

Quality and Operations Management in Food Supply Chains: A Literature Review

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Abstract

In this article, we present a literature review on quality and operations management problems in food supply chains. In food industry, the quality of the food products declines over time, and should be addressed in the supply chain operations management. Managing food supply chains with operations management methods not only generates economical benefit, but also contributes to environmental and social benefits. The literature on this topic has been burgeoning in the past few years. Since 2005, about 58 articles have been published on this topic in major operations research and management science journals. In this literature review, we concentrate on the quantitative models in this research field, and classify the related articles into four categories, i.e., storage problems, distribution problems, marketing problems, and food traceability and safety problems. We hope that this review serves as a reference for interested researchers and a starting point for those who wish to explore it further.

Keywords: Literature review; Food quality; Operations management; Supply Chain Management

1 Introduction

Food quality, including safety, has been a major concern faced by the food industry, partly due to a series of food safety crises and scandals ([Aung and Chang, 2014](#)). Quality of the food products continuously changes as they move along the supply chain, which can lead to significant social, economical and environmental consequences.

Food spoilage is one of the major issues related to food safety and quality. When food products move from farms to food processors, food retailers, and to end customers, spoilage cannot be avoided. Food perishability may cause huge wastes. It is estimated by the United Nations that approximately one third of all food produced for human consumption is wasted each year. In other reports, 40% of total production was wasted (FAO 2011; NRDC 2012). The economical loss caused by food perishability and waste reached \$218 billion in the U.S., \$143 billion in Europe, and \$27 billion in Canada (Young 2012; ReFED 2015; FUSIONS 2016). In addition to the economical impacts, food perishability also caused food safety problems in many regions. According to the WHO (2015), about 600 million people became ill after consuming contaminated food each year. Among them 420,000 died, including 125,000 children under the age of five years. This has raised serious concern about food safety in many countries.

The improvement of preservation technologies has provided many tools to reduce waste and improve safety in food supply chains. Many extensive reviews have been conducted on preservation and traceability technology adoptions in food supply chains. For example, Mercier et al. (2017) provided a comprehensive literature review on time-temperature management along the food supply chain. Badia-Melis et al. (2015) reviewed traceability technology adoptions in food supply chains. The adoption of various temperature control or traceability technologies allow information to be gathered to optimize inventory decisions, distribution decisions, retailing strategy, even enhance safety in food supply chains.

Also, the research progress in operations management provides many opportunities for companies to reduce product waste due to decaying and to enhance food quality. Akkerman et al. (2010) reviewed the quantitative operations management research on food distribution concerning food quality, food safety and sustainability. In this article, we mainly concentrate on the quantitative operations management models related to food quality management. The goal is to present the latest research development in this field as well as to identify future research opportunities.

As such, we propose the following two research questions: (1) What are the state-of-the-art development and trends in quantitative operations management research regarding food quality management? (2) What gaps exist in the current research, and what are the potential future research opportunities?

This paper is organized as follows: Section 2 presents the methodology of this research along with a descriptive analysis of the existing studies. Section 3 provides details of operations management problems and related research along the food supply chain, including storage, distribution, marketing, and traceability optimization. Section 4 is about the research implications and directions for future research. Section 5 discusses the conclusions and limitations of this review.

2 Methodology

To address the research questions, the study reviews the literature of food quality management in supply chains.

2.1 Data collection

The study aims to review published peer-reviewed articles in the targeted area from 2005

to 2017. Articles are collected from several databases, including Elsevier, Wiley Online, Informs, Springer, and Hindawi. The search was conducted based on the combination of two categories of key words – one is related to food quality and the other is related to operations management. An example of such key word combination would be ‘Inventory’+‘food quality’; another would be ‘distribution’ +‘perishable food’. Using such kind of keywords search in the databases, we found 392[JH1] articles in total.

2.2 Relevant literature and classification

In this stage, all articles were prudently reviewed. The searching guidelines and results are presented in Table 1. An article was removed from this study if it was not related to food quality, operations management, or not using quantitative methods. The remaining publications were then classified according to a conceptual framework proposed in Section 3.1.

Table 1 Searching guidelines and results

Filter type	Descriptions and guidelines	Results
Inclusion criteria	<p>Articles that were identified in the database search or appeared in the reference lists of one of the selected articles</p> <ul style="list-style-type: none"> • Topic: Articles that develop or apply quantitative models on food quality and operations management in food supply chain • Language: Limited to English • Time span: 2005-2017 • Paper type: Academic (peer-reviewed) journal articles 	
Keywords	<ul style="list-style-type: none"> • Group A keywords: “food quality”, “perishable food”, “perishable products”; • Group B keywords: “operations management”, “inventory management”, “marketing”, “customer behaviors”, “supply chain coordination”, “production planning”, “quality control”, “distribution” 	
Keywords search	<ul style="list-style-type: none"> • Selected online databases (e.g., Elsevier, Wiley Online, Informs, Springer, Hindawi, etc.) • All selected articles contain at least one keyword combination from group A and B in the title, abstract or list of keywords. 	426
Exclusion criteria	<ul style="list-style-type: none"> • Not related to food quality • Not related to the operations management problems • Not using the quantitative methodologies 	105 left

2.3 Journal statistics

The number of publications in different time periods is presented in **Figure 1** to show the evolution of research interest in this topic. Between 2005 and 2017, there were totally 87[JH2] articles on the operations management related to food quality in food supply chains. The number

of the articles is rather limited before the year 2008. Then the number rises slowly from 2008 to 2012. Since 2012, scholars have become more interested in this topic. The statistics show that while the total number of research in this area is still small, interest in this field has grown rapidly in recent years.

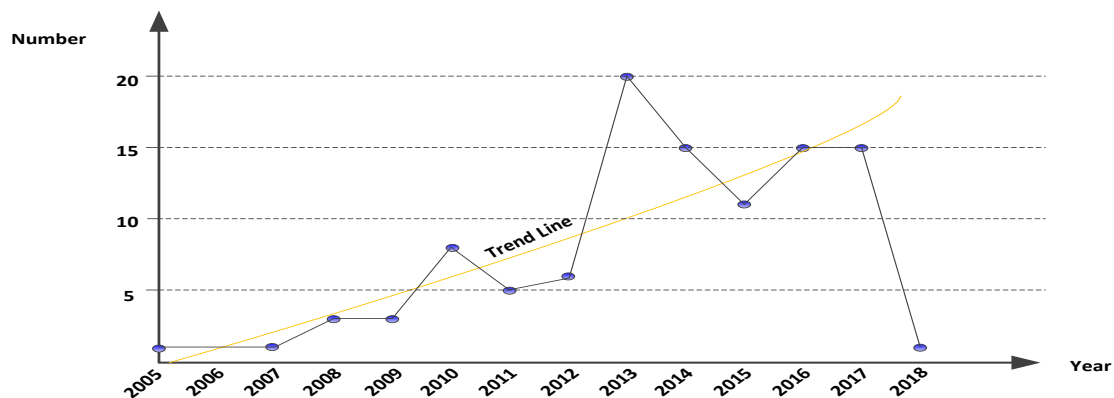


Figure 1 Distribution of articles over time[JH3]

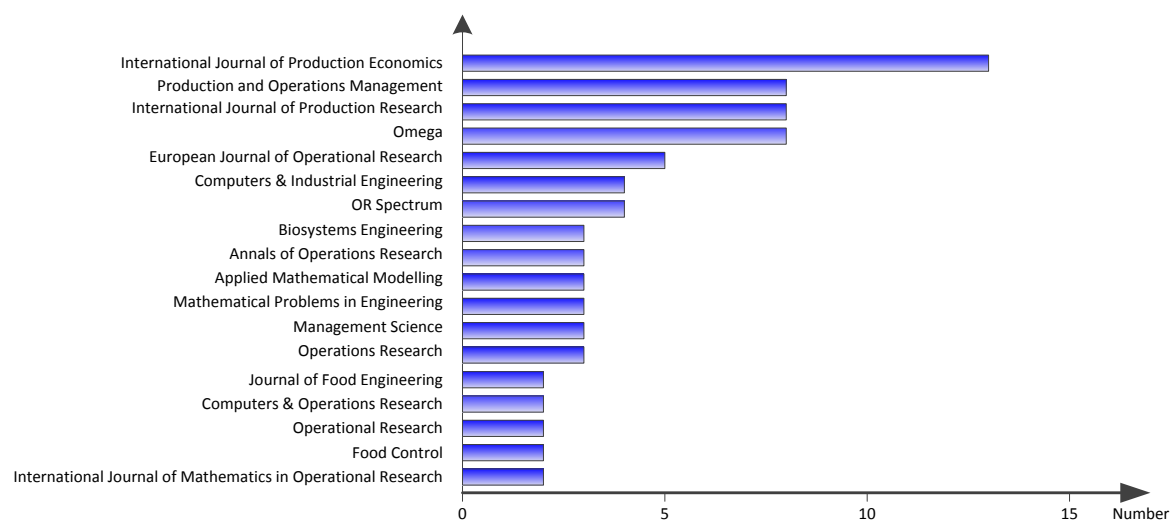


Figure 2 Distribution of journals (with number of articles ≥ 2)[JH4]

Figure 2 presents the distribution of articles in these major publication outlets. The 87 articles included in this study were published in more than 30 journals on operations management or food quality. Apparently, the top three journals are [IJPE, IJPR and Omega][JH5][FD6], which accounts for about one third of the total amount. The first half of the papers contributes to about 80 percent of the total papers. After carefully reading the 87 articles, we found that these papers represent an appropriate overview of the current state-of-the-art research in the area of operations management and food quality control in food supply chains.

3 Analysis

In this section, quality and operations management problems in food supply chains are discussed in detail. More specifically, we discuss the main issues with regard to related operations management problems, followed by a discussion of research challenges.

3.1 Conceptual framework

In order to identify the progress and gaps in the existing literature on food quality and operations management models, a conceptual framework is constructed to understand the key decisions, as shown in Figure 3. The framework helps us understand the achievements, challenges and opportunities in the research on food quality and operations management models.

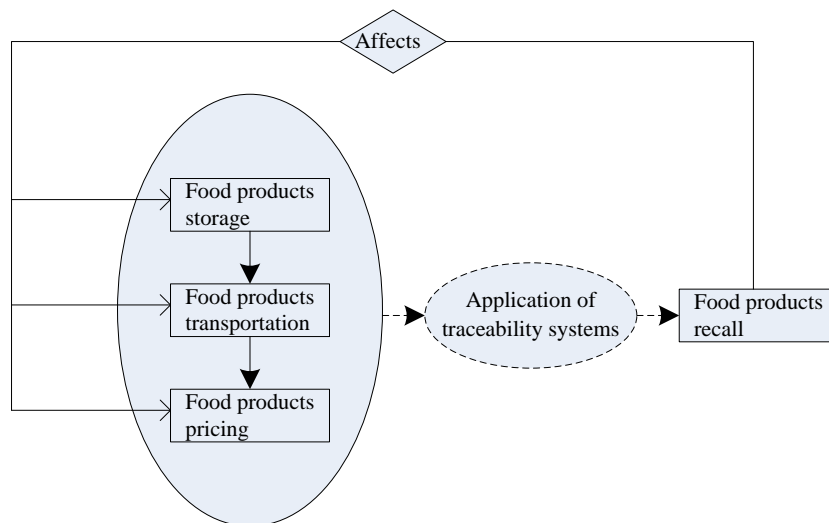


Figure 3 Conceptual framework

Section 3.2 summarizes the studies of inventory problems with preservation investment, followed by Section 3.3 on transportation planning problems in food supply chains. Next, Section 3.4 covers research on marketing strategies considering food quality and customers' preferences. Lastly, Section 3.5 presents the models pertaining to food traceability and food recall strategies.

3.2 Inventory planning with preservation investments

A lot of research deals with inventory management of perishable products, where their production or distribution planning is based upon an exogenous perishable rate. For example, fruits in supermarkets will perish in the selling period until they are not safe to eat. However, with the development of preservation technologies, the products' perishability can be reduced by making investment in equipment, production processes, etc. In other words, the perishable rate highly depends on not only by the natural perishable rate largely determined by environmental factors (such as temperature, humidity, light, oxygen content, microbial content) but also the preservation technology used in the warehouse and transportation vehicles.

Although the perishing process for food products is natural and cannot be stopped, it can be slowed down by specialized equipment, such as refrigerators and humidifiers, to make temperature low and humidity suitable for certain fruits. Hence, it is practical and important to

consider inventory decisions with preservation technology investment decision. Enterprises' preservation investment is often combined with other decisions, like pricing or replenishment decisions. The goal is to maximize the total profit or minimize the total cost by finding an optimal set of preservation investment level, price, or ordering quantity.

3.2.1 Single level supply chain inventory models

Some studies focus on a single firm's preservation and inventory decisions. [Hsu et al. \(2010\)](#) first developed an analytical economic ordering quantity model considering both ordering policies and preservation investment for perishable products. Under the assumption that the deterioration rate is exponentially linked to the investment level, they proposed a method to determine the optimal replenishment cycle, shortage period, order quantity and preservation technology cost so as to maximize the total profit per unit time. Numerical examples were presented to obtain further results. [Lee and Dye \(2012\)](#) extended the model of [Hsu et al. \(2010\)](#) by assuming market demand is linked to inventory level and shortages are allowed and partially backlogged. An algorithm was also proposed to solve the optimization model and determine the optimal replenishment and preservation technology investment.

[Dye and Hsieh \(2012\)](#) assumed that the deterioration cost is associated with both the preservation investment and time instance. The objective is to find the optimal replenishment and preservation technology investment strategies while maximizing the total profit per unit time over the infinite planning horizon. [Dye \(2013\)](#) assumed that the deterioration rate is non-instantaneous and controllable. The generalized productivity of invested capital, deterioration and time-depend partial backlogging rates were used to model the inventory system. The uniqueness of the global maximization was proved using fractional programming.

[Chen and Dye \(2013\)](#) proposed a finite time horizon inventory and preservation investment model, in which the preservation investment can be different in each replenishment cycle. They utilized particle swarm optimization to solve the nonlinear programming problem. [He and Huang \(2013\)](#) studied the optimal preservation, pricing and ordering decisions for a kind of seasonal products. [Hsieh et al. \(2013\)](#) formulated an EPQ model for deteriorating items with time-varying demand and controllable deterioration rate in a limited time horizon. A particle swarm optimization approach was also employed to solve the nonlinear programming problem.

[Singh and Sharma \(2013\)](#) studied an inventory model with ramp-type demand rate, controllable deterioration rate and two-level trade credit, in which shortages were allowed and partially backlogged. [Bardhan et al. \(2017\)](#) also studied an inventory problem with preservation investment for non-instantaneous deteriorating products. They studied two models depending on the on-hand stock finish time: before and after the deterioration starts. [Yang et al. \(2015\)](#) introduced the credit period theory into inventory models with preservation investment decisions. They studied a retailer selling perishable products to customers and offering a credit period to its customers to buy the products. They established a model to determine the optimal trade credit periods, preservation technology investment, and ordering strategies that maximize the total profit over a finite planning horizon.

Different from previous studies, [Dye and Yang \(2016\)](#) treated the selling price as a decisions variable. They considered customers' reference price behaviors and proposed a joint dynamic pricing and preservation technology investment model for a perishable inventory system with time- and price- sensitive demand. Theoretical results were obtained to demonstrate the existence of an optimal solution for the inventory problem. A simple iterative algorithm was utilized to solve the proposed model by employing the theoretical results. Features of the proposed model were illustrated with sensitivity analysis.

[Kouki et al. \(2013\)](#) extended the known (r, Q) inventory models by assuming products are perishable. They studied the impacts of the application of Time Temperature Integrator (TTI) technology on the inventory management decisions. The TTI technology enables firms to accurately monitor products' freshness and gives information on products' remaining shelf lives. [Zhang et al. \(2016\)](#) studied dynamic service investment problem simultaneously with preservation investment for perishable products. The analytical solution for dynamic service investment was obtained under the given sales price, preservation technology, and replenishment cycle by solving an optimal control problem. The impact of common resource constraint on the optimal investment policy was investigated. They found that for a relatively low common resource capacity, the firm prefers to invest in service improvement rather than preservation technology. [Mishra \(2016\)](#) studied an EPQ problem considering uncertain and controllable deterioration rate. Following [Day and Yang \(2016\)](#), [Mishra et al. \(2017\)](#) studied an inventory model that considers demand rate as a function of stock and selling price. They established an Economic Order Quantity (EOQ) model considering preservation investment, product deterioration, and two types of backordering scenarios. [Li et al. \(2017\)](#) studied an inventory control problem considering the optimal packaging decisions to extend shelf life. High quality packaging helps to better preserve the products but leads to higher costs for sellers. The goal is to minimize the total costs by choosing an appropriate packaging strategy.

Li Q, Yu P, Wu X. Shelf life extending packaging, inventory control and grocery retailing. *Production & Operations Management*, 2017, 26(7), 1369-1382.

3.2.2 Two level supply chain inventory models

The preservation investment problem has also been studied in two-level supply chains. [Tayal et al. \(2014\)](#) developed a two-level supply chain model, in which the products are perishable and the deterioration rate is controllable. Also, customers' demand is sensitive to the products' expiration rate. [Zhang et al. \(2015\)](#) studied a two-level inventory model for deteriorating items with controllable deterioration rate and price-dependent demand. They derived the optimal decisions for both the decentralized and centralized models. They found that the two-level supply chain can be coordinated with a revenue sharing and cooperative investment contract. The results show that only when the revenue sharing rate lies roughly between $1/2$ and $3/4$ can the contract perfectly coordinate supply chains in most cases, which has an important implication to supply chain coordination of deteriorating items with preservation investment. [Shah et al. \(2016\)](#) studied an inventory model in a two-level supply

chain consisting of a manufacturer and a retailer. The manufacturer offers a trade credit to the retailer and the retailer's deterioration rate is time dependent and linked with preservation investment. The retailer also offers partial trade credit to the buyers. [Giri et al. \(2017\)](#) studied a two level supply chain model with product deterioration, controllable deterioration rate and unreliable production.

3.2.3 Multiple facility inventory models

Researchers also considered the preservation investments for a multi facility supply chain. [Cai et al. \(2010\)](#) studied the optimal order quantity and fresh keeping efforts in a multi-level supply chain with long transportation distance and highly deterioration rate for in-transit products. [Yu et al. \(2013\)](#) developed a network-based food supply chain production model under oligopolistic competition and perishability, with a focus on fresh produce. The product differentiation is characterized by the different product freshness and food safety concerns, as well as the evaluation of alternative technologies associated with various supply chain activities.

[Tsao \(2016a\)](#) studied a joint model considering location, inventory, and preservation decision-making problem for non-instantaneous deteriorating items under delay in payments. In their model, an outside supplier provides a credit period to the wholesaler that has a distribution system with distribution centers. The goal is to determine the locations, the number, the replenishment time of the distribution centers and the preservation investments. [Tsao \(2016b\)](#) studied the network design problems in a supply chain including distribution centers and retailers considering trade credit arrangements, preservation investment and product deterioration. The goal is to determine the optimal locations of distribution centers, assignment of retailers to distribution centers, replenishment time and preservation investment to maximize the total profit.

Cai X, Chen J, Xiao Y, Xu X. Optimization and coordination of fresh product supply chains with freshness-keeping effort. *Production & Operations Management*, 2010, 19(3), 261–278.

3.2.4 Summary

In this subsection, the inventory problems combined with food preservation investment is presented. We classify the existing papers into three categories for different supply chain structures, i.e., single level supply chain, two level supply chain, and multilevel supply chain. The research contributions are presented in each part.

3.3 Transportation planning for perishable products

In this subsection, we discuss about the transportation planning in food supply chains considering food quality degradation. In economy, transportation plays an important role, which accounts for two-thirds of the total logistics cost and affects the level of customer service. In reality, food supply chains stretch from upstream agricultural farms to downstream consumers, with intermediate manufacturers, foodservice providers and sellers in the middle. Along the distribution process, food products may perish and temperature control becomes crucial for supply chain partners to reduce wastes and enhance food quality and food safety. To enhance the

profitability and competitiveness, many enterprises strive to handle the issue of product perishability so as to maintain the value of their products.

The transportation planning problems are mainly concerned with the optimization of delivery routes, delivery quantities, and delivery time. Transportation modes, such as flights, cargo vessels, or trains, should also be considered. Although great progress has been made in this direction in terms of considering product perishability properties, challenges still exist.

Transportation planning mainly deals with vehicle routing problems (VRP). When considering product perishability, more factors should be reconsidered in this research area. First, food safety is a main concern when enterprises distributing the food products from manufacturer to retailers and customers. For example, [Rijgersberg et al. \(2010\)](#) developed a simulation model of the distribution chain of fresh-cut iceberg lettuce under the consideration of quality and safety during distribution stage. Second, different types of perishable products should be stored in different conditions during transportation. Because the storage temperatures for chilled meat and fresh vegetable are different, a vehicle may be divided up into multiple compartments with different temperature control ([Derigs et al. 2010](#)). This makes the transportation planning more complex and more challenging. Third, distribution planning of the food products is often linked to customers' preferences and satisfactions ([Grillo et al. 2017](#)). In real life, the fresher of the products, the higher the price. Shorter delivery time helps to maintain the freshness, yet it increases the total transportation cost.

3.3.1 Transportation planning considering various factors

During the transportation of perishable products, factors like the product quality, the product safety, the transportation mode, the preservation conditions or multi-firms' coordination all have significant impacts on optimal decisions.

[Dabbene et al. \(2008a\)](#) assumed that quality of the perishable products during transportation is directly linked to time, and solved a distribution planning model by a heuristic approach. Quality change may lead to food safety problems. [Rijgersberg et al. \(2010\)](#) also developed a simulation model of the distribution chain of fresh-cut iceberg lettuce under the consideration of quality and safety during distribution stage. The main purpose was to study the impacts of product life cycle, customer purchasing behaviors and distribution lead time reduction on distribution strategies.

Some researchers demonstrate that transportation modes affect the optimal decisions significantly. [Ahumada and Villalobos \(2009b\)](#) considered transportation modes in their integrated production and distribution optimization models. They proposed that supply chain partners need to choose from the transportation modes of truck, rail or air to distribute their packaged perishable products under different conditions. The impacts of refrigeration cost were discussed in [Dabbene et al. \(2008b\)](#). [Rong and Grunow \(2010\)](#) studied the impacts of product dispersion during distribution on optimal distribution planning strategies. Although dispersion enhances supply chain efficiency, it also causes food safety problems. Their approach allowed decision makers to deal with the trade-off under different risk attitudes. [Cai and Zhou \(2014\)](#) studied the optimal production and delivery policies when facing two markets (i.e., local market and foreign market) and the transportation to foreign market may be disrupted. An optimal policy was proposed to minimize the total cost. [Eleonora and Jesus \(2015\)](#) analyzed the schemes for food delivery to urban food sellers. They studied the impacts of traffic regulations, delivery

services and an urban distribution center on the distribution efficiency in a case study of Parma, Italy. Ketzenberg and Ferguson (2010) studied the value of information sharing between the seller and the supplier in a two-level supply chain. They showed in the numerical tests that information sharing not only improves profits of the two parties, but also benefits customers by enhancing product freshness..

Ketzenberg M, Ferguson ME. Managing slow-moving perishables in the grocery industry. *Production & Operations Management*, 2010, 17(5), 513-521.

Cai X, Zhou X. Optimal policies for perishable products when transportation to export market is disrupted. *Production & Operations Management*, 2014, 23(5), 907-923.

In addition to the impacts of quality, safety and transportation modes, [Grillo et al. \(2017\)](#) proposed a mixed integer mathematical programming model to study an order promising process in fruit supply chains with subtypes of products due to the impacts of various natural factors, such as land, weather, or harvesting time. [\[JH8\] Bilgen and Günther \(2009\)](#) studied an integrated problem for production and distribution planning. They considered two different transportation modes in the distribution stage between plants and distribution centers: the full truck load and less than truck load.

[Soysal et al. \(2016\)](#) studied a routing problem with multiple suppliers and customers considering food perishability and horizontal collaboration between supply chain partners. They found that horizontal collaboration may reduce wastes and carbon emission and increase distribution efficiency of the whole supply chain. They used an experiment to study the impacts of related factors, and found that the gains are highly sensitive to the supplier size or the maximum shelf life of the products.

3.3.2 Transportation combined with inventory problems

It is common that transportation planning is often related to inventory planning problems. The combined inventory-routing approaches not only solve the short term VRP problems, but also help to overcome the long term production planning problems.

[Rong et al. \(2010\)](#) studied a joint production and distribution planning model under the consideration of food quality degradation. In addition to routing and storage planning decisions, the firm also makes decisions on the temperature during storage and distribution. The problem was solved with a generic approach. [Farahani et al. \(2012\)](#) studied an integrated production and distribution planning model for a kind of fast perish food product. To deal with the fast perishability, they proposed a policy to shorten the time interval between production and distribution. [Adelman and Mersereau \(2013\)](#) studied a dynamic capacity allocation problem when customers' ordering quantity is correlated to fill rates in the past. In their model, customers risk attitudes to the fill rates were different. Given customers' differentiated behaviors, a dynamic rationing policy of the fill rates was proposed to achieve higher profit and higher customer satisfaction.

[Coelho and Laporte \(2014\)](#) studied an integrated replenishment, distribution, and inventory management problem when products have various lifetimes. They showed in the numerical experiments that the optimal policy is either to sell the oldest available items first to avoid

spoilage, or to sell the fresher items first to increase revenue. [Devapriya et al. \(2016\)](#) studied an integrated production and distribution scheduling problem for perishable products in a multi-echelon chain. Their objective was to determine the optimal fleet size and trucks' routes in order to minimize the aggregated cost. Unlike the previous research, their study captured both production and distribution planning under the consideration of limited lifetime of the products. A mixed integer programming model was formulated to solve the problem and heuristics based on evolutionary algorithms were provided to resolve the models. [Liu et al. \(2017\)](#) studied the dynamic inventory rationing problem for perishable products over multiple periods for a wholesaler. The rationing strategy was not only determined by the perishable properties of the products, but also affected by the uncertain selling price in the future periods. [Qiu et al. \(2018\)](#) studied a generalized production-inventory-routing problem for perishable products. They have discussed several inventory management policies to illustrate the real-world applications of the proposed models.

More works can be seen in [Bilgen and Günther \(2009\)](#), [Makkar and Jha \(2012\)](#), [Cai et al. \(2013\)](#), [Rahdar and Nookabadi \(2013\)](#), [Uthayakumar and Priyan \(2013\)](#), [Jia et al. \(2014\)](#), [Diabat et al. \(2014\)](#), [Lee and Kim \(2014\)](#), [Gaggero and Tonelli \(2015\)](#), [Belo-Filho et al. \(2015\)](#), [Priyan and Uthayakumar \(2015\)](#), [Seyedhosseini and Ghoreyshi \(2014a,b,2015\)](#), [Sel et al. \(2015\)](#), [Mirzaei and Seifi \(2015\)](#), [Drezner and Scott \(2013\)](#), [Dobhan and Oberlaender \(2013\)](#).

Qiu Y, Qiao J, Pardalos P M. Optimal production, replenishment, delivery, routing and inventory management policies for products with perishable inventory, *Omega*, 2018. doi: 10.1016/j.omega.2018.01.006

3.3.3 Transportation combined with network design problems

In food industry, there exist many kinds of distribution networks. In practice, the network design problem is to jointly optimize the location of hubs and the flows from upstream manufacturers to downstream retailers and customers. Distribution network design plays a key role in reducing transportation costs and maintaining quality of perishable products in food supply chains. However, many of the existing models on distribution network design only consider single period problems, which cannot be used to solve the problems for perishable products with time limitations within the networks. To solve the network design problems, many new types of mathematical models and innovative algorithms were developed in the last decade.

[Firoozi et al. \(2013\)](#) studied a network design problem for perishable products which have limited storage time during transportation. Their model attempted to balance the benefit from enhancing storage conditions to maintain products quality and the associated costs to improve storage conditions. An efficient Lagrangian relaxation heuristic algorithm was developed to solve the proposed model. [Firoozi et al. \(2014\)](#) studied a similar network design problem considering product perishability. They proposed a memetic algorithm (MA), and proved that it works more efficient than the Lagrangian relaxation heuristic algorithm. Unlike [Firoozi et al. \(2013\)](#) and [Firoozi et al. \(2014\)](#), [Firoozi and Ariaifar \(2016\)](#) considered a fluctuated expected lifetime of perishable products during transportation due to unusual weather condition or malfunction of transportation and storage facilities.

[Drezner and Scott \(2013\)](#) studied an inventory and location decisions in a network with a

single distributor and multiple sales outlets for perishable products. Computational experiments showed that the location of the distribution center affects the inventory decisions significantly. Tsao (2016a) considered about the joint location, inventory and preservation decisions for a two-level supply chain with a supplier, a wholesaler and multiple distribution centres. Algorithms were proposed to solve the nonlinear optimization models. Dulebenets et al. (2016) studied an intermodal freight network design problem which deals with the decisions of production, inventory, and transportation. The numerical cases show that decaying cost significantly affects the transportation modes and the associated distribution routing. Rashidi et al. (2016) formulated a bi-objective mathematical model to optimize the joint location-inventory decisions in a network for perishable products. A Pareto-based meta-heuristic approach was proposed to solve the models. Keizer et al. (2017) studied the network design problems for perishable products under different product quality and delivery lead time. The objective was to study the impacts of quality decay and its heterogeneity on optimal network design strategies. They used a mixed integer programming approach to formulate the model, which is to maximize the total profit under quality constraints. The results showed that heterogeneous product quality decay has significant impacts on network design and profitability.

3.3.4 Summary

In this subsection, the papers on food products transportation problems are reviewed. In this area, people often study the transportation problems with various factors including product quality, product safety, transportation mode, preservation conditions, multi-firms' coordination. In addition, in real practice, transportation planning is often combined with inventory planning or network design or both. As such, we presented a comprehensive review of papers studying joint decisions of inventory-transportation problems and network design-transportation problems.

3.4 Quality based pricing for perishable products

In this subsection, we summarize the up-to-date research on pricing problems related to time-linked quality for perishable products. Recently, customers are more concerned about food safety, and become more sensitive to food quality when purchasing food products. The demand for food products is highly linked to food quality. Due to the nature of food products, quality drops with time following a dynamic state. Therefore, static pricing strategies may result in inappropriate quality control and excessive inventories in food supply chains. Many scholars did research on the dynamic pricing strategies to help firms reduce waste and enhance profit and food safety.

3.4.1 Models with single products and homogenous customer preferences

In today's food supply chains, various technologies (e.g. radio frequency identification technology (RFID) and time temperature indicator (TTI)) can be adopted to capture product information (e.g. temperature, humidity, and the time period, etc.) automatically. Thus, this kind of information can be used to predict food quality and remaining shelf life, which supports the decisions on inventory control and pricing decisions. Besides, customers are often sensitive to

the product quality and they alter their purchasing decisions toward products with different qualities.

Ferguson and Koenigsberg (2007) established a two-period model, considering product quality decline, quality dependent demand and competition, to optimally determine the prices and inventory to maximize the total profit. Blackburn and Scudder (2009) studied supply chain strategies together with pricing decisions based on perishable products' marginal-value-of-time (MVT). Sainathan (2013) studied the pricing and replenishment strategies for a perishable product with two-period lifetime when customers' utility is quality sensitive. In each period, new products and old products were differently priced to maximize the total profit. Wang and Li (2012) proposed a real time quality based dynamic pricing model for perishable foods in a supply chain with quality sensitive customers. Comparing to the static pricing strategy, this quality-based pricing strategy helps reduce food spoilage waste and bring more profit to the retailers. A real case was also used to illustrate the results in the analytical models.

Adenso-Díaz et al. (2017) proved that dynamic pricing can significantly reduce the total waste of the perishable products, as Wang and Li (2012) demonstrated. However, the spoilage reduction may come as a loss in total revenue that can vary dramatically, depending on the scenario and the speed of the price discount strategy. Also, based on the assumption that retailers can utilize time–temperature-indicator-based automatic devices, Herbon et al. (2014) studied an optimal dynamic pricing model considering product perishability and customers' satisfactions. Herbon and Khmel'nitsky (2016) studied an integrated ordering and dynamic pricing model for perishable products when customers are highly sensitive to food quality. Different from Wang and Li (2012), they studied a continuous dynamic problem rather than a discrete one. They also showed that the efficiency of the dynamic approach depends on the form of demand incorporated into the model.

Ferguson M E, Koenigsberg O. How should a firm manage deteriorating inventory? *Production & Operations Management*, 2007, 16(3), 306–321.

Blackburn J, Scudder G. Supply chain strategies for perishable products: the case of fresh produce. *Production & Operations Management*, 2009, 18(2), 129–137.

Sainathan, A. Pricing and replenishment of competing perishable product variants under dynamic demand substitution. *Production & Operations Management*, 2013, 22(5), 1157–1181.

3.4.2 Models considering product differentiation

Product differentiation is a factor that the retailers should consider when they make ordering or pricing decisions. When product lifetime is considered, products at different ages are different but still substitutable, which may affect customer purchasing behaviors. Chew et al. (2014) studied an integrated ordering and dynamic pricing problem for a kind of perishable product with multi-period life time. The products at different ages, mutually substitutable, are all available in the market. The results showed that under the assumption of product substitutions, the retailer's total profit increases significantly. Chen et al. (2014) studied a combined pricing and inventory control problem considering product perishability with a fixed shelf life over a

finite horizon. Heuristic policies were proposed to solve the models. In addition, they also proved that their model is applicable when the product's lifetime is stochastic.

[Herbon \(2015a\)](#) also studied the pricing policies for a kind of perishable product with different ages. They compared two strategies: fixed pricing and differentiated pricing. They found that an optimal pricing policy is to implement price discrimination with respect to consumers' sensitivity to freshness, while dynamically changing the price over time, starting with a lower price at the early stages of the product's shelf life and increasing it at a later stage. [Hu et al. \(2016\)](#) established a joint inventory and price markdown model considering customers' strategic behaviors. To reduce costs, the firm can either choose to discard the leftover inventory or set a clearance price. [Li et al. \(2016\)](#) studied an inventory control problem with clearance sales strategies and product perishability. They proposed two myopic heuristics to solve the problems with partial information.

Chen X, Pang Z, Pan L. Coordinating Inventory Control and Pricing Strategies for Perishable Products. *Operations Research*, 2014, 62(2):284-300.

Hu P, Shum S, Yu M. Joint Inventory and Markdown Management for Perishable Goods with Strategic Consumer Behavior. *Operations Research*, 2016, 64(1):118-134.

Li Q, Yu P, Wu X. Managing Perishable Inventories in Retailing: Replenishment, Clearance Sales, and Segregation. *Operations Research*, 2016, 64(6):1270-1284.

3.4.1 Models considering heterogeneous customer preferences

Customers often have different valuations towards the same kind of products with same quality. Such customer heterogeneity on product quality for perishable products has also been considered. [Akçay et al. \(2010\)](#) studied a dynamic pricing problem of a firm who sells multiple differentiated products with linear random consumer utilities. [Gallego and Hu \(2014\)](#) studied a dynamic price competition problem in an oligopolistic market when products perish over time. [Herbon \(2014\)](#) proposed a pricing model under consumer heterogeneity in consumers' sensitivity to freshness of a perishable product. He compared the model with and without the consideration of such heterogeneity. Also evaluated are the conditions in which a dynamic pricing policy is beneficial either to the retailer or to the consumer, as compared with a static pricing policy.

In [Herbon \(2015b\)](#), customers were also assumed to be heterogeneous in their sensitivity to freshness, i.e. their willingness to pay more for fresher products. A dynamic pricing model was developed to evaluate the extent to which both the retailer and the customers benefit from the dynamic pricing policy as opposed to the static pricing policy. [Herbon \(2017a\)](#) also studied a model with multiple competing perishables with different remaining lifetime and selling prices. It is found that when customers are homogeneous in their preferences, single-product-age operational mode outperforms the multiple-product-age operational mode. [Herbon \(2017b\)](#) studied an inventory and pricing model considering customers' heterogeneity towards the real time quality of the perishable products. The effects of remaining shelf-life, price and perceived quality on demand were investigated in their models. Also, it is shown that highly heterogeneity can benefit the sellers because more products will be sold. In addition, [Herbon \(2017c\)](#) demonstrated that customer information is crucial to determine firms' pricing decisions for

perishable products and customers' heterogeneous preference for product freshness.

Akçay Y, Natarajan H P, Xu S H. Joint dynamic pricing of multiple perishable products under consumer choice. *Management Science*, 2010, 56(8), 1345-1361.

Gallego G, Hu M. Dynamic Pricing of Perishable Assets Under Competition. *Management Science*, 2014, 60(5):1241-1259.

3.4.4 Models combined with inventory decisions

In many situations, inventory policies and pricing policies are mutually affected in perishable food supply chains. [Pasternack \(2008\)](#) studied a pricing problem for a kind of perishable product combined with customer returns. They showed that full credit provided by the manufacturer is effective to coordinate the supply chain when there is a single retailer, however non-effective when facing multiple retailers. [Li et al. \(2009\)](#) studied the pricing problem together with the inventory decisions in which price is linked to demand and products have two-period lifetime. [Li et al. \(2012\)](#) assumed that product perishability affects demand. Based on this assumption, they studied the joint dynamic pricing and inventory control problems for perishable products when the seller cannot sell new and old products at the same time. In each period, the seller determines to sell new products and makes replenishment policies or to sell old products and dispose the inventory at the end of the period. It is counter-intuitive that profit maximization does not guarantee lower expirations.

[Chen and Sapra \(2013\)](#) studied a joint pricing and inventory decisions for a perishable product with two period lifetimes. They compared the first-in-first-out and first-in-last-out strategies and found that bigger orders are placed in the FIFO system. [Chung and Erhun \(2013\)](#) studied a two-level supply chain coordination problem considering perishable products with two periods of shelf life. [Kaya and Polat \(2016\)](#) studied a problem of jointly determining the optimal pricing and inventory replenishment strategy for a deterministic perishable inventory system in which demand is time and price dependent. The price adjustment cost (also called Menu cost) is considered when the seller changes its selling price during the lifetime of the products. [Chen et al. \(2017\)](#) also considered Menu cost in their integrated dynamic inventory and pricing decisions models. They found that when Menu cost is moderate, a one-time price adjustment price policy outperforms the multi-time price adjustment policy. [Chua et al. \(2017\)](#) studied the optimal price discount and replenishment policies for a perishable product with short lifetime and uncertain demand.

Li Y, Cheang B, Lim A. Grocery perishables management. *Production & Operations Management*, 2012, 21(3), 504–517.

Chen LM, Sapra A. Joint inventory and pricing decisions for perishable products with two-period lifetime. *Naval Research Logistics*, 2013, 60(5), 343–366.

Chung YT, Erhun F. Designing supply contracts for perishable goods with two periods of shelf life. *IIE Transactions*, 2013, 45(1), 53-67.

Pasternack B A. Optimal pricing and return policies for perishable commodities. *Marketing Science*, 2008, 27(1), 133-140.

Li Y, Lim A, Rodrigues B. Note—Pricing and Inventory Control for a Perishable Product. *Manufacturing & Service Operations Management*, 2009, 11(3):538-542

3.4.5 Summary

In reality, customers are sensitive to the food qualities. Thus, to ensure the profit gains, firms need to provide more fresh products to customers. In the presented models, customers' preference is directly linked to the product quality in each instance. In the first part, researchers studied the single product pricing problems with homogenous customers' preference. Then models with multiple products or multiple types of customers are presented. Lastly, ordering decisions combined with pricing decisions are reviewed.

3.5 Quantitative models of food traceability and food recall

In this subsection, we discuss the quantitative models using the information of traceability, which aims to improve product safety and helps firms reach financial targets. Food safety crisis can happen at any stage of food supply chains. Food traceability systems can record product attributes, such as quality and safety parameters, which can be used to capture information about ingredients, processing, storage, and dates (sell-by, use-by), etc. When a food safety crisis occurs, the sold products should be recalled from the customer to mitigate the negative effects. Governments have realized the importance of food traceability, and built food traceability system in many countries. For example, [Hong et al. \(2011\)](#) discussed about the financial model for applying Radio Frequency Identification (RFID) technology to a food traceability system in Taiwan. In addition, food crisis can bring great loss to enterprises. The application of traceability systems helps avoid such loss by reducing the impacts of food crisis. Required for regulatory and/or commercial purposes, they have been widely used to resolve the issues of product recall and food safety ([Karlsen et al. 2013](#), [Bosona and Gebresenbet 2013](#)).

The traceability systems not only improve social welfares, but also contribute to firms' financial benefits. [Dupuy et al. \(2005\)](#) studied an optimization problem for food products under food quality risks and traceability systems. Under the given information, using a dispersion strategy, the firms can reduce the quantity of the recalled products, thus minimizing its costs. Their research showed that the traceability systems help mitigate food risks to customers. [Wang et al. \(2009\)](#) studied an optimization problem considering food traceability in a multi-level supply chain to achieve desired product quality and minimizing the impact of product recall in an economic manner. They showed that utilizing traceability systems and traceability information contributes to the reduction of food quality risks. [Wang et al. \(2010\)](#) also developed an integrated optimization model in which the traceability factors are incorporated with operations factors to determine the production batch size and batch dispersion. [Resende-Filho and Hurley \(2012\)](#) studied the impacts of information asymmetry in a two-level supply chain with a supplier and a retailer implementing a traceability system. The retailer can offer payment

to the supplier to induce its food safety effort. They found that traceability based batch dispersion can substitute for the retailer's payments. They also showed that mandatory implementation of the traceability system may not lead to higher food safety, because it increases the firms' costs.

Piramuthu et al. (2013) studied the recall problem in a three-level food network in which the products have contamination risks. They incorporated the long delay and the inaccuracy properties of the contamination source identification in the optimization models. Comba et al. (2013) proposed an optimization model to manage perishable bulk products under the use of traceability system. Although the implementation of food traceability systems helps reduce food safety risks in society, companies may hesitate to do so if the recall cost or the traceability system implementation cost is too high. For most companies, their first goal is to gain financial benefits. As such, managers have to balance the cost incurred by food quality risks and that of recall of products or the implementation of the traceability systems. Memon et al. (2015) proposed an integrated optimization model to minimize the expected loss to shareholders in recall crisis using batch dispersion methodology and taken into consideration of recall costs. It is shown that higher traceability level decreases the stakeholders' losses due to recall, but increases operational cost. Zhu (2017) demonstrated that significant investment cost acts as a major obstacle for the diffusion of traceability systems in the food industry. They studied the economical outcomes for the implementation of a RFID-enabled traceability system in a two-level perishable food supply chain. Considering customers' perceptions of food quality and safety when using the traceability system, they proposed a dynamic pricing scheme, which helps reduce waste and improve the seller's performance. Dai et al. (2017) also studied the pricing and tracking capacity decisions considering different levels of food tracking cost and recall cost. Results show that, there always exists a unique tracking capability and retailing/wholesale price with closed-form solutions to optimize the overall supply chain profit.

In summary, the application of traceability system can help to optimize the recall strategies when food crisis happens, therefore enhance food safety. In the quantitative operations management models, when considering food traceability and food recall, inventory planning strategies (Wang et al. 2009, 2010), transportation planning strategies (Piramuthu et al. 2013), and marketing strategies (Dai et al. 2017, Zhu 2017) will be changed. However, there is limited research on this area and more works can be done.

4. Directions for future research

In this section, we give our suggestions for some future research topics. Although progress has been made in operations management that accounts for food quality in recent years, there are still some challenges, which ought to be overcome in future research.

First of all, in the research area of inventory planning and transportation planning, more works should be done to formulate and solve stochastic optimization problems. It is widely agreed that demand can never be a deterministic parameter in this fast changing world. However, among the papers we reviewed, lots of them assume that demand is a constant parameter, or a price/quality dependent parameter. This assumption is quite unrealistic, which restricts the practicability of the proposed models. Although some papers have studied stochastic problems, no breakthrough occurs during the recent years. In this area, there are two directions for the

researchers. One direction is to formulate new mathematical models to solve more realistic problems and solve them with existing methods. Another way is to find new methods to solve the stochastic models, which is more challenging and more important for the improvement of this research area.

Next, supply chain disruption should be considered in the existing models. Disruption can happen at any stage of the food supply chain. It can either happen at the production stage, or at the transportation stage due to various reasons including weather changing, vehicle damaging, machine breakdown, etc. Comparing to normal products, disruption can even cause more severe damage in the food industry due to the short lifetime of the food products. Because, when the distribution is delayed, quality of the products will deteriorate in a short time. The prevalence of supply chain disruption in food supply chains makes it crucial to enterprises in the decision-making process. However, supply chain disruption has seldom be incorporated in the reviewed studies. In the future, one can reformulate the existing models by introducing supply chain disruptions in one of the distribution phase (inventory, transportation, retailing) or in multiple phases.

In addition, food quality should be modeled in more practical ways. In the existing body of literature, food quality decaying is roughly modeled and approximated with inaccurate parameters. The approximation does not guarantee the applicability of the models to all products. In future research, more realistic factors need to be considered in modeling food quality in OM models, such as fast changing quality status, chemical and microbial properties of the food, and environmental conditions.

Furthermore, the forward distribution and backward recall problems should be integrated. In the papers on distribution problems, some people studied the location problem. Also, in the recall problems, the location of the recall point also serves as a very important parameter. Therefore, when designing a network, enterprises should consider the forward and backward flows simultaneously. In the future, one can formulate the models with both the distribution problems and the recall problems jointly, with a goal to enhance the firms' benefit and the food safety.

Last, it is also a future research direction to incorporate new product tracking or temperature control technologies. With these new technologies, additional information will be obtained and stored. This will lead to more advanced decision making on food quality, more precise inventory control, and more efficient distribution systems.

5 Conclusions

In this paper, we have reviewed the operations management research on food quality and safety. Different from other disciplines that study food quality, the Operations Management (OM) field has focused on using optimization models to capture the effects of important operational variables (e.g., inventory, routing, pricing) on both economic and social benefits. In some studies, food quality is modeled as a constraint to the storage or distribution time, while in others, it is modeled as a decreasing parameter which depends on the required preservation conditions or time. We classify the literature into four categories, ranging from inventory decisions for perishable food products, distribution problems for perishable food products, dynamic pricing decisions for perishable food products, to operations management for food traceability and safety.

Furthermore, we survey the research contributions of the literature, discuss the up-to-date research development and identify challenges for further research within each category. The importance of product quality is reflected in the current research, in terms of both research contributions and the variety of the methodologies used. The future research agenda is also proposed to enrich the understanding of various kinds of operations management decisions and food quality.

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