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COST OPTIMISATION OF SUPPLY CHAINS IN THE FOOD INDUSTRY: COST FUNCTION MODELLING

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Abstract

The food industry faces complex challenges in managing supply chains, significantly affecting operational performance and costs. This paper explores the critical factors influencing the efficiency of food supply chains, such as product perishability, seasonality, climate change, and high logistics costs. The study uses an applied approach based on modelling a cost function that integrates the main components of supply chain expenses — procurement, transportation, warehousing, production and distribution — and how they are affected by industry-specific challenges. The proposed cost function allows for assessing the impact of these variables on total costs and identifying critical areas for optimisation. The results obtained demonstrate that monitoring logistical conditions, adjusting stocks based on seasonal forecasts and optimising transport routes are essential measures to reduce losses and increase the competitiveness of companies in the food industry. The study's applied impact consists of providing a practical cost optimisation tool applicable to manufacturers and distributors. The conclusions emphasise the importance of an integrated approach to risk and cost management in the food industry, providing recommendations for sustainable practices and strategies to increase long-term competitiveness.

Keywords: supply chain, cost, efficiency, food logistics, cost function

JEL classification: M11, M21

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Introduction

The food industry plays an essential role in the global economy, providing livelihoods for millions of people worldwide. This vast sector includes segments such as the fresh food, processed, and feed industries, each with its own specific, diverse environmental supply chain management requirements. Due to this complexity, the food industry's supply chain faces numerous challenges. Food supply chains are under unprecedented pressure in the current context, marked by global crises such as the COVID-19 pandemic, the war in Ukraine, and geopolitical instability in the Middle East. The COVID-19 pandemic has disrupted supply chains through transport restrictions, temporary closures of production units, and sudden changes in consumer demand (Ivanov, 2024). At the same time, the war in Ukraine has significantly increased agricultural raw materials and fuel prices, affecting production and distribution costs (European Council, 2024). Efficient logistics is vital, requiring delivery of the right products in the correct quantity and condition, at the right place and time, and at the optimal cost. This requirement is even more stringent in the food industry, where the perishable nature of the products requires additional measures, such as storing and transporting fruit under ideal conditions (controlled temperatures and optimal relative air humidity).

The development of businesses in the food industry is closely related to the increase in consumer demand. Food plays an increasingly complex role in society beyond satisfying basic needs and becoming a vector of cultural identity (Untari and Satria, 2021).

The supply chain consists of a set of activities through which raw materials are transformed into finished products and delivered to consumers. It involves several stages, from suppliers and manufacturers to warehouses, distribution centres, retailers, and end customers. Christopher and Gattorna (2005, p.115) defined supply chain management (SCM) as “the management of relationships with suppliers and customers to deliver superior value at reduced cost throughout the supply chain.” Stadtler et al. (2011, p.5) added that SCM involves “the integration and coordination of organisational units along the supply chain to synchronise the flows of materials, information, and resources necessary to ensure the competitiveness of the entire system”.

Supply chain management is critical to the success of modern companies. It involves planning, organising, and controlling the flow of goods, services, and information about the initial supplier to the final consumer (Hemant et al., 2022). The main objective of SCM is to maximise their profitability and satisfaction by reducing system-wide costs and ensuring the delivery of products and services at the right time and price (Wen and Gu, 2014).

Supply chains in the food industry are essential for the efficient distribution of products. They encompass all stages of production, from raw materials to delivery to the final consumer. These chains involve a variety of actors, from farmers and processors to distributors and traders. Integrating sustainability principles into food supply chains is essential to ensure long-term food security in a world affected by demographic pressures and climate change.

The food industry faces significant challenges in managing supply chain costs, which can directly affect the competitiveness of companies in this sector (Cagliano et al., 2016). The agri-food chain includes the production, processing, distribution, and consumption of food, which is an essential component of this industry. However, the current structure of these chains can generate inefficiencies and high costs, which contribute to the unsustainability of the entire system (Cagliano et al., 2016). Efficient logistics, ensuring delivery of the right

product, in the correct quantity and condition, at the optimal place and time, is essential for the success of this sector (Gebresenbet and Boso, 2012), having a positive impact on all partners in the supply chain.

The food industry contributes significantly to the global economy, being an important pillar of GDP in many countries, especially developing countries. Current trends in the food value chain are characterised by an increasing concentration of farms, food industries, and wholesalers and the evolution of integrated supply chains, which link producers with other actors in the system (Handayati et al., 2015; La Scalia et al., 2017).

Food business development is strongly influenced by consumer demand, which has evolved beyond simply satisfying basic needs, becoming a determining factor of consumer preferences. Despite the importance of efficient supply chain management, many food companies face difficulties optimising costs and maintaining competitiveness. Structural inefficiencies in supply chains can lead to high costs, product losses, and a negative impact on the entire system's sustainability. In this context, there is an acute need for optimisation models that integrate multiple variables, such as seasonality, industry-specific risks, and complex logistical requirements. The present paper aims to develop an integrative cost model for food supply chains, considering seasonal and sector-specific risk factors. Unlike previous studies, which individually address aspects such as logistics efficiency or sustainability, this model will provide a holistic perspective on cost optimisation by proposing an applicative model for cost optimisation in food industry supply chains, integrating variables such as seasonality, demand volatility, and logistics risks, as well as analysing the impact of costs on supply chain performance. By combining theoretical analysis with a practical model, the paper aims to make a relevant contribution to both the specialised literature and at the sector level, providing an applicable tool for managing the unique challenges of this sector.

1. Literature review

To achieve competitive advantages and high profitability, managers must use a variety of innovative strategies (Koc and Bozdog, 2017). Supply chain management is an effective strategy used to reduce costs and increase efficiency, thus contributing to profitability (Xia et al., 2015). The supply chain runs from the receipt of raw materials to the delivery of the product to customers. Developing and maintaining agility in the supply chain to meet customer demand while minimising company costs is a challenge for the management of any organisation (Tarafdar and Qrunfleh, 2017).

Over time, several specific theories and models have addressed supply chain management, each of which is very important because they emphasise different aspects of supply chain efficiency and optimisation. One of the important theories applied to supply chains is Systems Theory, which views supply chains as an interconnected system, where each system component (supplier, manufacturer, distributor, customer) depends on the others to function effectively. One of the prominent supporters of this theory, Von Bertalanffy (1968), laid the foundations of this model and highlighted that a system cannot be understood only by analysing its components separately but by understanding the relationships and interactions between them. In this context, a specific aspect of system theory is the application of systemic thinking to industrial and supply chain problems, emphasising the importance of dynamic system modelling to understand the complexity and side effects of changes in supply chains (Forrester, 1995). At the same time, Harland (1996) approaches the supply chain as a

complex system of relationships between parts and suggests a holistic approach between the parts of the system based on complex and interdependent interactions.

SCOR (Supply Chain Operations Model) is a new model developed for analysing, measuring and improving supply chains, being considered one of the most effective and complete tools for managing supply chains. The SCOR model is an SCM diagnostic tool that enables users to understand the processes involved in a business organisation and identify the vital characteristics that lead to customer satisfaction (Ntobe et al., 2015). SCOR enables companies to examine the configuration of their supply chains, identifies, and eliminates redundant and wasteful practices along supply chains (Li, Su and Chen, 2011).

The “Bullwhip Effect” theory explains how slight variations in consumer demand can lead to large fluctuations in the supply chain, amplified as information moves upstream from the distributor to the manufacturer. This can lead to unnecessary inventory, high costs, and inefficiencies. Hau Lee is one of the authors who described this phenomenon in detail and emphasised the importance of collaboration and informational transparency between supply chain partners to mitigate this negative effect (Lee et al., 1997).

Integrating “Just in Time” (JIT) theory into the supply chain is a methodology developed since the 1970s and focuses on delivering materials and products on time, exactly when they are needed in the manufacturing or distribution process to customers, so that there is a continuous, uninterrupted flow in the supply chain. In a dynamic business environment, the integration of the JIT methodology in the supply chain management contributes to the improvement of operational efficiency and competitiveness in international markets, helps companies to reduce costs, improve quality, and offer a varied range of products with fast and reliable delivery (Vokurka and Lummus, 2000). “Just in Time” supply chains have been the subject of much research in operation management (Chung, Talluri and Kovács, 2018; Yao and Hsu, 2018; Tseng et al., 2019; Yang et al., 2021). A JIT supply chain brings a multitude of advantages to companies, including reduced costs, reduced inventory, improved product quality, reduced delivery time, increased responsiveness, improved customer satisfaction, and other superior competitive advantages (Latifah et al., 2021).

Another theory specific to the supply chain is Lean Supply Chain, which is based on the elimination of waste in all specific stages of the supply chain, in order to continuously improve and optimise processes (Manzouri and Rahman, 2013). At the same time, specialists in the field emphasise the importance of flexibility and the ability to quickly react to changes in demand and market conditions by integrating the theory of agility. Thus, in an agile supply chain, processes are designed to deal with uncertainties and deliver products or services quickly and adaptively (Yusuf et al., 2004).

These supply chain management governing theories share the goal of increasing operational efficiency, reducing uncertainty, and improving flexibility, enabling companies to respond more quickly to changing consumer demands or external challenges. Their implementation can contribute to increased competitiveness and rapid adaptation in a constantly changing business environment.

In recent years, in addition to traditional theories, emerging technologies such as artificial intelligence (AI), blockchain, big data analytics, and the Internet of Things (IoT) have begun redefining supply chain efficiency, providing a higher level of automation, visibility and process optimisation. These innovations improve food traceability and safety and play a crucial role in optimising operational costs. A relevant example is the use of Blockchain and

IoT technologies in food traceability and the safety of supply chains, which brings significant benefits such as increased transparency, operational efficiency, increased consumer confidence, and support for sustainable development. However, this implementation involves challenges, such as high initial costs and the need for adequate infrastructure (Kurniawan et al., 2025). In addition, the ability of digital technologies to process a large amount of information in real-time is particularly important for optimising supply chains, contributing to increased operational efficiency, reduced human errors, and greater data accuracy (Odumbo and Nimma, 2025). The use of blockchain in demand forecasting offers a significant advantage, optimising supply chain management and ensuring greater transparency of logistics flows. At the same time, combining machine learning and evolutionary algorithms with support vector regression improves demand forecasting accuracy, contributing to the optimisation of supply chain processes (Douaioui et al., 2024). In addition to the obvious technological benefits, an essential dimension of these innovations is their impact on cost optimisation. Reducing waste, improving inventory management, and increasing the ability to react to market changes increase operational efficiency and generate significant savings for companies. Integrating advanced digital solutions allows for minimising logistics and operational costs, thus maintaining competitiveness in the food industry.

Furthermore, the incorporation of advanced data analysis and economic uncertainty, such as price volatility, not only helps to anticipate potential disruptions, but also to develop strategies that reduce their impact on the supply chain and improve the overall profitability of companies (Chen et al., 2024). Several authors have investigated critical aspects related to supply chain costs, highlighting different perspectives and solutions for their optimisation. Chen and Notteboom (2014) highlighted the importance of value-added logistics services in optimising costs and improving supply chain efficiency. In a complementary approach, Hu, Hu, and Xia (2019) analysed the investments needed to reduce costs and determined the role of each entity in the supply chain, investigating the relationship between manufacturers and retailers. Building on these studies, our research aims to apply and extend these approaches, providing a detailed analysis of cost optimisation in food industry supply chains.

2. Research methodology

This research is based on an applied approach, using theoretical analysis and a quantitative component to evaluate cost optimisation in the food supply chain. To ensure a rigorous understanding of supply chain management, the first stage of the research consists of a literature review to identify the main theories and concepts relevant to SCM. This serves as a theoretical foundation for the formulation of the applied model.

In the applied stage, the research uses a supply chain-specific cost function, integrating multiple components that influence operational and financial efficiency. The formulation of this cost function takes into account the following variables: acquisition costs of raw materials and auxiliary materials, transportation costs (internal and external) and distribution, handling and storage costs, including logistics infrastructure costs, production costs, which include labour, utilities and other operational expenses, costs associated with inventory management, taking into account maintaining an optimal balance between supply and demand, costs of losses, and inventory depreciation.

In order to assess the impact of these variables on total costs and operational efficiency, a systematisation of these variables is applied according to: i) storage and distribution period (expressed in days), ii) storage and transportation conditions (temperature, delay times), iii) percentage of product losses (determination of the impact on the marketable quantity), iv) costs associated with losses (assessment of the financial impact) and v) potential lost income.

The data used in applying the cost function comes from empirical sources. They were collected from a Romanian company in the food industry that specialises in producing and marketing apples. This data includes specific financial and operational information, which allows for realistic modelling of the supply chain and evaluation of the efficiency of the cost optimisation strategy. To ensure the relevance and validity of the results, the cost function analysis is performed based on historical data provided by the company, and the models used are calibrated to reflect the real dynamics of costs in the food industry.

2.1. Modeling the cost function in the food supply chain

To achieve performance objectives, the management of any company must ensure both functionality and competitiveness through a permanent adaptation and improvement of the management system to the current situation in the company, the organisational culture and the socio-economic context in which the organisation carries out its activities (State et al., 2022). Thus, to reduce costs, a company must know how to measure the cost of the supply chain. The cost of the supply chain is defined as all relevant costs in the supply chain of the company or organisation in question (Pettersson and Segerstedt, 2013). Sachan et al. (2005) studied the total cost in the supply chain of cereal production and defined it as the sum of the farmer's price, the total additional cost, the total markup, and the total waste. The farmer's price is the cost of growing and processing the cereal and the margin for the farmer. Additional costs include material storage cost, transportation cost, order processing cost, and packaging cost. Total markup cost is the amount added to the cost to obtain the selling price. Supply chain cost management requires optimising both fixed and variable costs and adopting efficiency-increasing approaches in all processes (Simchi-Levi et al., 2014). Supply chain cost elements come from different components at each stage, and these components significantly affect the total cost structure (Ayvaz, 2024).

Understanding and managing these cost elements effectively allows organisations to optimise their cost structures, so for effective supply chain cost management, it is essential to define a cost function that considers all major components, including procurement, transportation, warehousing, production, and distribution of products.

The general cost function can be represented as follows:

$$C(X) = C_{\text{acquisition}}(X_1) + C_{\text{trans}}(X_2) + C_{\text{storage}}(X_3) + C_{\text{prod}}(X_4) + C_{\text{dist}}(X_5) + C_{\text{stock}}(X_6) + C_{\text{losses}}(X_7) \quad (1)$$

Where:

$C_{\text{acquisition}}(X_1)$ Raw materials acquisition costs.

$C_{\text{trans}}(X_2)$ Raw materials and finite products transportation costs.

$C_{\text{storage}}(X_3)$ Storage costs (including perishable products associated costs).

$C_{\text{prod}}(X_4)$ Production costs (including workforce and utilities costs).

$C_{dist}(X_5)$ Finite product distribution costs, towards clients or towards selling points.

$C_{stock}(X_6)$ Stockpile management costs.

$C_{losses}(X_7)$ Product expiration or product returning related costs

This cost function enables the evaluation of each segment in the supply chain, providing an integrated view of cost sources and optimisation points.

Raw materials in the food industry are often subject to price fluctuations due to seasonal and climatic conditions or market demands; thus, monitoring raw material acquisition costs is essential to negotiate favourable prices and maintain an optimal ratio between quality and cost. Also, transportation in the food industry requires special attention due to the strict requirements regarding delivery time and temperature conditions, especially for perishable food products. Transport costs can increase significantly if long distances or the need for special vehicles are involved. Optimising routes and choosing the proper logistics providers are critical factors. Efficient transportation and logistics strategies can help reduce transportation costs and prevent time loss. In addition, integrating transportation methods and using multimodal transport options play a critical role in cost optimisation (Arendt et al., 2011). Storage costs can add up quickly for perishable products, especially when refrigeration is required. Efficient inventory management and modern technologies such as the “Internet of Things” (IoT) to monitor storage conditions can significantly reduce these costs.

Food processing involves many costs related to labour, utilities, and equipment maintenance. Optimising production processes through automation technology and implementing efficient energy management can reduce production costs. These costs can be optimised by improving more efficient production processes (Harrison et al., 2019). The distribution of finished products is a significant challenge for the food industry due to the requirements for fast delivery and the need to maintain product freshness. Optimising the distribution chain can bring about considerable savings by reducing travel distances and efficiently managing transport capacities. Keeping too much inventory can lead to high costs, while being out of stock can negatively affect customer relationships. Proper inventory planning, based on accurate demand forecasts, is crucial to reducing these costs.

Perishable losses can be a significant source of cost in the food industry. Solutions such as improving product traceability and optimising the supply chain can reduce wastage, thus helping to increase overall efficiency. An important aspect is integrating the cost function into the technological process, which gives companies a complete view of the expenses associated with each step in the supply chain. This brings several important advantages, among which we enunciate: i) reduction of financial risks by continuous monitoring of costs and their optimisation; ii) operational efficiency; iii) adaptability to market requirements; iv) increasing profitability by optimising each component in the supply chain (Figure no. 1).



Figure no. 1. The advantages of integrating the cost function into the technological process

A well-defined and adequately modelled cost function is essential in optimising supply chains in the food industry. Companies can identify opportunities for cost savings and process efficiencies by understanding and evaluating each cost function component. Cost optimisation is a strategic approach necessary to maintain competitiveness and ensure long-term success in an industry characterised by volatility and constant pressure to improve efficiency.

2.2. From cost function to challenges in food supply chains

The cost function described above provides a detailed structure of how costs are distributed throughout a food company's supply chain. However, this function does not operate in a vacuum — each cost component is influenced by specific challenges that can significantly affect operational efficiency and financial stability.

Among the challenges in food industry supply chains and how they affect each component of the cost function, we highlight:

- **Volatility in raw material prices and procurement costs.** In the food industry, the prices of raw materials (such as grains, dairy, meat, and vegetables and fruits) fluctuate significantly depending on the season, weather conditions, and global market demands. For example, severe droughts or floods can reduce the availability of some raw materials, thus increasing purchase prices. Changes in international trade policies can also influence prices or access to raw and/or auxiliary materials. Rising raw material prices directly affect the cost of purchases, increasing total costs and reducing companies' profit margins. Procurement planning thus becomes critical to mitigate the impact of these fluctuations.
- **Logistical complexity and transport costs.** The food industry relies on fast and efficient transport, especially for perishable products that require special conditions (refrigeration, through protection at optimal temperatures). Transport costs are, in turn, affected by volatile

fuel prices, infrastructure problems, and labour shortages in the transport sector. Delivery distances and requirements for special shipping conditions directly influence shipping costs. In addition, fuel price fluctuations or a lack of available transport capacity can lead to rapid and unanticipated increases in logistics costs.

- Limited storage capacity and perishable product management. Food products often have a limited shelf life, and effective inventory management is essential to minimise losses. Improper storage can lead to product spoilage, and limited storage space and the need for refrigeration add further pressure on storage costs. Storage costs are increased when constant refrigeration is needed or when storage capacity is not used efficiently. Overcrowded warehouses or failure to comply with appropriate conditions can also lead to significant product losses, indirectly increasing costs related to losses caused by product expiration or returns $C_{losses}(X7)$.

- Instability of demand and production costs. Demand in the food industry can fluctuate significantly due to seasonality or changes in consumer behaviour. This instability imposes an additional challenge in production planning, where the ability to respond quickly to market demands is essential to avoid missed opportunities. Demand volatility affects production costs, as companies must constantly adjust production lines, either to meet increased demand (which may require overtime and rapid investment in equipment) or to slow down production to avoid overproduction. This necessary flexibility in production can lead to additional costs.

- Distribution issues and inventory management. Effective inventory management is a challenge in the food industry, especially due to products' limited shelf lives. A delay in distribution or ineffective inventory planning can lead to product expiration, resulting in direct losses. Inventory management costs increase as products expire or if inventory is insufficient to meet demand. In addition, distribution costs are influenced by the need to quickly transport products to customers, sometimes using more expensive routes to reduce transit time.

- Significant customer product returns and losses. The food industry frequently experiences losses due to product expiration, packaging errors, or other quality issues. In addition, customer returns (either due to defects or shelf life) can incur additional costs. Returns and losses increase costs related to losses due to product expiration or returns, which can majorly impact a company's profitability. Effective product management, optimising traceability and preventing risks associated with perishability are essential to minimise these losses (Figure no. 2).

- Even though the cost function provides a clear picture of the costs associated with each component of the supply chain, to achieve real optimisation, food companies must consider numerous operational challenges that directly affect these costs. Each of these challenges — from raw material price volatility to perishable product management and efficient distribution — affects the cost function and, by implication, the financial health of the entire business. By addressing these challenges with innovative solutions (such as IoT technologies, predictive analytics or logistics optimisation algorithms), companies in the food industry can improve supply chain efficiency and gain a competitive edge in the market.

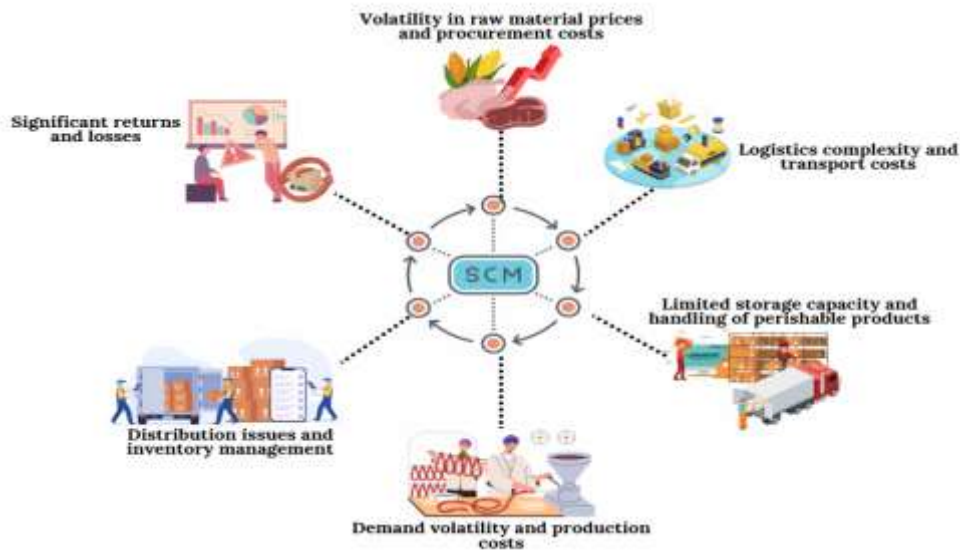


Figure no. 2. The role of SCM in solving challenges in the food industry

3. Results regarding the introduction of risk factors into the cost function – financial implications

The food industry is exposed to several external and internal factors that can significantly affect operational performance and, by implication, the cost function. Perishable food products such as fruits, vegetables, dairy, and meat have a limited shelf life, making their handling, transport, and storage highly sensitive to time and environmental conditions. Improper handling, inadequate temperatures, and delays in shipping can lead to significant product losses. To incorporate these risk factors, the cost function must be adjusted to include new variables that capture uncertainties and potential losses.

Thus, the additional costs associated with losses due to perishability can be modelled by a function proportional to storage time or logistics delay time.

$$R_{\text{perishability}} = \alpha / T_{\text{storage}} \quad (2)$$

Where:

α is the coefficient that reflects the rate of degradation of the product

T_{storage} represents the time of storage or shelving of the product

For example, to exemplify the risk of perishability for a company, the activity is the production and distribution of fruit (apples), we must consider the optimal conditions throughout the supply chain and their impact from a financial point of view depending on the times and storage conditions. The flow chart of the entire technological process from production to marketing of apples is represented in Figure no. 3.

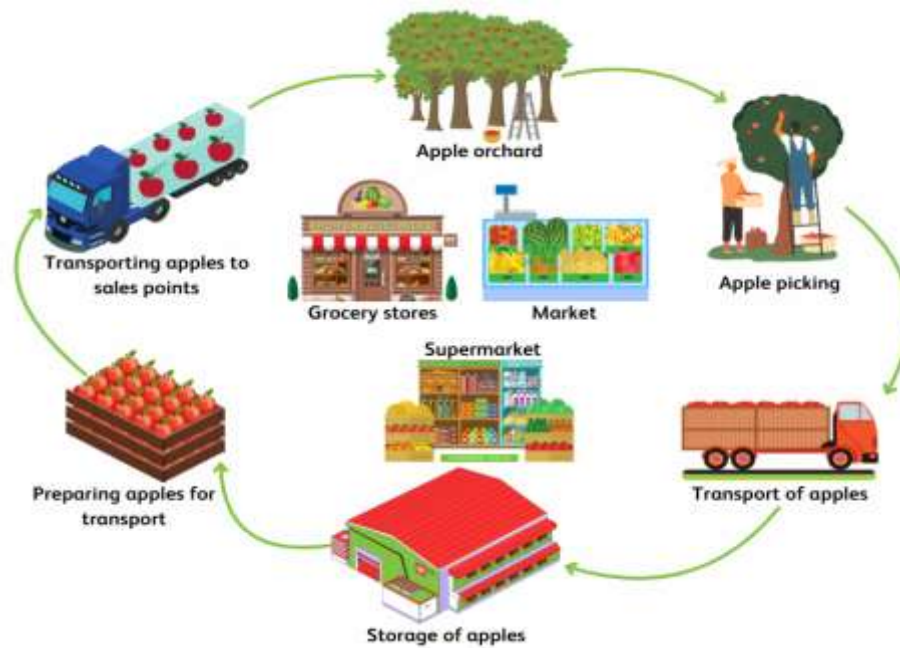


Figure no. 3. Logical scheme of the entire production-harvesting-distribution-marketing process

Under controlled temperature conditions, apples can last up to 4 - 6 months, while under ambient temperature conditions the life span can reach only 1-3 weeks. In this context, the risk of perishability directly influences the amount of products lost, but also the cost of these losses, which, in addition to the cost of production, must also include the loss of income.

$$C_{\text{perishability}} = C_{\text{production lost}} + L_{\text{rev}} \quad (3)$$

Where:

$C_{\text{perishability}}$ = Cost of quantity of production lost

$C_{\text{production lost}} = (\text{Amount of production obtained} * R_{\text{perishability}}) * CT_{\text{ppld}}$

CT_{ppld} = total costs of production, packaging, transportation and distribution of the product

L_{rev} = loss of revenue = Quantity of production lost * Selling price

The data presented in Table no. 1 illustrates the impact of logistical and storage conditions on apples' perishability, highlighting the risks associated with each stage.

Table no. 1. The risk of perishability, depending on the stages of the supply chain

Stage	Day	Conditions	Potential losses	Observations
Harvesting and cold storage	1	Ideal conditions	0%	The apples are fresh, without damage.
Transportation and handling	7	Room temperature, transportation delay	1-3%	Exposure to uncontrolled conditions can cause deterioration and softening.
Distributor storage	14	8-15°C, poor storage conditions	3-5%	Product life is reduced, and commercial appearance may be affected.
Shelf display at the selling point	21	Room temperature	5-8%	The risk of damage increases significantly, leading to commercial losses.

Cumulative losses of approximately 12% are caused by factors such as uncontrolled temperatures and extended time to market. Under ideal conditions (continuous cold storage), losses could have been minimal, but delays and poor management amplify the risk of depreciation. These data are taken directly from the analysed company, which provided the relevant information for this study. As part of the research methodology, we collaborated with it to obtain precise data on logistics and storage conditions and their impact on apple perishability.

To reduce losses due to perishability, optimal storage and transport parameters must be observed. Monitoring temperature (°C) and relative air humidity (%), along with observing hygienic and sanitary conditions, contributes to maintaining the freshness of fruits over a long period. Therefore, applying appropriate conditions throughout the supply chain can significantly reduce economic and commercial losses.

In this context, Table no. 2 presents a new fruit storage scenario based on the essential parameters of temperature and humidity. Scenario II, in which apples are stored at a temperature between 0 and 3°C and a relative air humidity of 85-90%, ensures the lowest level of losses due to perishability. This configuration is optimal for maintaining product quality and for efficient transport to distribution points.

Table no. 2. Optimising losses in apple production and distribution through temperature control

Stage	Day	Conditions	Optimised losses	The impact of optimising storage conditions
Harvesting and cold storage	1	Ideal conditions	0%	Maintaining the temperature at 0-3°C and humidity at 85-90% prolongs the freshness of the fruit.
Transportation and handling	7	Transport under controlled conditions (0-3°C, 85-90% humidity)	0-1%	Transport under controlled conditions (0-3°C, 85-90% humidity) reduces losses to 0-1%.

Stage	Day	Conditions	Optimised losses	The impact of optimising storage conditions
Distributor storage	14	Storage at 0-3°C and 85-90% humidity	1-2%	Storage at 0-3°C and 85-90% humidity reduces losses to 1-2%.
Shelf display at the selling point	21	Controlled temperature 0-3°C and 85-90% humidity	3-4%	Maintaining a cold chain until display reduces losses to 3-4%.

The perishability of apples is directly influenced by factors such as temperature, humidity, and duration of exposure to uncontrolled and inappropriate conditions. Post-harvest studies confirm that storage at low temperatures and optimal humidity contributes significantly to maintaining quality and extending the shelf life of fruits. The ideal apple storage temperature is between 1 and 3°C, with a relative humidity of approximately 90% (Bücheler et al., 2024). In this context, Table no. 2 presents the concrete impact of optimising storage conditions on losses. Implementing rigorous temperature and humidity control at each stage of the supply chain can reduce cumulative losses from 12% to approximately 6%, translating into significant savings and higher net income for producers.

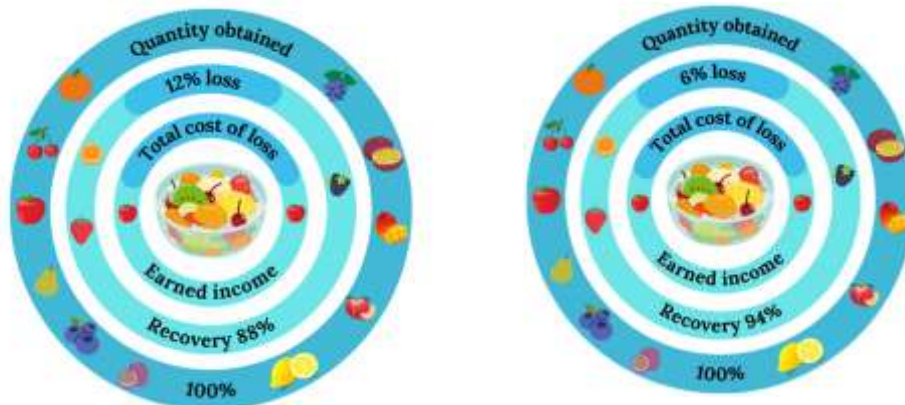
This analysis highlights the importance of implementing best practices in the supply chain, including temperature monitoring and reducing handling times. The implications are significant for distributors and retailers, suggesting the need for investment in modern infrastructure and monitoring technologies, such as temperature monitoring systems, to minimise losses and maintain product quality over a long period. The estimate of losses due to product perishability is presented in table no. 3.

Table no. 3. Estimation of losses due to the perishability of products

Indicator	Value	Comments - Scenario I	Value	Comments - Scenario II
Total fruit quantity	1,000 kilos	Total harvested and available for marketing before losses.	1,000 kilos	Total harvested and available for marketing before losses
Percentage of losses due to perishability	12%	According to the analysis scenario.	6%	Losses decrease due to optimal storage conditions
Lost quantity	120 kilos	As a result of applying the loss percentage to the total amount	60 kilos	As a result of applying the loss percentage to the total quantity
Marketable quantity	880 kilos	The difference between the total quantity and the lost quantity	940 kilos	The difference between the total quantity and the lost quantity
Total loss cost	180 lei	Information calculated based on the cost of production, packaging and transport (data taken from financial reports)	90 lei	Cost decreases due to loss reduction
Energy cost due to temperature optimisation	-	-	130 lei	Additional cost for temperature and humidity control

Indicator	Value	Comments - Scenario I	Value	Comments - Scenario II
Potential revenue lost	360 lei	Information calculated based on sales price (data taken from financial reports)	180 lei	Reducing losses leads to less loss of revenue
Potential net income (without losses)	3,000 lei	The maximum amount that could be collected if there were no losses	3,000 lei	The maximum amount that could be collected if there were no losses
Net realisable income (with losses)	2,640 lei	The amount collected from the sale of the products	2,820 lei	The actual value collected from product sales after optimisation

In the first scenario, the loss of perishability of 12% means that out of 1,000 kg of fruit, only 88% will be marketable, the amount of production lost being 120 kg. The total loss of income of the analysed company is 540 lei. Thus, we observe that the total financial risk of perishability in the case of the 1,000 kg of production obtained is 540 lei for a period of 21 days, which represents 18% of the theoretical income of the company and shows the significant impact that these risks have on the profitability of the organisation (Figure no. 4). In the second scenario, the loss of perishability of 6% means that out of 1,000 kg of fruit, 94% will be marketable, the amount of production lost being 6%. The total loss of income of the analysed company is only 270 lei. And even if the company's total costs increased as a result of the energy costs necessary to maintain the controlled temperature, overall scenario II is more advantageous, the total financial risk of perishability in the case of the 1,000 kg of production obtained is 400 lei for a period of 21 days, which represents 18% of the company's theoretical revenues and shows the significant impact that these risks have on the organisation's profitability (Figure no. 4).



a) Scenario I
b) Scenario II
Figure no. 4. Estimation of production and marketing items

4. Discussion regarding process optimisation based on cost function

By integrating these seasonal coefficients, the cost model becomes much more accurate and adapted to the specific realities of the food industry. Adjusting the cost function based on seasonality enables a more accurate estimation of costs and risks throughout the year, helping to optimise inventory, manage transportation risks, and reduce losses. This enhanced function can serve as a strategic decision tool for resource allocation during seasonal periods.

While the proposed model highlights the importance of seasonal cost adjustment in the food industry, numerous recent studies explore applying similar techniques for supply chain optimisation and risk reduction. Thus, articles that analyse the integration of seasonal coefficients in financial and logistics models can provide additional insight into the effectiveness of these approaches and their impact on strategic decisions. Liu and Liu (2023) explore the use of a seasonal ARIMA model to predict raw material prices and optimise replenishment decisions based on seasonality, by developing a methodology that integrates price forecasts with inventory management strategies, considering seasonal fluctuations in demand and costs. Similarly, Wen et al. (2024) investigate linear correlations and seasonality in vegetable sales, highlighting the importance of detailed analysis of historical data to optimise supply decisions and reduce seasonal risks. As in the case of the configuration of logistics networks for perishable food supply chains, where seasonal adjustments are essential to minimise losses, recent research on pricing and replenishment models under seasonal conditions highlights the need for adaptive resource management in the face of seasonal market fluctuations (Orjuela Castro et al., 2021). In addition, Hofmann and Bosshard (2017) highlighted the limits of the traditional accounting system as being function-oriented and not process-oriented, making it quite difficult to correctly identify costs. Oriji and Joel (2024) propose the use of advanced accounting models, such as the activity-based method, the lean management system in supply chain management, allowing for a more precise allocation of costs and better adaptation to market dynamics. At the same time, technological innovations in agri-food supply chains, which aim to optimise the management of perishable products and reduce seasonal risks, have been the subject of studies in this field on the integration of seasonal coefficients in cost models, highlighting the importance of adapting logistics strategies to new technological realities (Cricelli et al., 2024). A similar study stated that blockchain technology plays a crucial role in optimising agri-food supply chains, ensuring traceability and reducing risks associated with product perishability, thus complementing previous studies on the implementation of seasonal logistics strategies and innovative technologies for efficient inventory management and loss reduction (Sri Vigna Hema and Manickavasagan, 2024). According to Ivanov et al. (2019), AI technologies such as machine learning and data analytics can significantly improve the accuracy of demand forecasting. The authors found that integrating AI tools led to a 20% reduction in forecasting errors compared to traditional methods.

The efficient management of supply chains in the food industry, especially in the context of perishable and seasonal products, depends largely on the integration of predictive models and innovative technologies. The use of seasonal coefficients in cost models, the application of advanced technologies, as well as the optimisation of logistics networks, are essential to ensure traceability, operational efficiency, and reducing the risks of losses. These approaches not only improve the performance of supply chains, but also contribute to increasing sustainability and transparency, strengthening the trust of consumers and all parties involved.

Conclusions

Food industry supply chains play a critical role in ensuring global food security, but this responsibility comes with several challenges. From the significant impact on the environment to the risks associated with the specifics of the food industry, integrating sustainability and effective cost management throughout the supply chain is becoming necessary in the current context.

Sustainability can be addressed by applying innovative technologies such as digitising processes, using artificial intelligence to optimise logistics, and implementing data-driven solutions to reduce food waste. Collaboration between actors in the chain – from producers and distributors to authorities and consumers – is essential to ensure transparency, efficiency, and a reduction of the carbon footprint.

On the other hand, integrating industry-specific risks into supply chain management models is vital for system resilience. Among these risk factors are the high perishability of products, which requires fast delivery times, the seasonality of supply and demand, which requires flexible planning, and strict food safety regulations, which can add operational complexity. An adjusted cost function that reflects these vulnerabilities and uncertainties allows for a better allocation of resources and a significant reduction of losses, also contributing to an increase in company profitability.

Through a cost-effective approach, food supply chains can not only respond to consumers' increasingly complex demands but can also become a key factor in achieving global competitiveness and sustainability goals. Adopting responsible practices can help build a fairer, more efficient, and more resilient food system capable of meeting the challenges of the future.

In conclusion, transforming supply chains into a model that combines sustainability with innovation and efficient cost management is essential to create a balance between the economic, social, and environmental needs of an ever-changing world.

This research contributes to the literature by integrating a cost optimisation model that considers multiple variables, including acquisition, transportation, storage, production, distribution, inventory management, and perishable losses. By applying this model, the study demonstrates that cost optimisation in food supply chains should not be viewed in isolation but as part of a complex ecosystem influenced by economic, logistical and technological factors. The results support existing theories about the importance of operational efficiency and confirm that reducing waste and using advanced technologies can contribute to increasing the profitability and competitiveness of companies.

Although the study provides a solid approach to analysing costs in food supply chains, certain limitations must be taken into account: the data used comes from a single economic actor, which may limit the generalisation of conclusions to the entire industry. Also, the analysis focuses on a single food product, and the results may vary depending on the specifics of other agri-food products.

To extend the results of this study and address the identified limitations, future research could extend the analysis to a larger sample of companies from different segments of the food industry to identify variations in cost structure and investigate the impact of emerging technologies, such as blockchain and artificial intelligence, on optimising the traceability and efficiency of supply chains.

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