resources, and physical goods across all phases of the supply chain to deliver customer value and generate profits for all stakeholders within the chain (Enz and Lambert (2023)). SCM constitutes a comprehensive field, and over recent decades, researchers have approached it from a variety of perspectives.

Over time, the definitions of Supply Chain Management (SCM) have evolved and expanded to encompass a broader range of applications. However, these definitions have primarily revolved around manufactured goods and services, with relatively limited attention directed towards agricultural products or the food sector. Food supply chains (FSC) stand apart from other product supply chains in several distinctive ways. The fundamental distinction lies in the continuous and significant alterations in the quality of food products throughout the entire supply chain until they reach their final consumption points (Ahumada and Villalobos (2009)). Additionally, FSCs exhibit complexity exceeding that of other supply chains due to various factors, including the perishable nature of the produce, pronounced fluctuations in demand and prices, heightened consumer concerns regarding food safety, and reliance on climatic conditions (Mor et al. (2018)).

The substantial perishability of agricultural food products has led to an amplified global demand for increased food production. Simultaneously, reducing waste at every stage of the food supply chain presents itself as a viable option for capitalizing on heightened production levels. Primary operational factors contributing to wastage include inefficiencies in production, storage, handling, and transportation (Kuurdve et al. (2015), Anand and Barua (2022)). Furthermore, the absence of effective planning and management practices within food supply chains can emerge as a prominent operational factor in various nations. In developing countries, where farmers often hold small land parcels and engage in sharecropping, their limited access to technology, market insights, and financial incentives is also regarded as a contributing factor (Kc and Race (2019)).

Researchers and practitioners employ a variety of strategies to combat food loss and waste. To effectively reduce food loss, it is imperative to examine and take action throughout the entire food supply chain. Many countries, at the governmental level, employ diverse approaches to minimize loss. For instance, in the production stage, governments often support farmers by enhancing access to agricultural extension services, facilitating market entry, and advancing harvesting techniques. Moreover, initiatives such as improving handling and storage facilities, upgrading processing and packaging technologies, and conducting consumer education campaigns are proposed and implemented in various regions (Porat et al. (2018)). This review provides an evaluation of research conducted over the past decade concerning perishable food loss and optimization strategies employed to minimize losses within food supply chains, considering various facets of this multifaceted issue.

## II. Objective and Research Methodology

The primary aim of this paper is to conduct a comprehensive review of research within the realm of Food Supply Chains (FSC), specifically focusing on the issue of perishable food losses and the methodologies employed to optimize and enhance the sustainability of these supply chains. To fulfill this overarching objective, the review addresses the following key points :

**Segmentation of Research Papers :** The review categorizes and organizes research papers based on their relevance to perishable food losses and optimization strategies.

**Product Type Consideration :** It examines the types of perishable products studied in the research papers.

**Optimization Approaches :** The review assesses the various optimization approaches utilized in the context of perishable products within the food supply chain.

**Identification of Research Gaps :** It identifies areas within the existing body of research that warrant further investigation and exploration.

The papers included in this review are sourced from diverse scientific journals, such as Emerald Insight, Elsevier, and IEEE publishers, which are closely aligned with the paper's core subject matter. The research papers were selected based on specific keywords related to the food supply chain, including "food supply chain," "food supply chain loss," "post-harvest loss," and "food supply chain optimization." Relevant papers were further examined based on their titles and abstracts for inclusion in the review.

Numerous optimization approaches are employed for modeling and enhancing the food supply chain. In this review, our focal point is the perishable food supply chain due to the limited shelf life of perishable products and their prominent role as a primary source of food loss. Additionally, it is noted that there is relatively limited existing research on modeling and optimization within the domain of perishable Food Supply Chains, underscoring the need for further investigation in this area.

## III. General context

The current global population, standing at 7.2 billion, is anticipated to expand by one billion within the next 12 years, ultimately reaching 9.6 billion by the year 2050, as outlined in a 2013 United Nations report. Consequently, the growing challenge lies in the existence and accessibility of resources worldwide, prompting the need to devise strategies that can increase resource availability at a rate surpassing population growth (Madhav et al. (2018)). This reality is evident not only in practical terms but also through various literature sources, underscoring the concerted efforts of nations to create opportunities that meet the needs of their populations.

In contemporary times, the availability of "food" has become scarcer than ever, with the processes and methods of food production presenting significant challenges. In light of these circumstances, countries must prioritize sustainable means of food production and provisioning to ensure the well-being of their populations.

Rather than being solely attributed to factors like population growth or climate change, food loss within the food supply chain significantly impacts food security. According to a 2011 report by the FAO, as much as 50% of food produced for consumption is lost and wasted at various stages along the supply chain, spanning from the initial production to the final consumption phase, often referred to as "from field to fork." These losses and wastage manifest across all tiers of the Food Supply Chain (FSC), encompassing farming, processing, wholesaling, and even consumer levels. This phenomenon holds true for both developed and developing countries.

This issue raises profound moral questions, as wasting food while millions around the world suffer from hunger is a stark contrast (Watts (2013)). Additionally, it has the potential to precipitate a future food crisis (Savary et al. (2020)). The environmental consequences are also substantial, as the inefficient utilization of natural resources, such as water, energy, and land, takes a toll (Byaro et al. (2023)). Furthermore, the disposal of food waste in landfills leads to pollution and the release of methane, a potent greenhouse gas. Lastly, there are economic ramifications associated with food wastage, which ultimately affect all entities and individuals involved in the supply chain, including the end consumer (Krishnan et al. (2022)). Consequently, food loss has emerged as a significant global issue that has garnered the attention of governments, non-governmental organizations, and various sectors involved in the food supply chain (Mukwarami et al. (2023)).

Food loss and waste can manifest at various stages within the Food Supply Chain (FSC). These occurrences can occur during production or harvest, where grain and fruit may be left behind due to inadequate harvesting equipment or fish may be discarded for not meeting quality standards. Additionally, losses can transpire during handling and storage, resulting from food degradation caused by pests, fungus, and disease. In the processing and packaging stages, losses may occur in the form of spilled milk, damaged fish, or fruit that is unsuitable for processing.

Furthermore, during distribution and marketing, edible food may be discarded simply because it does not meet aesthetic quality standards. Finally, at the consumption stage, food purchased by consumers, restaurants, and caterers may end up uneaten, contributing to overall food waste (Bilska et al. (2022)).

The stages within the supply chain where losses occur and the underlying causes differ significantly between developed and developing countries. In developed nations, the predominant portion of losses transpires at the final stage of the supply chain. These losses are often attributed to challenges in interpreting food labeling, errors in purchasing plans, and inadequate food preservation techniques. In contrast, in developing countries, the most substantial losses occur at the initial stages of the food supply chain. This can be attributed to limitations in technology and infrastructure, particularly in areas such as transportation and storage. Additionally, a lack of expertise in various aspects, including land preparation, sowing, cultivation, harvesting, processing, and storage, contributes to losses (Lelea et al. (2022)).

Analysing the management of stocks of perishable products using the EOQ (Economic Order Quantity) model is of crucial importance in various sectors, including food, pharmaceuticals and logistics. This mathematical model can be used to determine the optimum quantity to order in order to minimise the total costs associated with stocks of perishable products (Rahal (2023)).

The literature offers diverse strategies and opportunities for mitigating food loss within the Food Supply Chain. These include consumer education (Luo et al. (2022)), the adoption of post-harvest technologies (Mutungi et al. (2023)), increasing waste disposal costs, fostering private and public sector partnerships to jointly reduce food waste, and sharing responsibility (Picavet et al. (2023)). Furthermore, the literature presents modeling and optimization approaches that support these strategies. Supply chain modeling and optimization encompass a wide range of factors, including inventory management, processing costs, scheduling and distribution strategies, and customer-specific demand, among others. This complexity stems from the fact that structuring a supply chain network is a multifaceted decision-making process. Addressing supply chain losses, managing supply and demand variability/uncertainty, and optimizing the supply chain network are essential components of serving customers efficiently (Schwab (2022)).

The modeling and optimization of Food Supply Chains (FSC) require a delicate balance between traceability and the capacity to realistically capture the fundamental aspects of food supply chains. Mathematical optimization stands as the predominant method for modeling the food production stage within these supply chains. Similar to the design of general supply chain networks, the configuration of a food supply chain involves determining variables such as the number, location, capacity, and type of processing facilities and distribution centers. Additionally, it entails quantifying the quantities of materials and items to be procured, manufactured, and transported from suppliers to customers. In the context of agri-food supply chains, special attention must be paid to logistics, particularly when dealing with perishable agricultural products. While models and solution methods for supply chain problems related to industrial products are relatively abundant, the same does not hold true for agri-food supply chain problems.

In the majority of research endeavors (Zerafati et al. (2022)), mixed-integer programming models are the preferred choice for supply chain network design. This preference can be attributed to the widespread popularity of these models. Given the NP-hardness of supply chain network design problems and the substantial scale of real-world problems, meta-heuristics, such as Evolutionary Algorithms (EA) (Hussain et al. (2023), Cheraghalipour and Roghanian (2022)), have gained widespread acceptance and application. In the following section, we delve into the application of these modeling and optimization approaches as employed in research studies.

## IV. Methods and Optimization Approaches

In this section, we delve into the research that centers on the reduction of perishable food losses and the optimization techniques employed. We organize the review papers according to the following categories :

**Research Segmentation :** This entails categorizing research by year of publication, the journal in which it was published, and the country of origin.

**Product Types Under Analysis :** We scrutinize the types of perishable products studied within the research.

**Optimization Approaches for Perishable Products :** We assess the optimization approaches utilized to address the issue of perishable products and delve into the corresponding solution methodologies.

## V. Modeling Approaches for Perishable Products

The escalating demand for food, particularly in the past decade, has led to a surge in research related to food-related issues, with food supply chain management studies claiming a substantial portion. These studies employ a diverse array of tools to aid decision-making in food supply chain management problems, all sharing a common objective of enhancing supply chain performance. Consequently, scholars have introduced a variety of modeling tools, including Linear Programming (LP), Mixed Integer Programming (MIP), Goal Programming (GP), Dynamic Programming (DP), Analytical and Simulation Models. Notably, Evolutionary Algorithms have also gained prominence as of late.

When it comes to optimization approaches in supply chain management, they can be classified as deterministic or stochastic, based on the parameters employed (Deliktas et al. (2023)). Deterministic modeling leverages various mathematical tools such as LP, DP, MIP, GP, among others. Conversely, for stochastic modeling approaches, techniques like Stochastic Programming (SP), Stochastic Dynamic Programming (SDP), and Stochastic Simulation (SIM) are utilized.

Over the years, there has been a significant upswing in research concerning the modeling and optimization of food supply chain systems. Within the context of this review, we focus on papers that delve into modeling and optimization techniques specifically tailored to perishable products, with an emphasis on the operational factors contributing to perishable food loss or waste. In a majority of research studies, losses occur at elevated rates during production, transportation, and inventory management activities across the food supply chain. Therefore, our review of modeling and optimization techniques is dedicated to these three operational facets within the realm of food supply chain loss.

### 1. Production Decision

The increasing demand for food products has led to a growing emphasis on decision-making techniques related to food production. Researchers have introduced numerous models addressing farm location, crop planting, and harvesting analysis. Several reviews have explored topics such as farm planning, demand planning, and the production and distribution of fresh produce, all of which pertain to production issues [39]. Within this production context, various decision-making approaches are employed to minimize losses or waste during the production stage. Traditionally, decisions were heavily reliant on the expertise and experience of individuals in the field. However, today, this conventional approach has been progressively replaced by operational research tools and mathematical models that assist in optimizing the food supply chain (Paul et al. (2022)).

(Rahal and Elloumi (2022)) are aims that the bullwhip effect is a phenomenon that occurs in supply chain management when there is an amplified variation in orders as they move up the supply chain from consumers to manufacturers or suppliers. This distortion in demand information can lead to inefficiencies, increased costs, and stockouts. While the bullwhip effect is a well-known concept, its impact on perishable products introduces some unique challenges. Thus, the bullwhip effect can have significant consequences for the supply chain of perishable products due to their limited shelf life and sensitivity to demand fluctuations. Implementing better forecasting, inventory management, and collaboration practices are essential for mitigating these challenges and improving the efficiency of the supply chain for perishable products.

For instance, (Khan et al. (2022)) analyzes plant production under uncertainty, examining crop growth and price formation through simulation and regression meta-modelling. (Allende et al. (2022)) employ simulation modeling to monitor and mitigate microbiological food safety risks across all phases of food production and supply. Furthermore, they utilize simulation to assess climate change scenarios and the logistics of fresh produce distribution, optimizing the system to maintain the quality and safety of fresh produce (Vilas-Boas et al. (2023)). In many of the reviewed papers, operational decisions related to production are geared toward long-term profit objectives (Almeida et al. (2022)).

The review reveals a prominent focus in the majority of papers on aspects such as supply fluctuations, farm labor productivity, production technologies, harvesting scheduling, and farm locations (Abbas et al. (2022), Jazinaninejad et al. (2022), Gupta et al. (2023)). Notably, optimization tools such as LP, MIP, SIM, DP, and SP are frequently employed. However, it is evident that there has been relatively limited attention directed toward addressing loss or waste at the production stage within these papers. The primary objective for most of these studies is revenue maximization, with loss reduction receiving comparatively less emphasis.

Furthermore, the studies primarily concentrate on developed countries, with limited attention devoted to developing countries where substantial losses occur, particularly at the production (harvesting) stage.

## 2. Transportation Decision

Transportation plays a pivotal role in connecting economic activities and forming the bedrock of a sustainable supply chain. Without efficient transportation, products cannot be effectively moved across various stages of the supply chain. In the context of perishable products within the food supply chain, transportation assumes a critical function as it can significantly impact product quality. Consequently, optimizing transportation in the food supply chain is of paramount importance for ensuring the sustainability and security of the food supply.

Linear Programming (LP) has emerged as the prevailing modeling approach for optimizing transportation, primarily due to its user-friendly nature and its capacity to accommodate a wide range of decisions. These decisions encompass aspects such as scheduling, the capacity and location of distribution centers, site selection, transportation investment, and more (Wang et al. (2023)).

The majority of reviewed papers on transportation modeling and optimization predominantly concentrate on minimizing transportation costs within the food supply chain (Becerra et al. (2022), Luo et al. (2022), Krishnan et al. (2022)). Relatively fewer papers delve into the issues of losses or waste associated with transportation and logistics activities within the food supply chain. According to (Aragao et al. (2022)), transportation accounts for some of the highest levels of loss or waste in food supply chain management. This can be attributed to the handling and deterioration of products during transportation activities (Tirkolaee and Aydin (2022)). Consequently, decisions regarding vehicle routing, especially concerning time windows for perishable food products, have become crucial to meeting customer demand with minimal time, distance traveled, and vehicle usage. This kind of modeling problem is notably intricate and has garnered increased attention from researchers.

In the realm of food supply chain management, numerous literatures employ diverse modeling approaches for optimizing transportation. These approaches encompass LP, Mixed Integer Programming (MIP), Dynamic Programming (DP), Non-Linear Programming (NLP), and Stochastic Dynamic Programming (SD). Specific instances include the application of mixed-integer linear programming by ((Omar et al. (2009)), Rong et al. (2011)) using dynamic programming for agri-food supply chains, and (Chen et al. (2009)) employing a non-linear programming model for food product distribution, with transportation cost minimization and revenue maximization serving as primary objectives.

In addition to conventional optimization approaches, scholars are incorporating state-of-the-art techniques such as neural networks, fuzzy optimization, genetic algorithms, and particle swarm optimization into the design and analysis of various supply chain systems. For example, (Paksoy et al. (2012)) utilized a fuzzy optimization technique with the aim of minimizing transportation costs, while (Xia et al. (2011)) employed a hybrid particle swarm optimization approach to optimize both production and transportation costs within the agri-food supply chain.

Upon reviewing the literature, it becomes apparent that the majority of research in transportation and distribution systems does not directly target loss minimization. Nonetheless, these studies can serve as valuable inputs for optimizing loss reduction efforts. Only a limited number of research papers have addressed issues related to fresh produce, particularly losses incurred during transportation and handling. Furthermore, it is evident that time plays a critical role due to the stringent delivery windows imposed by customers and the continuous deterioration of fresh produce. In a general context, when modeling or optimizing transportation in perishable product supply chains, it is imperative to consider loss as a crucial factor. Doing so not only maximizes revenue but also enhances the availability of food.

## 3. Inventory Decision

In many inventory systems, the assumption typically made is that stock items can be stored indefinitely to meet future demands. However, the impact of perishability cannot be disregarded when dealing with certain types of inventories, as they may gradually or entirely become unsuitable for consumption over time. Consequently, managing perishable products presents a significant economic challenge (Liu et al. (2021)). Perishable products are highly sensitive to temperature conditions during handling and necessitate specific storage conditions to maintain their freshness. Once an item loses its freshness, it is considered lost and no longer safe for use. Consequently, perishable inventory management has garnered extensive attention, with numerous models proposed by researchers. (Santos et al. (2020)) have conducted reviews of inventory theories pertaining to perishable products.

Managing stocks of perishable products is a complex but essential aspect of supply chain management. Perishable products, such as fresh produce, pharmaceuticals and dairy products, have a limited shelf life and are highly susceptible to spoilage. Effective stock management for these products involves a number of key considerations. Firstly, it is essential to forecast demand accurately to ensure that the right amount of stock is available to meet customer demand without excess. (Rahal and Elloumi (2021)) have argued that good stock management of perishable products minimises wastage, maintains product quality and ensures that customers have access to fresh, safe products when they need them.

Research has categorized these models based on product characteristics, leading to the classification of inventory models into three categories : (1) models for inventory with a fixed lifetime, (2) models for inventory with a random lifetime, and (3) models for inventory that decays, correlating with a proportional decrease in utility or physical quantity (Qiao et al. (2023)). This review primarily analyzes models associated with the third type of inventory issue, which pertains to perishable food inventory that degrades in terms of its quality, notably its shelf-life.

(Singh et al. (2022)) employed a dynamic pricing model as an approach to reduce food spoilage waste and maximize profit by leveraging product shelf life. Their methodology incorporated a kinetic model to predict the product's shelf life.

In the work of (Lejarza and Baldea (2022)), a simulation optimization framework was proposed for managing supply chain inventory, particularly for highly perishable products. Their optimization approach centered on a class of order-up-to policies, specifically designed for handling such highly perishable products, including fresh vegetables/fruits, dairy/meat, and blood, within a single-vendor multi-buyer supply chain. The study validated the formulated mathematical model using a case study of a regional blood center. Additionally, other studies by (Aleawabdeh (2021)) operated under the assumption that certain products, such as blood platelets and packaged food, expire rather than undergo decay after a specific period of time.

(Fudhia et al. (2023)) employed a system dynamics approach as a modeling and analysis tool to address strategic issues within the food supply chain, both for single and multi-echelon supply chains. The research specifically examined capacity planning policies, taking into account transient flows influenced by market parameters or constraints. This examination was conducted using a multi-echelon network of a fast-food chain.

(Avanzini et al. (2023)) proposed a dynamic programming methodology for optimizing agri-chain supply chains, giving due consideration to product appearance and quality. Optimization was achieved through the development of routes that factored in distribution and storage to minimize supply costs. In the context of inventory models for perishable products, the deterioration rate emerged as a critical factor. Most studies assumed a constant deterioration rate in their inventory models, although a few authors considered exponential deterioration rates, with some following a Weibull distribution pattern (Bankole et al. (2022)).

The review highlights that the majority of studies primarily address operational decisions within the inventory system, encompassing factors like demand, transportation lead time, storage capacity, and inventory policies. Notably, there is limited consideration of loss reduction decisions within the existing literature. Consequently, this becomes a crucial avenue for researchers and practitioners to explore in future studies.

### 4. Supply chain sustainability

CO2 emissions in the supply chain management for perishable items refer to the greenhouse gas emissions, specifically carbon dioxide (CO2), that are generated throughout the various stages of the supply chain, from production or sourcing to distribution and consumption of perishable goods. Managing and reducing these emissions is crucial for both environmental sustainability and cost-efficiency. Dwivedi et al. (2020) suggested a new twoechelon agro-food grain SCN with carbon emissions as well formulated a new MINLP model. Their goals are to minimise the total transportation costs and carbon emissions. Hence, quantum-based genetic and genetic algorithms are utilised to "nd Pareto solutions. Rabbani et al. (2020) developed a multi-objective multi-period sustainable location-allocation SCN model under uncertainty considering CO2 emissions. To handle uncertainty parameters, a novel approach of uncertainty named hybrid robust possibilistic programming-II (HRPP-II) was suggested. Finally, a case study was solved by the improved augmented ε-constraint method (AUGMECON2) to attain Pareto solutions. Cheraghalipour et al. (2019) suggested a bi-level formulation for a rice SCN using an algorithm constituted by a hybrid of the PSO and GA, and a modi"ed version of the GPA meta-heuristic algorithms. Roghanian and Cheraghalipour (2019) presented a set of meta-heuristic algorithms for a multi-objective closed-loop citrus SCN regarding CO2 emissions, which sought to maximise demand responsiveness and minimise total costs and CO2 emissions.

## VI. Conclusion

This paper explores the modeling and optimization techniques employed in the literature concerning perishable food supply chains. The focus extends beyond product perishability to encompass waste and loss assessment within the food supply chain. The utilization of modeling and optimization tools spans various domains to enhance decision-making and attain greater advantages. In the contemporary landscape, decisions regarding supply chain matters have grown increasingly complex due to the heightened intricacies of the system.

In this review, we initially organized the papers by publication year and country. This examination revealed that approximately 60% of the papers were published within the past two years. This trend suggests that researchers and practitioners are paying heightened attention to the issue due to the global scarcity of food and related products. Furthermore, the scarcity of research related to modeling and optimization approaches within the field of perishable food supply chain management contributes to the increased volume of recent publications. Additionally, the development of novel state-of-the-art optimization approaches has prompted researchers to apply these tools in their own research endeavors.

Research papers primarily originate from developed countries, addressing various food and supply chain management issues. However, it is important to acknowledge that food loss is a global problem affecting all nations. Hence, future research efforts in developing countries should prioritize optimizing food loss to enhance food availability.

Within this review, the literature is also categorized based on the strategies employed to facilitate decision-making in food supply chain management. The predominant approach in most research papers involves the use of Linear Programming (LP) models to optimize the food supply chain. However, recent papers have started incorporating state-of-the-art optimization techniques such as evolutionary optimization approaches. Furthermore, a substantial portion of these papers relies on case studies to validate their models. This suggests that the adoption of advanced modeling techniques is maturing and warrants further exploration in the realm of perishable food products.

The paper focuses on production, transportation, and inventory as the main stages where food loss is most prevalent in the agricultural supply chain. From the review, it is evident that many research efforts concentrate on maximizing revenue within the supply chain. However, it is crucial to note that there is significant food loss along the food supply chain, and limited attention has been given to mitigating this loss. This presents an opportunity for researchers and practitioners to leverage optimization tools to reduce food loss within perishable food supply chains.

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