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Quality, safety and sustainability in food distribution: A review of quantitative operations management approaches and challenges

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Abstract
The management of food distribution networks is receiving more and more attention, both in practice and in the scientific literature. In this paper, we review quantitative operations management approaches to food distribution management, and relate this to challenges faced by the industry. Here, our main focus is on three aspects: food quality, food safety, and sustainability. We discuss the literature on three decision levels: strategic network design, tactical network planning and operational transportation planning. For each of these, we survey the research contributions, discuss the state of the art and identify challenges for future research.

Keywords: food industry, distribution management, network design, network planning, transportation planning

1. Introduction

The distribution of food is different from the distribution of other products. Food products show continuous quality changes throughout the supply chain, all the way until final consumption. Hence, in food distribution, quality, health and safety require central consideration. The importance of food safety has repeatedly been vigorously discussed after the occurrence of food scares *e.g.* caused by the presence of salmonella in chicken or by cows infected with BSE, which led to serious illnesses, even death, and major product recalls. Finally, the distribution of food in the current globalized economy is a major discussion point in society – as well as in academic literature – and the food industry has been at the forefront in developments related to sustainability (reflected for example in discussions about food miles).

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The limited shelf lives of food products, requirements with regard to temperature and humidity, possible interaction effects between products, time windows for delivering the products, high customer expectations, and low profit margins make food distribution management a challenging area that has only recently began to receive more attention in the operations management literature.

The main objective of this paper is to review the quantitative operations management literature on food distribution management. Furthermore, we explore the research opportunities in this area. Here, we choose to focus on three important food-industry-specific challenges: (*i*) food quality, (*ii*) food safety, and (*iii*) sustainability. These issues are dominating the current debate in the society with respect to the food sector, demonstrated by extended coverage in newspapers and trade journals.

This paper limits itself to the share of the operations management literature labelled axiomatic quantitative model-based operations management research. The models developed in this type of research can both explain (part of) the behaviour of real-life operational processes and capture (part of) the decision-making problems that are faced by managers in real-life operational processes; thereby aiming to support decision-making on design, planning, controlling and executing operations (Bertrand and Fransoo, 2002).

Methodologically, the models rely a.o. on mathematical programming, analytical approaches and simulation techniques. Variables that are manipulated, such as shipping quantities or production batch sizes, would usually be referred to as decision variables while performance variables such as logistics costs or service degree would be referred to as objectives. Analytical approaches relevant for the food sector have appeared mainly in the context of inventory management of perishable products. For a discussion of this body of literature, we refer to the seminal papers by Nahmias (1982), Raafat (1991) and Goyal and Giri (2001), and the recent review by Karaesmen et al. (2011). In this last contribution, the sections on multi-echelon inventory systems and logistics are particularly relevant. It should however be noted that the part of the work discussed by Karaesmen *et al.* (2011), which refers to practical problems, mostly relates to blood, and not food. To the best of our knowledge, no review article has as yet addressed food distribution management approaches relying on the remaining methodologies. In this paper, we focus on the specific challenges found in the food sector. This also means we will not address more general issues such as logistics costs or service levels, as long as they are not specific for food distribution management.

The organization of the paper is as follows. Section 2 develops a classification scheme based on the characteristics of food distribution systems and the challenges in the industry. Sections 3 to 6 subsequently review quantitative operations management studies on the strategic, tactical and operational level as well as studies that treat these levels integratively. These sections discuss (*i*) which planning decisions are involved, (*ii*) how these decisions may be supported by the current literature, and (*iii*) where the current body of knowledge is still lacking, hereby identifying directions for further research. Finally, in Section 7, we summarize our results and discuss further research opportunities.

2. Food distribution management

In this section, food distribution management is discussed in more detail. More specifically, we discuss different chain types and decision-making processes with regards to distribution management, followed by a discussion of the food-specific challenges, resulting in a framework that is used in the remainder of the paper to organize our literature review.

To develop this discussion, we used qualitative studies and trade journal articles, leaving the quantitative studies for the literature review part of our paper. Our literature search was based on searches in well-known databases such as ISI Web of Knowledge and EBSCO, followed by reference and citation analyses to find older and more recent contributions. In the review, we limit ourselves to articles in peer-reviewed journals, meaning we did not include unpublished manuscripts or papers in conference proceedings.

2.1. Food distribution systems

Food supply chains stretch from agricultural producers to consumers and usually involve a manufacturing stage, as well as foodservice or retail activities. Distribution management normally refers to the physical flows and storage of products from the final production point to the customer or end user (Rushton *et al.*, 2006) (see Figure 1 for an illustration). Defined like this, food distribution does not include the initial stage of the supply chain - from agricultural producers to the manufacturers. Food manufacturers procure agricultural raw materials and process those before further distribution. Here, processing is defined in a broad sense; ranging from simple packaging of fresh produce to extensive cooking or preservation operations. The part of the supply chain before that, the production and distribution of crops, has been the focus of other reviews, most recently Lowe and Preckel (2004) and Ahumada and Villalobos (2009a).

An important characteristic of many food distribution systems is temperature control. For a wide variety of products, temperature control is essential in controlling food quality and food safety. It does however lead to additional energy consumption. As such, temperature-controlled distribution is related to all three food-specific aspects that are the focus in our discussion: quality, safety and

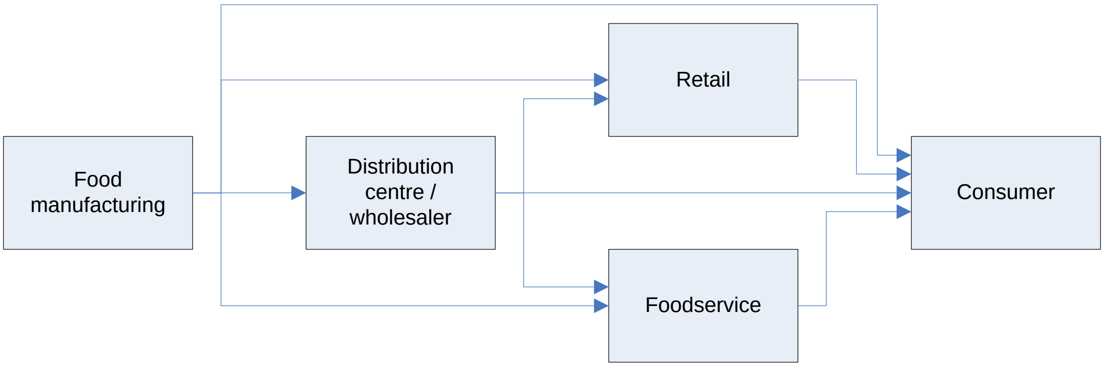

Figure 1. General structure of the distribution part of the food supply chain.

sustainability. In the following, we will introduce in more detail (*i*) the two main types of food distribution chains, and (*ii*) temperature control in distribution.

2.1.1. Types of food distribution chains

After the manufacturing stage, three main actors distribute the food products through the supply chain to the final consumers: wholesalers, foodservice businesses, and retailers (as seen in Figure 1). As the main actors here are retail and foodservice, we specifically focus on those two types of distribution systems. Eastham *et al.* (2001) distinguish retail and foodservice from a consumer perspective, basically by referring to the consumption location, which is respectively inside or outside a hospitality operation. They acknowledge that this boundary is increasingly fuzzy, due to *e.g.* the increase of ready-to-eat meals sold in retailing and the establishment of restaurants within retail stores. Regarding the whole chain, both industries are still quite different in terms of *e.g.* outlet dispersion, supply volumes, and the use of technological systems like EDI (Electronic Data Interchange) or EPoS (Electronic Point of Sale).

For the retail industry, the main actors are large supermarket chains, smaller convenience retailers, and specialist shops. The industry has seen significant consolidation and concentration, which has led to domination of the market by large retailers (Dobson *et al.*, 2001). Specialist shops often gain their competitive advantage due to a deep product assortment and a focus on high-quality products (Huddleston *et al.*, 2009). However, many conventional large retailers are now also offering a wider range of products. In recent years, online retailing has increased (Boyer and Hult, 2005), often leading to different distribution channels, such as direct shipment from producers to consumers (Agatz *et al.*, 2008). In the distribution systems of such online retailers, there is special attention to *e.g.* pricing schemes based on delivery time windows in relation to expected routing costs (Campbell and Savelsbergh, 2006), or the creation of special distribution centres for the fulfilment of internet customer orders (De Koster, 2002). In the remainder of this paper, we only include studies that specifically address the distribution of food products, and do not include more general retail distribution literature. For more information on this body of literature, we refer readers to *e.g.* Le Blanc *et al.* (2006) and Mercer and Tao (1996).

The main actors (or customers) in the foodservice industry are restaurants, cafes, takeaways, street vendors, hospitals, schools, prisons, residential homes, hotels and other premises where food is produced for immediate consumption (Taylor, 2008b). The foodservice industry is dominated by SMEs (small- and medium-sized enterprises), often small-scale production units that take care of their own distribution network. The industry does however experience a trend towards industrial scale food production (Engelund *et al.*, 2009). The consumption of prepared meals is increasing and will continue to grow in the foreseeable future, due to trends in demography and life-style, such as the increase in the number of elderly people, the number of one-person households, and the rising share of out-of-home dining (Buckley *et al.*, 2007). In some foodservice chains, identifying the manufacturing stage is not straightforward, as the product is often processed in several stages. For instance, agricultural raw materials are first processed at food manufacturers, and then further processed in kitchens of foodservice operators.

In retail chains, an increased availability of data has led to industry initiatives like Efficient Consumer Response (ECR), aiming to improve the efficiency in the collaboration between producer, distributor and retailer, establishing an efficient product flow. This is often achieved through creating a pull distribution system, based on an IT system that relies on EPoS data (Hoffman and Mehra, 2000). The large retailers that dominate the retail market have been a leading party in this effort. For the foodservice industry, there are no such large dominating parties, but a similar initiative was started by some industry organizations under the name Efficient Foodservice Response (EFR) (Hill and Scudder, 2002). It should however be noted that in reality, despite initiatives like ECR and EFR, the integration possibilities between different actors in a food distribution system are often limited by product or production characteristics (Van Donk *et al.*, 2008) or obstacles preventing information sharing (Lee and Whang, 2000).

2.1.2. Temperature-controlled distribution

In the distribution of food products, temperature control is an essential factor; it affects product quality by influencing the level of quality degradation, and affects product safety by influencing the growth of potentially harmful bacteria (such as *Salmonella* and *E. coli*). Furthermore, insufficient temperature control may even lead to chemical reactions that could change a product's appearance or texture. These undesirable changes in product characteristics determine the shelf life of the food product, which is hence often linked to a temperature requirement.

In relation to temperature control, we can basically identify three types of food supply chains: frozen, chilled and ambient. For the frozen and chilled chain, a number of different temperatures are used. The frozen chain mainly operates at −18°C, although a product like ice cream requires a frozen chain with an even lower temperature of −25°C. For the chilled chain, temperatures range from 0°C for fresh fish to 15°C for *e.g.* potatoes and bananas (Smith and Sparks, 2004). Finally, an ambient chain concerns products that do not require temperature control, such as canned goods.

The exact temperature levels within the frozen and chilled chain are important for the products involved, but a basic classification of frozen, chilled and ambient is sufficient in relation to our discussion of the food distribution management literature. This classification reflects the main modes of handling products in terms of production and distribution technologies, related to temperature control and product packaging (*e.g.* cooling equipment or insulating packaging material). It also corresponds to different ways of dealing with quality degradation, which in a frozen state may be almost stopped for some products. Numerous studies investigate heat transfer and microbial growth during transport. For more information on this type of modelling work, we refer to James *et al.* (2006).

For chilled products bought from retailers, a large share of the shelf life must be left for the final consumer, as most of these products spend a significant time in home refrigerators, in which temperature is often higher than recommended (James *et al.*, 2008), leading to rapid quality degradation.

2.2. Decision-making processes in distribution management

Managerial decision making is commonly divided into different levels of decision, mainly relating to the time horizon for these decisions (see *e.g.*, Anthony, 1965; Bitran and Tirupati, 1993). This normally leads to the distinction between long-term, mid-term, and short-term planning, or alternatively: strategic, tactical, and operational planning. In this hierarchical approach, we can distinguish three distinct planning levels in distribution management:

- Distribution network design, concerning long-term decisions on the physical distribution structure. This includes *e.g.* the number and sizes of warehouses and cross-docking points, as well as the related transportation links.

Table 1. Characteristics of distribution planning on different hierarchical levels (based on Shapiro, 2007).

	Planning horizon	**Time representation**[a]	**Objective function(s)**	**Frequency of analysis**[b]
Distribution network design	1-5 years	None, or years	Maximize net revenue or return on assets	Major studies once a year; special studies if needed
Distribution network planning	1-12 months	Days, weeks, months	Minimize total costs of meeting forecasted demand or maximize net revenue by varying product mix	Once a month
Transportation planning	1-30 days	Minutes, hours, days	Minimize myopic distribution costs	Once a day and event-driven rescheduling during the day

[a] Time representation: Type of periods incorporated in underlying models.
[b] Frequency of analysis: The number of times each year, month, week, or day that managers and planners use the planning system.

- Distribution network planning, concerning mid-term distribution planning decisions related to fulfilling demand (or forecasts) on an aggregate level. This includes *e.g.* aggregate product flows and delivery frequencies.
- Transportation planning, concerning short term planning of the distribution of actual customer orders. This includes *e.g.* the loading and routing of vehicles.

For each of the planning levels, some typical decisions are mentioned in the list above; a more extensive discussion can be found in the remainder of the paper, where the review of literature for each of the levels is introduced by a more detailed discussion of the typical planning problems.

Planning decisions are typically made based on cost or profit evaluations (Shapiro, 2007). The characteristics of distribution planning on the different hierarchical levels are summarized in Table 1. Next to cost- or profit-based objectives, considerations regarding resource utilization, customer responsiveness, or flexibility are sometimes included in the distribution management literature. For detailed discussions of different objectives on the different decision levels, we refer to the recent reviews by *e.g.* Melo *et al.* (2009) and Mula *et al.* (2010). For our review, we will not discuss the objectives of the various contributions unless food-specific aspects are involved.

Not only do the above planning levels relate to different planning decisions and their related planning horizon, but they are also (*i*) strongly related to hierarchical levels in the organization, and (*ii*) distinctly different in terms of the models that are developed and implemented in planning systems to support these decisions. Obviously, some of these differences have to do with how detailed the time aspect is modelled, if included at all. Also, the time distribution managers spend on analysing the solution differs significantly; strategic and tactical decision-making often includes extensive scenario analysis based on the modelling work, while operational decision-making needs quick solutions and the possibility to replan on an ad-hoc basis.

2.3. Food-specific issues in distribution management

In the remainder of this section, we discuss the three food-specific aspects this paper focuses on and their interdependence. As mentioned in the introduction, the aspects that were chosen – due to their relevance in today's food industry – are (*i*) food safety, (*ii*) food quality, and (*iii*) sustainability.

2.3.1. Food safety

Food safety generally refers to the prevention of illnesses resulting from the consumption of contaminated food. The increasing attention of the industry for food safety is partly due to the fact that much legislation has been enforced on this matter, but it also has an economical motivation: food safety (or related information) can be a competitive factor, and more importantly, the implications of a major food safety failure can be commercially devastating. This includes product recalls, damage to reputation and punitive liability damages (Hobbs, 2006).

A well-known example of such a food safety crisis is the recent recall of peanut butter in the USA due to the presence of salmonella. It was the largest product recall ever in the history of the country, involving more than 200 food manufacturers downstream in the supply chain – in total recalling more than 2100 products (Terreri, 2009). In addition to such well-known large recalls, it has been shown that there are also a very large number of recalls of smaller scale, which in some cases still lead to serious illness or death (Salin *et al.,* 2006).

In relation to food safety, various systems and standards have been developed over the last decades. The best-known are the Hazard Analysis Critical Control Point (HACCP) system (FAO, 2003), the ISO 22000 standard (ISO, 2005) and the British BRC standards (British Retail Consortium, 2004). Systems like HACCP are developed to manage food safety, based on risk management principles and cover a range of biological, chemical and physical hazards. The basic idea behind a HACCP system is to provide a structured way to identify food safety risks and reduce or eliminate these. Standards like ISO 22000 and BRC normally include HACCP aspects, but also provide a management system to incorporate food safety in an organization.

Although HACCP development is currently quite widespread in large food manufacturers, its use is limited within smaller businesses, especially in the foodservice sector (Taylor, 2008a). It should however be noted that there have recently been activities to improve this situation by developing (and validating) an alternative food safety management system that is tailored to the foodservice sector (Taylor, 2008b; Taylor and Taylor, 2008).

In addition, governments are imposing legislations that enforce traceability of food products during all stages of production, processing, and distribution (*e.g.* European Parliament and Council, 2002). Despite the importance of traceability, the reality is that in complex, interconnected food supply chains, complete traceability is more the exception than the rule (Miller, 2009). Schwägele (2005) argues that traceability has to be in food companies' interest, and not just seen as legislation that has to be followed. Some recent literature follows this by discussing how the introduction of traceability might actually be used to add value to the operations of a company (Wang *et al.*, 2009a).

Several factors relevant in relation to food safety risks relate directly to distribution management. In an extensive list of critical safety factors, Van Asselt et al. (2010) found for instance the number of chain participants and the distribution of products to be of particularly strong impact.

2.3.2. Food quality

A second important characteristic is food quality. As noted by Grunert (2005), it normally refers to the physical properties of food products, but also to the way the product is perceived by the final consumer. This can for instance include microbial aspects, but also texture or flavour.

Due to the importance of product quality in the food industry, Trienekens and Zuurbier (2008) expect that quality assurance will dominate the process of production and distribution, and that the costs for certification, auditing and quality assurance may evoke responses like technological innovation to create higher efficiency and reduce costs. New technological developments such as time-temperature integrators or indicators, can be used to improve temperature monitoring throughout the distribution system (see *e.g.* Giannakourou and Taoukis, 2003). This also allows for improved shelf life estimation with a chain perspective, as is for example shown by Raab *et al.* (2008) for pork and poultry chains and Dalgaard *et al.* (2002) for fish chains.

In the foodservice sector, the culinary quality of meals is a much debated issue throughout Europe (*e.g.* Mikkelsen *et al.*, 2007; Hartwell *et al.*, 2006; Wright *et al.*, 2006), and is especially relevant considering the expected increase in consumption of professionally prepared meals.

2.3.3. Sustainability

Over the last years, sustainability has become of increasing importance in the food industry (*e.g.* Mattson and Sonesson, 2003). Sustainability commonly refers to how the needs of the present human generation can be met without compromising the ability of future generations to meet their needs (WCED, 1987). It is increasingly evident that market and regulatory sustainability drivers shape the organization and operation of supply chains. Food supply chains are at the forefront of this development (*e.g.* Wognum et al. 2010, Vasileiou and Morris, 2006).

Next to commonly-used cost-based performance measures, sustainability includes environmental aspects as well as a social dimension (Kleindorfer *et al.*, 2005). This entails for instance employees' health and safety, ethical trading in procurement of raw materials, and animal welfare. For example, fair trade initiatives have been developed to improve the position of food producers in developing countries.

Next to the direct impacts retailers and caterers have on sustainability (among which temperature control and distribution are main parts), sourcing sustainable products from food manufacturers is also of major impact (Baldwin, 2009b), also related to waste and refrigeration related to storage, and foodservice operations during preparation and service (Turenne, 2009). Another well-known concept in relation to the sourcing and the sustainability of food chains is that of labelling, for example in the form of food miles, which relate to the distance a food product has travelled to get to the consumer. Although this only partially reflects the carbon footprint or even total environmental impact of the production and distribution system, the concept has become relatively popular (Saunders *et al.*, 2006; Wilson, 2007). It should be noted that any assessment of sustainability must be made for the supply chain as a whole. Benefits of local products in terms of food miles may be lost through a production and or storage stage with a higher environmental burden (Weber and Matthews, 2008). This evaluation may also depend on whether or not a product is 'in season', as this may have a large impact on the energy usage during storage (Sim *et al.*, 2007).

The environmental dimension of sustainability has probably received the most attention. One of the best-known examples is Life Cycle Assessment, an analytical tool that helps in assessing a products environmental impact from product development to consumption (Hauschild *et al.*, 2005). Although these assessments can be and are used to decrease the environmental load of products, further standardization is still needed to improve comparative studies and to broaden practical applications in the food sector (Roy *et al.*, 2009).

The social dimension has received less attention in the literature (Lehtonen, 2004). Numerous companies have started to work on these issues under the label 'Corporate Social Responsibility' (CSR). In many cases they also communicate their CSR performance to stakeholders like employees or customers. For instance, all ten major retailers in the UK have stated that they see CSR as an integral element of their business environment, although there are substantial variations in the nature and extent of the CSR information they provide (Jones *et al.*, 2005). Recent work has however provided some guidelines on how to approach this with a combination of methodologies to eventually be able to combine all three dimensions (White and Lee, 2009). Also, there are several developments towards a 'social LCA', which is supposed to supplement the existing LCA methodologies and as such work towards a methodology that would address all dimensions of sustainability (see *e.g.* Hauschild *et al.,* 2008; Hutchins and Sutherland, 2009).

Promoting social and environmental awareness can also be beneficial for a corporate image (Chinander, 2001), and in some occasions it might lead to cost savings at the same time, for instance while reducing food waste.

2.3.4. Interdependence between quality, safety and sustainability

The tree topics described in the previous sections are currently dominating the public debate in relation to the food sector. It is however important to realize that there are strong relationships between these topics.

The fact that food distribution deals with products that are eventually meant for human consumption results in a strong focus on food quality and food safety. This is especially true for products that do not undergo extensive shelf-life-extending treatments and remain 'fresh products' with short shelf lives. Both quality and safety are based on changes in the food product. The main difference being that food quality is based on a more continuous process of degradation, whereas safety is modelled as a binary; a product fulfils safety requirements or it does not. However, underlying is often a continuous process related to *e.g.* the growth of a certain bacteria.

Product changes are often reduced by temperature-controlled storage and distribution, which however normally require a significant amount of energy, thereby negatively affecting the environmental impact of the products (*e.g.* James and James, 2010). Twinn (2007) discusses the challenges the cold storage and distribution sector faces with respect to environmental concerns and increasing electricity costs. She stresses that not only new technological solutions should be developed, but also the use of existing machinery and processes should be optimized.

Nowadays, systems that are originally designed to control food safety (like HACCP) are also used to increase the product quality throughout the supply chain (Panozzo *et al.*, 1999). This also concerns nutritional quality, as can for instance be seen in the recent development of the Nutritional Control Points (NCP) concept (Rodrigues *et al.*, 2010). This is based on the HACCP system, and can be used to identify the critical points in production and distribution systems related to nutritional product changes and eventually help to increase nutritional quality.

Extending these quality and safety control systems into transparent food chains that are able to supply affordable food with high quality and diversity are some of the challenges related to the sustainability of the food industry (Fritz and Schiefer, 2008). The challenge for the industry is, as

Smith (2008) stated, to extend responsibility for product quality into social and environmental performance of food supply chains. Wognum et al. (2010) investigate how existing technology designed for enhancing the transparency of food supply chains such as the safety focused traceability systems can be expanded to also help to improve sustainability.

Furthermore, food distribution is rapidly moving towards globally inter-connected systems with a variety of relationships. This means that products are sourced from markets all over the world, leading to a focus on quality preservation, and at the same time cost-effectiveness. Apaiah *et al.* (2005) therefore argue that the design of such food distribution systems requires a combined effort from the fields of food process technology, operations research, environmental science, marketing, and business economics.

In light of sustainability, wasted product is also an important performance measure. In general, food products that are not ending up being consumed have had a significant environmental impact without adding value. Partly, this is due to food products deteriorating and having to be thrown away. In most countries, around 30% of food products is said to be wasted throughout the supply chain (Chapman, 2010). Even though a large part of this waste occurs at the final consumer, retail and foodservice also contribute significantly.

All in all, the above aspects illustrate the strong interdependence between sustainability on the one hand and the control of food quality and food safety on the other hand, and demonstrate why food quality and safety are often included in wider definitions of sustainability and can even be seen as the fundament of a sustainable food supply (Baldwin, 2009a), especially with regards to global sourcing and its environmental impact.

2.4. Summary

The topics covered in the previous sections (and summarized in Figure 2) make up the framework we use in the following sections to review the literature. Each of the identified planning levels will be discussed separately. In each of the sections, tables will be presented to summarize the contributions. To keep these tables compact, we used a classification scheme to identify the type of distribution system, which can be either foodservice (S), retail (R), or unspecified (U). Temperature levels can be ambient (A), chilled (C), frozen (F), or unspecified (U). For example, the classification R|CF would refer to a contribution discussing the distribution of chilled and frozen products in the retail sector.

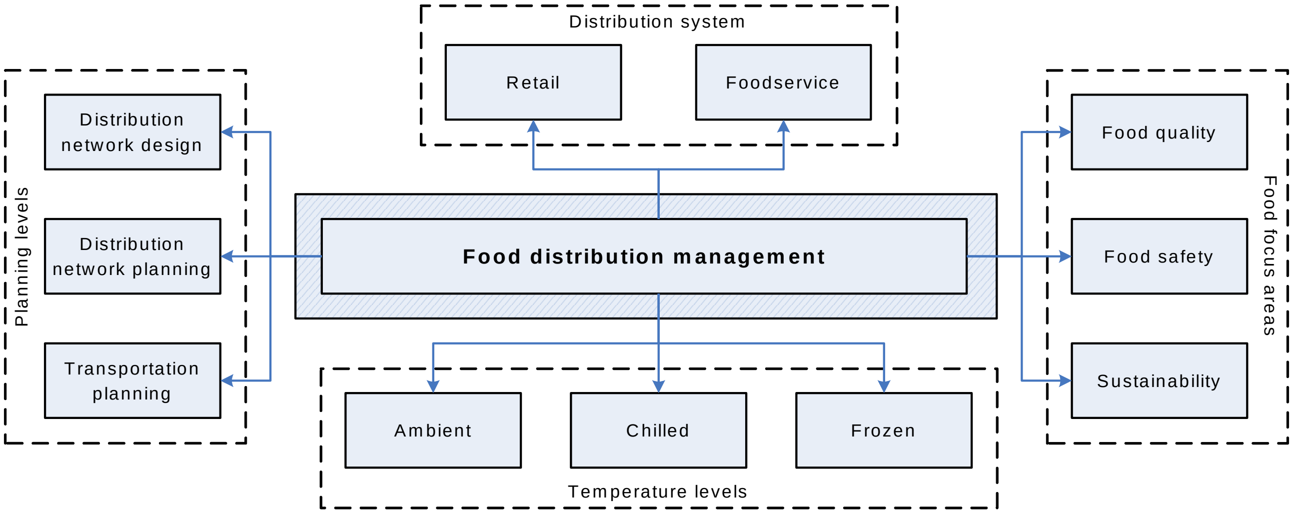

Figure 2. Framework used to review the literature on food distribution management.

3. Distribution network design

3.1. Introduction

Distribution network design concerns long-term decisions on the physical distribution structure of a new network or on the redesign of an existing network. It includes *e.g.* the location, number and sizes of warehouses and cross-docking points, as well as the related transportation links. Distribution network design is among the most critical operations management decisions facing a firm, as it affects costs, time, and quality of customer service (Jayaraman, 1998).

The main decisions are normally (*i*) where to locate facilities, and (*ii*) how to allocate customers to facilities and facilities to each other in case of supply chains with multiple echelons. Together, this is generally referred to as facility location-allocation (Meixell and Gargeya, 2005; Melo et al., 2009).

Typically, the location-allocation problem leads to mixed-integer linear programming models in which binary decision variables are used to decide whether a potential manufacturing plant or potential distribution centre is actually going to be used. Continuous decision variables are used to denote the aggregate product flow in the distribution network ending at the customers where demand has to be fulfilled. Typically, the objective function minimizes the total cost for opening facilities in certain locations, and the production and distribution costs for shipping products through the distribution network (75% according to the review by Melo *et al.*, 2009). Alternatively, profit maximization is used (16%), and to a fairly limited extent other objectives (*e.g.* robustness, resource utilization, flexibility, and customer responsiveness) are included, but then mostly in addition to financial aspects.

It should be noted that the location-allocation problem is usually described in a basic single-period model. When considering a longer time horizon and multiple periods, the net present values of the included costs have to be used. In today's globalized setting, one might also have to extend this with *e.g.* exchange rate parameters and different taxation rules (Meixell and Gargeya, 2005). We refer to Klose and Drexl (2005) for a further discussion on modelling facility location-allocation, with a focus on mixed-integer linear programming approaches. For extensions to the facility location-allocation problem, see for example Cordeau *et al.* (2006), who also integrate supplier selection, transportation mode selection, and product range assignment. Furthermore, extensions often include more detailed tactical and operational decisions related to the planning of production and inventory and routing decisions (Melo *et al.*, 2009). In Section 6, we will provide a more detailed discussion of models integrating different decision levels.

As profit margins can be quite low in the food industry and distribution operations constitute a significant portion of total supply chain costs, great efforts and investments are often put in network design. It is however a challenging task to design food supply chains for products that have good quality, are not expensive and are environmentally friendly (Apaiah *et al.*, 2005). The network design significantly affects the eventual safety of the food product, as the design determines the number of actors, and the extent to which products are dispersed through the network. Regarding product quality, the design of the network influences for example the time a product is subject to quality degradation during distribution. The design of distribution networks has a strong impact on sustainability, for instance related to the distance products have to travel to reach the final consumer, or to the environmental impact of the transportation method involved.

For foodservice chains, the aim is often to pursue a low stock level or a no-stock-overnight policy in distribution centres, and to frequently ship in smaller amounts with high variations in demand. This will often also affect the length of the chain: direct delivery from the producer to the caterer is for instance common for these products (Bourlakis and Weightman, 2004). Another typical aspect found in foodservice systems is that production activities are not always confined to the initial food manufacturing stage, as it is often the case that additional production steps take place at the caterer (*e.g.* final meal assembly and preparation).

3.2. Contributions

Several authors have studied the location-allocation problem for specific food industries, using mixed-integer linear programming approaches (cf. Table 2). Most of these models include both the locations of production plants and distribution centres. Geoffrion and Graves (1974) provide a general model, which they apply to analyze the locations of distribution centres for a large food producer with distribution centres throughout the US.

Pooley (1994) and Wouda *et al.* (2002) both study location-allocation cases from the dairy industry. Pooley (1994) focuses on building a simple model that would be understood and accepted by the management of the dairy company. Wouda *et al.* (2002) construct a more elaborate model, also including the inter-facility shipment of by-products such as whey and cream, which might be needed in other facilities as ingredients. The resulting model is then used to analyze several production strategies (such as regionalisation of production and distribution, and product specialization at production plants).

Table 2. Overview of food distribution network design contributions.

	Product	**System**	**Method**	**Characteristics (with focus on safety, quality and sustainability)**
Blackburn and Scudder (2009)	Fresh produce	U|AC	Analytical /scenario analysis	Decreasing product value over time, focus on different transportation options.
Gelders *et al.* (1987)	Beer	RS|U	MILP	Special attention to data collection and estimation of cost parameters
Geoffrion and Graves (1974)	Unspecified	U|U	MILP	General location-allocation model
Groothedde *et al.* (2005)	Palletized	R|U	Heuristic	Study of potential additional hub layer between food manufacturers and retail DCs.
Köksalan and Süral (1999)	Malt	U|U	MILP	Focus on scenario analysis
Levén and Segerstedt (2004)	Wild berries	U|F	Heuristic	Use of load-distance analysis. Frozen storage result of seasonal product.
Pooley (1994)	Dairy	U|U	MILP	Focus on a simple model to aid acceptability by management
Reiner and Trcka (2004)	Pasta	R|U	Simulation	Analysis of different demand situations (in relation to bullwhip effect).
Van der Vorst *et al.* (2009)	Pineapple	R|C	Simulation	Explicit modelling of quality degradation and sustainability issues
Wouda *et al.* (2002)	Dairy	R|U	MILP	Flows of by-products included
Zhang *et al.* (2003)	Unspecified	R|CF	Metaheuristic: Tabu search	Explicit modelling of quality degradation

The location-allocation problem in the beer industry is studied by Gelders *et al.* (1987) and Köksalan and Süral (1999). Gelders *et al.* (1987) analyze the distribution system of a large Belgian brewery, proving that the idea of the brewery to drastically reduce the number of distribution centres is not to be recommended at all. They stress that the increased understanding of the distribution system amongst managers due to extensive what-if analyses is possibly an even more important outcome of their study. In subsequent work, Köksalan and Süral (1999) describe a follow-up project, which focuses on a different part of the beer supply chain, namely the location-allocation of new malt plants supplying malt to the breweries owned by the same company. The MILP model they develop is extensively used for scenario analysis in cooperation with company personnel.

Zhang *et al.* (2003) also consider a location-allocation problem, but explicitly include quality degradation of the food product throughout a food supply chain with multiple levels (manufacturers, central warehouses, distribution centres, and retailers/caterers). They include penalty costs for this quality degradation, based on time and temperature throughout the chain. The penalty value depends both on the amount of degradation and the amount of product. In their network design model they introduce a fixed quality degradation parameter for each distribution path from a food manufacturer to a retailer/caterer, and multiply this with the flow quantity to calculate the penalty costs. In addition, they limit the quality degradation permitted during distribution to a maximum. Zhang *et al.* (2003) then use this penalty cost a tabu search-based solution method.

Levén and Segerstedt (2004) also study a situation in which a location decision needs to be made. The situation described deals with the supply chain of frozen wild berries, a seasonal product that is only supplied during a 4-6-week period, but distributed to customers throughout the year. The authors use a load-distance method to analyze different potential storage locations.

For a large network of food manufacturers and retailers, Groothedde *et al.* (2005) study the possibility to develop a collaborative hub network, aiming to consolidate palletized flows between the production sites of the manufacturers and the distribution centres of the retailers. The main decisions to be made are the locations of the hubs and the determination of fixed transportation paths through the network. For the transport between hubs, shipping on vessels is considered, leading to significant cost savings, but increased transportation times. A combination between the modes of transportation is suggested in which easily forecastable demand is shipped by vessel before the actual order is placed, while the unpredictable part of the demand is delivered on short notice by direct trucking.

Blackburn and Scudder (2009) look at the supply chain of fresh produce that has a deteriorating quality after harvest. The authors minimize product value loss in a hybrid supply chain that initially focuses on responsiveness, to get the product in the cold chain as soon as possible, and once the product is in the cold chain, and value (and quality) deterioration is lower, the focus can be shifted to cost efficiency. The main decision that is modelled in the distribution part of the supply chain is the transportation mode.

Apart from optimization approaches, some authors have also used simulation to study distribution network design. Reiner and Trcka (2004) study a pasta distribution network and investigate how having a distribution centre in the network between production and retail affects the bullwhip effect, looking at different demand patterns (*i.e.*, smooth or volatile). Under volatile demand, the distribution centre does reduce the bullwhip effect, which means a longer distribution chain could be beneficial, opposing the common idea that shorter chains reduce the bullwhip effect.

Finally, Van der Vorst *et al.* (2009) introduce a new simulation environment with the specific aim to support the design and redesign of food supply chains. They stress that the design of distribution networks depends on the desired food quality at the customer, and also call for quality-controlled logistics on the lower decision levels. Next to logistical costs, they include quality decay and sustainability measures. The templates in their modelling environment are developed to include food-specific characteristics, such as quality change for product entities, and climate control for storage and distribution entities. The authors also illustrate the approach for a pineapple supply chain, analysing two possible distribution network designs with regards to costs, product quality, energy use and CO_2 emissions.

3.3. Research directions

Despite the importance of the food industry, there is only a limited number of contributions on food distribution network design. Even though all of the discussed papers relate to applications in the food industry, most of them are actually generic facility location-allocation studies; *i.e.*, there are no aspects that make the studies distinctive for the food industry.

The inclusion of product quality was seen in some recent work (Zhang *et al.*, 2003; Blackburn and Scudder, 2009; Van der Vorst *et al.*, 2009), but still seems to be in its infancy. A function like the one introduced by Zhang *et al.* (2003) to calculate the total quality degradation can be used in two ways: as a penalty function in the objective function, or as a constraint where it can be used to limit the total quality degradation in the distribution network. This obviously assumes that it is possible to estimate the degradation between manufacturer and retailer/caterer. A discussion of the impact of operational decisions on e.g. storage duration and transportation and of the microbial and chemical characteristics of the food products is required. Otherwise, extremely conservative values for decay parameters and thresholds need to be used which may impair the efficiency of the distribution operations significantly.

Food safety considerations are thus far not addressed in network design research. Considering the importance of this issue, this provides many opportunities for further work. Distribution network design decisions for instance affect how many actors are involved, how far products travel, and how wide they get spread geographically. These factors have a major effect on food safety and on the sizes of potential product recalls.

Sustainability is explicitly only included in the work by Van der Vorst *et al.* (2009). They relate the travelling distance in networks to the environmental impact. However, considering the relevance of sustainability in the food sector, there is a need for additional work in this direction.

No contribution addresses the specific situation of the foodservice industry. Here, the network design must provide a strong link between production and distribution. Also, the suitable division of production over different stages has not yet been investigated.

4. Distribution network planning

4.1. Introduction

Distribution network planning concerns mid-term decisions related to fulfilling demand (or forecasts) on an aggregated level. Here, the distribution network is a given, but the focus is on achieving efficiencies in managing distribution as an integrated system (Tayur *et al.*, 1999). The literature on this mid-term decision level covers a large variety of decision problems, and we refer to Mula *et al.* (2010) for a general discussion. In comparison with distribution network design, distribution network planning requires more detailed modelling of production and distribution. Most importantly, a time dimension is added. In optimization models, the time horizon is discretized into periods which are linked through inventory, *i.e.*, food is produced in one period and distributed and consumed in a later period. This may be an efficient way to, for instance, cover a peak in seasonal demand or achieve efficiencies in distribution. This also means that most of the decision-making on distribution is integrated with decision making on production and inventory.

Assessing the range of contributions for our review, it became clear that there are two main research fields studied in relation to food distribution management. First of all, there is a significant amount of work on the planning of aggregate product flows between the various actors in the distribution network which we will discuss in Section 4.2. Secondly, a significant amount of work is related to the determination of delivery frequencies. These studies focus on a more detailed level, where the time periods considered are also smaller: mostly days. However, the determined frequencies will be applied for a longer time span. Contributions to this decision problem will be discussed in Section 4.3. The remaining contributions on the distribution network planning level will be covered in Section 4.4, after which we will conclude with a general discussion of distribution network planning approaches and challenges in Section 4.5.

4.2. Aggregate flow planning

Modelling approaches in aggregate flow planning often use mixed integer linear programming models similar to the distribution network design models sketched in the previous section. There are however significant changes to incorporate the time dimension and the possibility of keeping product in inventory between periods. A general model for distribution network planning uses continuous decision variables to decide on the product flows in the distribution network for each time period and the inventory levels at the various locations are taken into account. Typical other model constituents include inventory balances and demand coverage constraints. In terms of objectives, there is in the literature again a large focus on financial aspects, occasionally combined with customer-related aspects such as service levels or flexibility (Mula *et al.*, 2010).

Table 3 provides an overview of the literature related to aggregate flow planning. These contributions all present models that are similar to the general model outlined above. The main questions that are addressed are related to the production quantities in different plants and the shipment quantities from these plants to retailers, possibly through distribution centres.

A typical approach is found in Duran (1987), who studies the production and distribution network for a brewery. An interesting aspect in relation to modelling food production systems is the distinction the author makes between processing a certain quantity of a food product, and packaging a certain SKU, so that processing and packaging activities are treated separately. This means that next to inventory balance constraints, there are also constraints necessary to balance processing and packaging. Considering that numerous food production systems are structured in these two stages, this distinction is natural and widely applicable.

Various other special aspects are also considered. In the model presented by Del Castillo and Cochran (1996), a return flow for soft drink bottles is included in the distribution network. Ioannou (2005) includes a distinction between different packaging formats. Each is treated as a separate flow in the distribution network.

Table 3. Overview of food distribution planning contributions – Aggregate flow planning.

	Product	**System**	**Method**	**Characteristics (with focus on safety, quality and sustainability)**
Ahumada and Villalobos (2009b)	Packaged fresh produce	U|U	MILP	Selection of transportation mode. Linear quality decay over period of shelf life. Includes crop planning.
Bilgen and Günther (2009)	Fruit juice, soft drinks	R|U	MILP	Demand modelled at DC level. Strong emphasis on production planning. Also including daily vehicle requirements.
Brown *et al.* (2001)	Cereal	R|U	LP	Developed for use on different time scales. Production and packaging treated separately.
Del Castillo and Cochran (1996)	Soft drinks	R|U	LP + Simulation	Inclusion of returnable containers.
Duran (1987)	Beer	U|U	MILP	Large focus on solution approaches like LP relaxations and various decompositions. Production and packaging treated separately.
Ekşioğlu and Jin (2006)	Unspecified, perishable	R|U	MILP	Perishability modelled through maximum number of periods in inventory.
Higgins *et al.* (2006)	Sugar	U|U	MILP + heuristics	Includes assignment of ships to ports (which act as DCs), production costs and capabilities differ for the sugar mills.
Ioannou (2005)	Sugar	R|U	LP	Different packaging types considered. Complete network flexibility in terms of direct deliveries and transhipments.
Rong *et al.* (2009)	Bell peppers	R|C	MILP	Explicit modelling of quality degradation and decision-making on temperature levels

Brown *et al.* (2001) develop a large-scale linear program that models the production and distribution network of the Kellogg Company, a large producer of breakfast cereals and other foods. A noteworthy aspect of the model is that it is developed to function on different time scales, using weeks or, alternatively, months as time units. As in Duran (1987), Brown et al. (2001) distinguish between processing and packaging activities.

For a sugar distribution system, Higgins *et al.* (2006) schedule the shipment of sugar from production sites (mills) to ports that act as distribution centres from which ships are used to export sugar internationally. Overall aims of this study are obviously to improve the efficiency in sugar production and distribution, including port operations, and to support the scheduling procedure, but also to facilitate rescheduling during the season to account for changing production rates which may be due to varying harvesting volumes or qualities. An important aspect of the production of sugar is the setup time required to change to the production of a different type of sugar, which is why Higgins *et al.* (2006) limit the number of product changes over the planning horizon.

Bilgen and Günther (2009) present an integrated model for production and distribution planning. Next to the traditional product flow variables, the distribution part also distinguishes two different transportation modes in the distribution between plants and DCs: full truck load (FTL) and less than truck load (LTL). This *e.g.* leads to the determination of the daily vehicle requirements for FTL shipments and its inclusion in the cost function. As the model also includes production quantities at different locations and related setup settings, total production and distribution costs can be minimized.

The selection of transportation modes is also a main focus of Ahumada and Villalobos (2009b), who study the production and distribution of packaged fresh produce. After packaging the products, the supply chain consists of several more stages in which choices have to be made on using truck, rail or air to transport the products. The authors also include product quality degradation in the model, both in terms of a limited storage time and in terms of a decreasing value of the product over time (based on a linear decrease during the shelf life). Using an index to keep track of the harvest period, the authors are able to track the shelf life. In a typical aggregate flow planning model this leads to the revision of the demand coverage constraint to only include products that have been harvested in the most recent periods (depending on the maximum number of periods the product can be stored).

Regarding the consideration of product quality, a similar contribution is made by Ekşioğlu and Jin (2006), who develop a general MILP approach for network planning of perishable products. Here, perishability is also modelled by a maximum number of periods the product can be stored. In a typical aggregate flow planning model, the authors add a constraint to make sure product inventory in distribution centres is not used to cover the demand after having been stored beyond the specified maximum number of periods. It should be noted that this model assumes that the demands are satisfied from exactly one distribution centre and that the inventories are managed on a first-in-first-out basis.

Finally, a recent contribution by Rong *et al.* (2009) presents a MILP approach for food production and distribution planning, explicitly modelling the quality change of products throughout the distribution network. This is based on the time-temperature profile during storage and transportation of the product, and is also linked to decision-making on the temperatures during storage and distribution. The authors develop a generic modelling approach and apply this in a case study.

4.3. Delivery frequency determination

Delivery frequencies refer to a fixed pattern of deliveries to customers. These frequencies were the main topic of several studies. Often, such recurring patterns are fixed for a reasonable time period, as that facilitates retailers/caterers to plan their activities around that. Therefore, the decisions on how often and when exactly customers will get deliveries are made on a tactical level. Table 4 gives an overview of the studies focusing on determining delivery frequencies. As opposed to aggregate flow planning, we here also find contributions that exclusively consider distribution-related decisions without including production or inventory aspects.

Table 4. Overview of food distribution planning contributions – Delivery frequency.

	Product	**System**	**Method**	**Characteristics (with focus on safety, quality and sustainability)**
Adenso-Díaz *et al.* (1998)	Dairy	R|U	Local search	Hierarchical approach, including *e.g.* the distribution of customers among sales promoters, and the delivery frequency.
Jansen *et al.* (1998; 2001)	Catering products	S|ACF	Simulation	Evaluation of logistic scenarios (delivery frequencies for different product classes).
Pamuk *et al.* (2004)	Beer	R|U	MILP	Modelling the assignment of customers to weekdays, in relation to delivery frequency.
Van der Vorst *et al.*(2000)	Salads	R|C	Simulation	General modelling method for simulating food distribution systems (focus on delivery frequencies).
Zanoni and Zavanella (2007)	Unspecified, perishable	U|U	MILP	Decisions on delivery frequencies and the related number of vehicles used.

To improve the delivery system of a beer producer in Turkey, Pamuk *et al.* (2004) model the assignment of customers to weekdays. The main decision is whether customers get deliveries once or twice a week, and on which day(s), taking into account that the workload of weekdays should be reasonably balanced. Adenso-Díaz *et al.* (1998) also determine on which days of the week a certain customer should be served, but they include several other decisions in a hierarchical approach, such as the distribution of customers among sales promoters to balance their workloads.

In Jansen *et al.* (1998; 2001) and Van der Vorst *et al.* (2000), simulation studies are presented that have wider scope, but in the illustrative scenario analysis the main focus is on delivery frequencies. Van der Vorst *et al.* (2000) additionally considers inventory at the retail level, where out-of-date products have to be discarded.

Zanoni and Zavanella (2007) look at a similar situation, but present a generic MILP model to find delivery frequencies and the related number of vehicles for the case of shipping from a single origin to a single destination. Several different product types are included requiring their own vehicle type, which could for instance relate to products that require chilled, frozen, or ambient distribution. The key focus of the model is on cost minimization, while making sure the shelf life of the different product classes is considered in the resulting time between deliveries.

4.4. Miscellaneous network planning decisions

Table 5 presents the remaining contributions to distribution network planning. These do not fit the two categories presented above: they do not build on the typical flow models presented in Section 4.2 nor do they focus on the determination of delivery frequencies as discussed in Section 4.3.

Table 5. Overview of food distribution planning contributions – Miscellaneous.

	Product	**System**	**Method**	**Characteristics (with focus on safety, quality and sustainability)**
Boronico and Bland (1997)	Turkeys	R|F	Stochastic Dynamic Programming	Seasonal product. Frozen storage at DC. Includes stochasticity in the receipt quantities.
Broekmeulen (1998)	Vegetables and fruits	R|AC	Local search	Product keeping quality is explicitly modelled in development of storage policies for DC.
Dabbene *et al.* (2008a; 2008b)	Fresh food	U|C	Local search	Combination of time-driven and event-driven dynamics. Including a variety of operations conditions relating to physical and timing variables.
Rijgersberg *et al.* (2010)	Fresh-cut iceberg lettuce	R|C	Simulation	Combination of logistical modelling, pathogen growth modelling, and sensory quality modelling.
Rong and Grunow (2010)	Unspecified	U|C	MILP + heuristics	Focus on food safety. Trade-off between dispersion of production batches and production efficiency.
Villegas and Smith (2006)	Cookies, biscuits, crackers	R|U	LP + Simulation	Focus on the relationship between safety stocks and variation in production and distribution quantities.

In relation to order quantities, Boronico and Bland (1997) determine optimal procurement plans for a distribution system of frozen turkeys, which have a distinct seasonal demand pattern, but are supplied throughout the year. The method also includes uncertainty in the actual receipt quantity after ordering.

The management of a distribution centre for vegetables and fruits is studied by Broekmeulen (1998). Here, the minimization of quality loss was the focus of the storage assignment plan developed, basically assigning products to the different temperature zones in the warehouse. Next to temperature, the model includes a variety of other food-related characteristics, such as an interaction between products in terms of their quality degradation. The operational implementation of the assignment plan is studied by use of simulation.

Dabbene *et al.* (2008a) study a distribution network for fresh foods. They present a generic model combining both time-dependent characteristics of food products and distribution aspects. The approach also includes a detailed model of the operational conditions during the processing stage (before distribution). In a companion paper, Dabbene *et al.* (2008b) consider a case study of a fresh-food supply chain in which they study the decision-making on refrigeration power used and processing time before distribution. The product temperature can be adjusted in combination with distribution decisions, with the objective to deliver the product at a certain time and a certain temperature.

Rijgersberg *et al.* (2010) develop a simulation model of the distribution chain of fresh-cut iceberg lettuce. The focus of this model is on the quality and safety of the product being distributed. The authors analyse various scenarios, investigating primarily food safety aspects, by studying the growth of *Listeria Monocytogenes*, a relevant pathogen in this type of food product. Next to this, product shrinkage and retail out-of-stock are considered as additional performance measures. The main focus is on the impact of use-by-dates, customer selection behaviour in stores (steering the customer towards buying the older products), and lead time reduction in the distribution chain.

Production batches get dispersed when distributed through in a distribution network. Rong and Grunow (2010) investigate the implications for food safety management. Their idea is that decreasing dispersion by using smaller production batches would be beneficial in case of food safety problems, but on the other hand decreases production efficiency. Their approach is able to support this trade-off based on the risk attitude of the decision maker.

Villegas and Smith (2006) study the relationship between inventories and variations in production and distribution order quantities. They develop a System Dynamics model to show the dynamics of the distribution network, and the occurrence of the bullwhip effect. They also provide LP models that are used to mimic the behaviour of an Advanced Planning System. Using these models, the authors show that most of the demand variation leads to adjustments in production and distribution quantities, while capacity shortages lead to the use of additional inventories. Finally, they provide an alternative planning model to reduce the variability in production and distribution quantities.

4.5. Research directions for distribution network planning

Based on the contributions discussed, it is clear that there is a wide variety of decisions being supported by the modelling work on the network planning level. Various approaches based on aggregate flow planning were discussed, mostly on fairly coarse time discretization. On a more detailed level, several studies focused on the aspect of delivery frequencies. Finally, work was discussed that did not fit in the categories for aggregate flow planning or delivery frequency determination. This last category showed some interesting examples of how food quality and safety can be addressed on this decision level.

Regarding food quality, there are some studies that explicitly model continuous quality change, and some others that deal with the issue implicitly. Implicit modelling approaches toward quality change can be found in Brown *et al.* (2001) and Ekşioğlu and Jin (2006), who consider a limitation on product storage time so as to avoid product spoilage. Broekmeulen (1998) models quality degradation during storage explicitly and investigates different storage policies for vegetables and fruits, using a penalty for quality changes above a certain maximum. However, Broekmeulen (1998) only focuses on minimizing quality change and does not look at the trade-off between quality loss and storage, handling or transportation costs. Rong *et al.* (2009) however integrate decision-making on logistical issues with issues affecting food quality degradation, such as initial quality levels and temperatures during storage and transportation. They use a discretized quality scale to track product quality throughout the production and distribution system. It should be noted that modelling approaches with time discretization in months (as is typical in aggregate flow models) are only applicable if the quality decay of the food is limited. If highly perishable food is regarded, the time discretization (and the problem horizon) needs to be adjusted, which leads to problems in terms of computational tractability, or suitable aggregation schemes need to be developed. The development of suitable mathematical modelling approaches hence still needs further research. In an alternative approach, Jansen *et al.* (1998; 2001) and Van der Vorst *et al.* (2000) therefore used simulation modelling to handle product quality as a performance indicator next to cost aspects.

Food safety has also seen only limited (and recent) consideration in the reviewed work. Rong and Grunow (2010) aim at reducing the impact of possible recalls by reducing the dispersion of production batches in distribution networks. The work presented by Rijgersberg *et al.* (2010) provides a promising simulation approach combining microbial risk assessment with logistical modelling.

It is noteworthy that sustainability does not seem to have gotten any attention on the distribution network planning level. Some of the studies do however contain cost elements that also have an environmental side, such as the temperature control factors included by Dabbene *et al.* (2008a; 2008b) and Rong *et al.* (2010). These factors relate to energy use for refrigeration, an important aspect in the discussions around the environmental impact of food transportation.

Finally, it is worth noticing that, so far, the focus of the literature has been mainly on retail chains, leaving the distribution challenges in foodservice behind. Only Jansen *et al.* (1998; 2001) focus on this industry

5. Transportation planning

5.1. Introduction

Transportation planning concerns the short term planning of the distribution operations and mostly deals with the planning of deliveries to different customers. Transportation plays a key role in today's economies; accounting for up to two-thirds of the total logistics cost. Moreover, it also has a major impact on the level of customer service (Ghiani *et al.*, 2004). Transportation planning takes place in a highly dynamic environment requiring frequent re-considerations of previously made decisions (Crainic and Laporte, 1997).

Typical decisions on this decision level are the details of delivery routes; at what exact times, by which vehicle, and in what sequence customers will get their products delivered. In addition, also warehousing decisions may have to be made on the operational level, such as the assignment of inbound and outbound trucks to dock doors. For a more comprehensive discussion of decisions related to operational warehouse operations, we refer to Gu *et al.* (2007).

For certain food products, international agreements have been made to regulate the transportation of chilled and frozen foods. In a recent paper, Panozzo and Cortella (2008) argue for the extension of these agreements to other perishable food products, such as prepared dishes, and (minimally processed) fruits and vegetables. Next to increased food safety and quality, Panozzo and Cortella (2008) expect that this would also lead to positive economic and environmental effects, mainly resulting from decreased energy consumption.

As outlined in Section 2, the transportation of food products requires different temperature levels. A vehicle may be divided up into multiple compartments with different temperature control. A recent paper by Derigs *et al.* (2010) provides a general model for multicompartment vehicles, also stressing that most of the previous work in this area concerns fuel distribution and is hence not relevant for this review.

Most approaches in the transportation planning part of our review are based on the well-known vehicle routing problem (VRP), often including delivery time windows. A basic mathematical programming formulation of such a problem would use binary decision variables to denote whether a trip from a location to another location is included in the route for a specific vehicle. For each of these locations the model includes delivery time windows: an earliest delivery time and a latest delivery time. Objectives are often the minimization of total duration of the routes, the minimization of the total distance travelled, or the minimization of the total number of vehicles needed to perform the deliveries (Bräysy and Gendrau, 2005a). Our paper only focuses on food transportation problems and their characteristics. For a detailed discussion of general vehicle routing problems we refer to early work by Dantzig and Ramser (1959) and Golden *et al.* (1977), the seminal paper by Bodin *et al.* (1983) or the more recent review on vehicle routing problems with time windows by Bräysy and Gendrau (2005a).

Mathematical programming models often become large and hence computationally time-consuming. For this reason, heuristic approaches are normally developed to be able to solve the routing problem within reasonable time. For a detailed discussion of solution methods, we refer to Bräysy and Gendrau (2005b) or Tarantilis *et al.* (2005).

5.2. Contributions

Table 6 presents an overview of the literature on food transportation planning. As mentioned in the previous section, the work on this planning level mainly encompasses contributions related to VRP applications to the food industry. For this reason, we also chose to present two columns with model characteristics. The first contains characteristics that distinguish the contribution from a VRP perspective, whereas the second contains (food-specific) additional characteristics. In the first column, we only presented characteristics that make the contribution different from a standard VRP problem. Here, we understand the standard VRP problem to consist of one distribution centre (or depot) from which certain quantities of a single product have to be delivered to several customer locations (no split delivery), using an undetermined number of identical vehicles. These vehicles have to return to the distribution centre, and only do one delivery tour each.

Most contributions use a heuristic approach to solve the routing problems; well-known construction and improvement methods are used. Therefore, Table 6 does not include information on the solution methods. The only paper that does not use such a heuristic approach is De Angelis *et al.* (2007), who employ integer programming. It should however be noted that the problem these authors study is fairly small, and also contains some simplifying assumptions, for example are only full cargo loads distributed to customers.

Table 6. Overview of food transportation planning contributions.

	Product	System	VRP characteristics	Special characteristics
Adenso-Díaz *et al.* (1998)	Dairy	R|U	Heterogeneous vehicle fleet, time windows	Whenever possible, additional customers in the same town that are initially scheduled for a separate visit are added to a route.
Ambrosino and Sciomachen (2007)	Highway food store supplies	R|CF	Multi-product, split delivery	Use of compartmentalized trucks to distribute different products, maximum number of stops for frozen products.
Bartholdi et al. (1983)	Meals	S|A		Creation of a very simple heuristic, no computer support required.
Belenguer *et al.* (2005)	Meat	RS|U	Heterogeneous vehicle fleet, time windows	Preferred zones to take advantage of drivers' knowledge.
Carter et al. (1996)	Groceries	R|U	Time windows	Combined approach with decision on delivery quantities, based on delivery costs, inventory costs, and backorder costs
Chen and Vairaktarakis (2005)	Unspecified	S|U	Multi-product	Combined with production scheduling, also to study the value of this integration.
Chen *et al.* (2009)	Unspecified, perishable	R|U	Multi-product, time windows, stochastic demands	Combined with production scheduling, product value continuously decays after production.
Cheong *et al.* (2002)	Soft drinks	U|U	Heterogeneous vehicle fleet, multiple trips, split delivery	Grouping of customers in zones, and detailed routing within those zones. Daily planning allows vehicles to help other zones.
Chung and Norback (1991)	Food-service products, also perishables	S|ACF	Heterogeneous vehicle fleet, time windows	Combined with allocation of drivers and vehicles, also related to refrigeration requirements. Extension to earlier work by Evans and Norback (1984, 1985)
De Angelis *et al.* (2007)	Food aid	U*|U	Multi-depot, multiple trips, fixed fleet size	Model maximizes total demand satisfied by IP, using only full cargoes. (* Chain structure unspecified because food aid does not fit into the traditional retailer – foodservice distinction)

	Product	System	VRP characteristics	Special characteristics
Faulin (2003a, 2003b)	Vegetables	R|F		Truck utilization restricted by product specifics (safety of transporting canned goods).
Hsu *et al.* (2007)	Unspecified, perishable	R|CF	Time windows, time-dependent travel times	Explicitly models the perishability of food using a decreasing value over time. Dependent on both tour length and number of times the cargo hold is opened.
Hu *et al.* (2009)	Meat	R|C	Heterogeneous vehicle fleet, open routes	Special attention to network structure in metropolitan area.
Osvald and Stirn (2008)	Vegetables	R|U	Time-dependent travel times, time windows	Including a linear product quality loss over time.
Privé *et al.* (2006)	Soft drinks	U|U	Multi-product, heterogeneous vehicle fleet, time windows, pickup and delivery	Including the collection of recyclable containers
Rochat and Semet (1994)	Flour and pet food	R|U	Heterogeneous vehicle fleet, time windows	Inclusion of driver breaks, customer vehicle type constraints
Semet and Taillard (1993)	Groceries	R|U	Heterogeneous vehicle fleet, time windows	Trucks can have trailers, which can be dropped off for subtours (affecting customer vehicle type constraints, as well as costs)
Tarantilis and Kiranoudis (2001)	Dairy	R|U	Heterogeneous vehicle fleet, fixed fleet size	
Tarantilis and Kiranoudis (2002)	Meat	R|U	Multi-depot, open routes	Development of a general meta-heuristic, based on threshold accepting algorithms
Van Vliet *et al.* (1992)	Sugar	U[**]|U	Heterogeneous vehicle fleet, fixed fleet size, multi-depot, time windows	Combined with bulk truck loading ([**] Business-to-business delivery)
Zeng *et al.* (2008)	Soft drinks	U|U	Heterogeneous vehicle fleet, multiple trips, split delivery	Alternative methods to solve problem described by Cheong et al. (2002), significantly reducing the number of vehicles required.

Looking at the characteristics of the VRP problems studied, we see that most authors extended the basic VRP problem. Most common is the inclusion of time windows. In some cases this is just included to make sure the retail stores that have to be supplied are open (Rochat and Semet, 1994), but in most cases the time windows are shorter, and often they are similar. For instance, in the meat distribution example presented by Belenguer *et al.* (2005), most butchers would like to be supplied early in the morning. Secondly, a distinction between different types of vehicles is made. This characteristic is often included to distinguish between different vehicle capacities (*e.g.*, Belenguer *et al.*, 2005; Tarantilis and Kiranoudis, 2001) or the potential use of a trailer (Semet and Taillard, 1993). However, in the situation described by Chung and Norback (1991) the distinction also includes different refrigeration capabilities, which is essential to consider in food distribution. Finally, some recent contributions (Hsu *et al.*, 2007, Osvald and Stirn, 2008) also include time-dependent travel times, which are becoming more and more relevant on today's busy road networks. The difference in travel times between rush hours and non-rush hours can be significant, and often needs to be taken into account.

We can also see in Table 6 that a wide variety of food products has been studied, ranging from single-product distribution such as sugar (Van Vliet *et al.*, 1992) to distribution of different products to retail outlets (Ambrosino and Sciomachen, 2007; Carter *et al.*, 1996) or caterers (Chung and Norback, 1991). Some recent contributions (Hsu *et al.*, 2007; Chen *et al.*, 2009) develop general approaches for perishable food products, making their models generally applicable for most food products.

Table 6 also presents an overview of the special characteristics covered in each of the studies. For instance, one of the earliest contributions (Bartholdi *et al.*, 1983) focuses on creating a heuristic that would be usable without the use of a computer. Even though the presence of computers is not a big issue in the current time, it is still interesting to see that a simple clustering approach is able to lead to a reasonable performance, and might still be useful for the many SMEs that operate in the food industry. More recent work by Belenguer *et al.* (2005) and Cheong *et al.* (2002) are also based on clustering customers into zones, but these authors do this to be able to take advantage of the drivers' knowledge of the specific regions.

In order to explicitly model product quality, Chen et al. (2009) present an approach that includes a decrease in product value over time, and incorporate that in a model aiming at profit maximization. Osvald and Stirn (2008) quantitatively control the quality of products by considering a linear relationship between quality and transportation time. Most contributions do not specifically mention the temperature during distribution. However, a few papers specifically mention or consider chilled or frozen distribution (Ambrosino and Sciomachen, 2007; Chung and Norback, 1991; Hsu *et al.*, 2007; Hu *et al.*, 2009). An interesting factor considered in some of these contributions the stops of the vehicles, relating to how often the temperature-controlled cargo hold has to be opened (Ambrosino and Sciomachen, 2007; Hsu *et al.*, 2007). The reasoning behind this is that these temperature disruptions negatively affect the food product. Ambrosino and Sciomachen (2007) limit the quality degradation of products during transportation by setting a maximum number for the number of stops for each vehicle carrying frozen products. Hsu *et al.* (2007) assume that the degradation in quality happens mainly during the time that the cargo hold is open and vehicles are serving the customers. For an otherwise typical VRP model, this leads to an additional term in the objective function related to the total expected loss of food product. This expected loss is calculated dynamically dependent on the time elapsed since vehicle departed from the distribution centre and the time the cargo hold is opened (which in turn depends on the customer demand volumes at the individual customer sites visited thus far). Another interesting characteristic, included by Ambrosino and Sciomachen (2007), is the use of compartmentalized trucks to distribute different products at different temperatures.

Finally, one contribution does not present a variety of a VRP problem, and is therefore not included in Table 6. Boysen (2010) deals with the operational scheduling of trucks at a cross-docking terminal. The author considers frozen foods and assumes that there is no possibility to store products as that would lead to defrosting and product degradation. This means that the inbound and outbound operations are strongly connected and should be synchronized. To do this, Boysen presents dynamic programming and heuristic procedures that are able to solve real-life-sized problems.

5.3. Research directions

Keeping quality during transportation of foods is a challenge for food distributors. This issue has mostly been considered implicitly by assuming that the planning horizon is shorter than the shelf life of the products or by minimizing transportation time and distance. Among the available literature, only selected studies take a more explicit approach toward modelling food quality during transportation. However, it should be noted that these papers manly model quality degradation as a (continuous) decrease in product value (often starting from the start of distribution), which might not be the kind of quality decay that is experienced with all food products. Often, a product would be considered completely perished at a certain quality level. Because initial quality status might not be easily detectable, it can be hard to estimate the remaining shelf life in such cases. Modelling degradation throughout the network in a proper way would be of significant benefit. Related to this is an effort to improve coordination between production and transportation planning, allowing for better quality control. This is an area that deserves further research, especially for products that are highly perishable. The importance of coordinating production and transportation has also recently been stressed by Chen (2010), who presented the state of the art on modelling integrated production and outbound distribution scheduling.

One approach (Faulin, 2003a, 2003b) explicitly mentions safety in transportation of canned food products. However, Faulin's approach towards safety is only related to physical safety of transportation operations, and not the safety of food products. Therefore, there is still a significant opportunity for operations management researchers to identify efficient ways to improve safety measures and to reduce the impacts of safety problems. Several approaches try to utilize driver knowledge by assigning certain groups of customers to the same driver. Indirectly, this is a way to increase food safety, as the driver's knowledge would also include information of food control systems used by the customer (including *e.g.* temperature checks and sampling for quality control). Also, the development of methods that use or improve the traceability of foods in the chain has not been considered so far, and could be one way to improve the safety of foods. This could be based on some recent approaches that look at the dispersion of raw material or production batches in production and distribution systems (Dupuy *et al.*, 2005; Wang *et al.*, 2009b; 2010; Rong and Grunow, 2010). So far, this concept has not been used in relation to transportation planning, but it seems logical to also use this in these decision problems. As such approaches rely on extensive product information; they should be supported by tracking and tracing models, such as the one that has recently been developed by Fritz and Schiefer (2009).

Hsu *et al.* (2007) take the sustainability of the transportation system explicitly into account by trying to reduce the energy consumption. The reverse product flow included by Privé *et al.* (2006) is also a relevant contribution to the sustainability of distribution systems, as the environmental impact of distribution does not stop after a product is delivered; a reverse flow is often found, ranging from empty containers or boxes in the retail industry to bowls and plates in the foodservice industry. Including these flows in modelling approaches can be very useful to in relation to sustainability, and could for instance be used to evaluate the impact of using recyclable packaging material. Developing these models would improve the possibilities for a proactive approach to sustainability; deciding on when and where to use certain transport or package options to minimize the environmental impact of distribution, something which is currently lacking in the quantitative operations management literature.

6. Integrated approaches

So far, this paper dealt with distribution management challenges on the strategic, tactical and operational level. In some cases however, it makes sense to integrate the decision making on different hierarchical levels. For example, in a recent survey of supply chain network design studies, Melo *et al.* (2009) show that about 60% of the papers in their review extends beyond the basic location-allocation problem. This section will outline the most important applications of such integrated approaches found in relation to food distribution management. Table 7 provides an overview of these contributions, also identifying what decision levels are involved in the integration.

Table 7. Overview of integrated approaches to food distribution management.
Decision levels: strategic distribution network design (S), tactical distribution network planning (T), and operational transportation planning (O).

	Product	**System**	**Method**	**Decision level**			**Characteristics (with focus on safety, quality and sustainability)**
				S	**T**	**O**	
Custódio and Oliveira (2006)	Unspecified	R|F	Heuristic		X	X	Focus on the trade-off between inventory cost and transportation cost. Includes estimation of safety stock levels.
Federgruen et al. (1986)	Unspecified, Perishable	U|U	Heuristic		X	X	Inclusion of different product classes for fresh and old products. Out-of-date cost in objective.
Hwang (1999)	Food aid	U*|U	Heuristic		X	X	Food supply to famine relief areas. Assignment of limited supplies to needy locations and clustering of ‘customers’ and routing of vehicles in a hierarchical way. (* Chain structure unspecified because food aid does not fit into the traditional retailer – foodservice distinction)
Köksalan *et al.* (1995)	Beer	U|U	MILP	X	X		Focus on location of breweries. Inclusion of seasonal demands, requiring the inclusion of more detailed production decisions.
Rusdiansyah and Tsao (2005)	Vending machine supplies	U|U	MILP + heuristics		X	X	Focus on the trade-off between inventory cost and transportation cost. Deciding delivery frequency in combination with vehicle tours.
Watson-Gandy and Dohrn (1973)	Unspecified	R|U	Scenario analysis	X		X	Selection of warehouse locations, with sales amounts that are decreasing with distance.

6.1. Combining network design with network planning

Typically, distribution network design modelling does not consider a time aspect, but only focuses on *e.g.* yearly average flows. This mostly leads to MILP models without time indices (as discussed in Section 3). Distribution network planning, on the other hand, deals with more detailed decision-making, where the time dimension is more prominent in the modelling efforts (see Section 4).

Köksalan *et al.* (1995) study a distribution network design problem, in which they focus on the location of the breweries, but they model production on a more detailed level, to be able to include the effects of seasonal demands in relation to production capacity utilization and inventory build-up towards the summer months. This leads to a model that combines elements from the distribution network design and distribution network planning models discussed in the previous sections. The trade-off between investing in excess capacity or investing in inventory is essential in their decision problem. To do this, Köksalan *et al.* (1995) add more detail to their model to track monthly production and inventory. Using this, the cost of building up inventory in the off-season can be added to the objective function.

6.2. Combining location decisions with transportation planning

A typical combination of decisions on the strategic and operational level is the facility location decision and the subsequent vehicle routing. The reasoning behind this is that the total cost of the distribution system can be minimized by taking the short-term routing decisions into account in facility location problems. This would lead to solutions that are able to take advantage of an efficient non-fragmented distribution of goods, which might result from separate decision-making (Min *et al.*, 1998). As such, location-routing is location planning with tour planning aspects taken into account (Nagy and Salhi, 2007). These approaches do however assume that it is possible to determine realistic routing plans on a long time horizon, which might be difficult considering the often dynamic behaviour of customers. Routes change significantly when minor changes in demand volumes or shifts in time windows occur, which are likely to happen within the time horizon considered in location decisions.

One of the first contributions in location-routing for food products deals with a British food and drink company, which is reconsidering its warehouse locations (Watson-Gandy and Dohrn, 1973). In the distribution costs, the authors consider (*i*) costs for local delivery from warehouses to customers, based on average tour distances for a certain number of customers visited, (*ii*) costs for shipments between plants and warehouses and (*iii*) costs for the depots. The approach aims at maximizing profits, while account for sales which decrease with the customer distance from the warehouse.

Although there are numerous studies dealing with location-routing problems in the literature, specific applications to food distribution systems seem to be limited to the article by Watson-Gandy and Dohrn (1973). For more details on the existing general location-routing literature, we refer to Nagy and Salhi (2007).

6.3. Combining inventory decisions with transportation planning

It can sometimes be difficult to consider the operational problem of transportation planning, without affecting more tactical issues like inventory decisions. Integrated inventory-routing approaches try to minimize short-term vehicle routing cost or distances, while also looking at the longer-term cost factors related to inventory levels and delivery frequencies (see *e.g.* Federgruen and Zipkin, 1984; Moin and Salhi, 2007).

The general model presented by Federgruen and Zipkin (1984) is generalized in Federgruen *et al.* (1986) for perishable products. More specifically, they identify separate product classes for fresh and old product, using a fixed lifetime for the product. This also leads to an out-of-date cost in their objective function, reflecting the cost of discarding product.

Some more recent work has been done by Rusdiansyah and Tsao (2005) and Custódio and Oliveira (2006). Both of these papers focus on the trade-off between inventory and transportation cost. For a frozen food distribution network, Custódio and Oliveira (2006) study the integration of inventory management and vehicle routing, and devise a heuristic procedure to solve this problem where demand is considered to be deterministic at this stage. The model helps to determine the inventory levels, safety stocks, inventory replenishment frequencies for the products, and the vehicle routes. Rusdiansyah and Tsao (2005) look at a distribution network for the supply to food vending machines, deciding on delivery frequency in combination with vehicle tours. Both of these studies do however not include any food-specific characteristics.

Another application of inventory-routing of food products is presented by Hwang (1999), who studies a distribution network in a famine relief area. Although the paper does not provide much detail on the modelling work, the authors suggest a hierarchical approach which first assigns inventory to the various locations in need of food. Then, in subsequent steps, these locations are assigned to supply centres and vehicle routes are created, both based on heuristic methods.

For more details on inventory-routing studies, we refer to recent overviews presented by Moin and Salhi (2007) and Andersson *et al.* (2010).

6.4. Research directions

The contributions described in this section crossed the traditional boundaries of the hierarchical framework presented in Section 2. The main reason for this seems to be the need to include more detailed analysis, leading to an extension of the models into lower decision levels. There has only been limited attention to food quality in these contributions and none to food safety and sustainability. The modelling work by Federgruen *et al.* (1986) includes a cost aspect for perished products. The inclusion of some tactical decisions in a strategic decision problem studied by Köksalan *et al.* (1995) is done to be able to include the effects of seasonal demands. Considering that numerous food products experience seasonality – in demand or supply – this approach seems a valuable extension of the standard models for location decisions in this industry.

7. Conclusion and discussion

In this paper, we have reviewed the quantitative operations management research on food distribution management. Our contribution lies in the classification of the literature in a hierarchical framework consisting of distribution network design, distribution network planning, and transportation planning. Furthermore, within each of these levels, we survey the research contributions, discuss the state of the art and identify challenges for further research. Special focus is given to the aspects of food quality, food safety and sustainability.

7.1. Main conclusions

In general, it has to be noted that most of the literature on food distribution management does not cover the key challenges found in the food industry. Most noticeable in the review is that there are very few studies in the literature that include food safety aspects in distribution management.

The importance of product quality is, however, reflected to a slightly larger extent in the current research, both in the number of contributions and in the variety of the methodology used. A number of papers includes quality changes implicitly by limiting product storage or transportation time, other papers model quality decay explicitly be including a cost factor or degradation parameter dependent on the distribution path chosen or the time required.

In general, these approaches are based on only a very rough approximation of quality degradation, which hence leads to extremely conservative quality decay parameters and thresholds to make sure that the quality is sufficient for all products, independent of the often varying initial quality status, the chemical and microbial properties of the food, the environmental conditions and distribution operations. Furthermore, such an approach often results in local operating rules such as the definition of a maximum storage time in a DC, and hence does not permit trading off additional storage time in a certain stage in the distribution network with *e.g.* a faster delivery elsewhere in the network, or with other means of keeping quality degradation within limits.

Most of the contributions reviewed in this paper do not specify the temperature level during distribution, even though temperature control is a main factor with regards to the control of food quality and food safety. The work that does specify the level of temperature control mostly does not integrate any related quality or safety aspects in the presented modelling approaches. A notable exception is the work on the transportation planning level taking into account the opening of the cargo hold; acknowledging the effects this would have on the temperature the food products are exposed to (Ambrosino and Sciomachen, 2007; Hsu *et al.*, 2007). Rong *et al.* (2009) explicitly track quality through a production and distribution network and integrate logistical decision-making with temperature control, and Van der Vorst *et al.* (2009) integrate quality changes depending on time and temperature in their simulation approach.

Even though today's society is more and more concerned with sustainability, this review shows that there is only very limited attention to designing and operating sustainable food distribution networks. In the few cases in which sustainability is considered, it mainly concerns the environmental dimension of sustainability. The lack of attention to the social dimension is likely due to the fact that it is harder to quantify.

Finally, it is worth mentioning that most of the research so far is aimed at the retail industry, whereas the foodservice industry received much less attention. This is probably highly related to the prevalence of SMEs in this sector, where the development and use of the kind of decision support models described in this paper is less common than in the larger companies found in the retail industry. However, it should also be noted that recent developments in the retail sector, such as the increasing use of EPoS data in ECR initiatives, are not reflected in the literature.

7.2. Future research directions

Developing planning approaches for distribution network structures and operations that can contribute to an increased product safety is something that requires more attention. Although legal frameworks have been put in place to improve safety of final food products, leading to the development of safety management systems like HACCP, supporting the development of these systems in a quantitative way has hardly received any attention. For instance, the positioning of critical control points in a distribution network is an important aspect that might be worth additional attention by researchers. A possible starting point would be the methodology Bertolini *et al.* (2007)

propose for the determination of critical control points in food manufacturing systems. In the brainstorming processes normally used in practice, decision making is typically hindered by an inability to discriminate and prioritize risks. The structured method by Bertolini *et al.* might be a way to include these aspects in quantitative operations management approaches, allowing for managers to gain more insight in tradeoffs between *e.g.* food safety and related costs. Also, designing distribution networks that can react appropriately when a safety crisis occurs is a key research challenge. For instance, as product recalls can be a major challenge and a significant expense, designing and operating a distribution network that facilitates the rapid identification of affected products and that limits the size of product recalls can reduce the exposure of final consumers to food safety crises and increase the reliability and ultimately subsistence of food distribution systems.

Quality changes during distribution were considered by some authors. In most cases, however, the integration of product quality still requires significant simplification of the dynamic process of quality change. Considering the increasing focus on high-quality food products, in combination with the globalized food market, this remains a challenging research area. Here, we also want to reiterate the point made by Apaiah *et al.* (2005) that designing food distribution systems that are able to provide high-quality food in a cost-efficient way is a challenge that requires an interdisciplinary focus with efforts from *e.g.* food engineering and operations management. It is also important to note that there is a lack of approaches that are able to cope with multiple products having different shelf lives and supply and demand patterns, which is a finding that has also been reported in relation to analytical approaches to the inventory management of perishable products (Prastacos, 1984; Karaesmen *et al.*, 2011).

Regarding the temperature control during distribution, the recent developments in tracking temperature during distribution using time-temperature indicators, provides opportunities for further research. The additional knowledge gained from these technologies would allow for more advanced decision making with regards to *e.g.* the modelling of quality degradation or the impact of cargo hold openings during transportation.

Defining new methods to quantify and integrate performance indicators from the different sustainability dimensions also remains a challenge for future research. This involves a broad perspective on triple-bottom-line thinking, integrating profit, people, and the planet into the culture, strategy, and operations of companies (Kleindorfer *et al.*, 2005). Including aspects such as CO_2 emissions or product waste in the design and management of food distribution systems is a necessary step in this research area. Recent developments in relation to social life cycle assessments might provide the possibility to quantify some of the social aspects, which would facilitate the inclusion of this dimension in quantitative operations management research, and would significantly improve the capabilities of companies for managing (and reporting) their Corporate Social Responsibility activities. Further, an integration of different sustainability indicators would give significant insight in the trade-offs between economic, environmental, and social performance indicators and also lead to an improved knowledge base for discussions between the private and public sector on the governance of food distribution, for example on the issue of local versus global sourcing.

In sum, quantitative operations management research still has a long way to go until a comprehensive methodology is in place on which managers can draw when seeking decision support in food distribution which is able to cope with the key challenges the industry is currently facing in managing quality, safety and sustainability.

We structured our analysis according to the traditional hierarchy of the decision problems. However, it has also been shown that the implementation of hierarchical planning structures and algorithms can be difficult in practice and modelling the relationship between hierarchical levels is one of the main difficulties in implementing decision support tools such as Advanced Planning Systems (Zoryk-Schalla *et al.*, 2004). One of the main challenges that has to be overcome is inherent in hierarchical planning approaches: the issue of aggregation-disaggregation, mainly referring to the coordination of different levels of detail in modelling (Schneeweiss, 2003). At the higher level, anticipation mechanisms must be developed, which represent the lower level decision problem in an aggregate way. In food distribution management, this mainly seems to be related to the inclusion of food quality and safety. Both of these aspects are normally modelled on detailed time scales, to be able to include the dynamics of microbial and chemical processes. How to anticipate for that in models on strategic and tactical levels, where time scales are normally coarser is an open question. This so-called temporal aggregation requires the development of suitable aggregation mechanisms and will be a central problem in future research.

Especially when dealing with product safety, it is often necessary to include stochastic risk information in the modelling approaches. Here, the simulation approach presented by Rijgersberg *et al.* (2010) seems very suitable to study the impact of distribution network decisions in light of microbial risk assessment. However, when the number of alternative solutions is large, the integration of this stochastic risk information in optimization approaches is required. Combining mathematical programming with simulation might be one way to achieve this in future research.

In light of the growing importance and increasing industrialization seen in the foodservice sector, the current lack of attention to this industry will become even more significant. This industry mostly deals with fresh food. Hence, production and distribution are closely connected. This leads to challenging research issues in relation to an integrative treatment of these stages. Such work can also profit from data-driven initiatives like ECR and EFR.

In addition to sales data, vast amounts of distribution information become available due to the recent traceability efforts of the food industry. Utilizing this information not only to adhere to the legal requirements but also to improve the efficiency, quality, safety and sustainability of food distribution systems is the logical next step. The advantages of utilizing this traceability information extend from the quality and safety benefits that originally led to the introduction of traceability to the minimization of recall sizes and the improvement of operational efficiency along the supply chain (*e.g.*, Wang *et al.*, 2009a). Quantitative operations management research has the ability to advance these potential benefits from the conceptual stage to specific decision support for food producers and distributors.

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References

Adenso-Díaz, B., González, M., García, E. (1998), A hierarchical approach to managing dairy routing, Interfaces, Vol. 28, No. 2, pp. 21-31.

Agatz, N.A.H., Fleischmann, M., Van Nunen, J.A.E.E. (2008), E-fulfillment and multi-channel distribution – A review, European Journal of Operational Research, Vol. 187, No. 2, pp. 339-356.

Ahumada, O., Villalobos, J.R. (2009a), Application of planning models in the agri-food supply chain: A review, European Journal of Operational Research, Vol. 196, No. 1, pp. 1-20.

Ahumada, O., Villalobos, J.R. (2009b), A tactical model for planning the production and distribution of fresh produce, Annals of Operations Research, article in press, doi: 10.1007/s10479-009-0614-4.

Ambrosino, D., Sciomachen, A. (2007), A food distribution network problem: a case study, IMA Journal of Management Mathematics, Vol. 18, No. 1, pp. 33-53.

Andersson, H., Hoff, A., Christiansen, M., Hasle, G., Løkketangen, A. (2010), Industrial aspects and literature survey: Combined inventory management and routing, Computers & Operations Research, Vol. 37, No. 9, pp. 1515-1536.

Anthony, R.N. (1965), Planning and Control Systems: A Framework for Analysis, Harvard University Press, Boston, MA.

Apaiah, R.K., Hendrix, E.M.T., Meerdink, G., Linnemann, A.R. (2005), Qualitative methodology for efficient food chain design, Trends in Food Science & Technology, Vol. 16, No. 5, pp. 204-214.

Baldwin, C. (ed.) (2009a), Sustainability in the food industry, Wiley-Blackwell and IFT Press, Ames, Iowa, USA.

Baldwin, C. (2009b), Sustainability in food retailing, in: Baldwin, C. (ed.), Sustainability in the food industry, Wiley-Blackwell and IFT Press, Ames, Iowa, USA, Chapter 9, pp. 213-224.

Bartholdi, J.J., III, Platzman, L.K., Collins, R.L., Warden, W.W., III (1983), A minimal technology routing system for meals on wheels, Interfaces, Vol. 13, No. 3, pp. 1-8.

Belenguer, J.M., Benavent, E., Martínez, M.C. (2005), RutaRep: A computer package to design dispatching routes in the meat industry, Journal of Food Engineering, Vol. 70, No. 3, pp. 435-445.

Bertolini, M., Rizzi, A., Bevilacqua, M. (2007), An alternative approach to HACCP system implementation, Journal of Food Engineering, Vol 79, No. 4, pp. 1322-1328.

Bertrand, J.W.M., Fransoo, J.C. (2002), Operations management research methodologies using quantitative modelling, International Journal of Operations & Production Management, Vol. 22, No. 2, pp. 241-264.

Bilgen, B., Günther, H.-O. (2009), Integrated production and distribution planning in the fast moving consumer goods industry: a block planning application, OR Spectrum, in press (doi:10.1007/s00291-009-0177-4).

Bitran, G.R., Tirupati, D. (1993), Hierarchical production planning, in: Graves, S.C., Rinnooy Kan, A.H.G. (eds.), Handbooks in Operations Research and Management Science, Volume 4: Logistics of Production and Inventory, Elsevier, Amsterdam, Chapter 10, pp. 523-568.

Blackburn, J., Scudder, G. (2009), Supply chain strategies for perishable products: The case of fresh produce, Production and Operations Management, Vol. 18, No. 2, pp. 129-137.

Bodin, L.D., Golden, B.L., Assad, A.A., Ball, M.O. (1983), Routing and scheduling of vehicles and crews: The state of the art, Computers & Operations Research, Vol. 10, No. 2, pp. 63-211.

Boronico, J.S., Bland, D.J. (1997), Customer service: the distribution of seasonal food products under risk, British Food Journal, Vol. 99, No. 5, pp. 168-176.

Bourlakis, M., Weightman, P. (2004), Introduction to the UK food supply chain, in: Bourlakis, M., Weightman, P. (eds.), Food Supply Chain Management, Blackwell Publishing, Oxford, UK, Chapter 1, pp. 1-10.

Boyer, K.K., Hult, G.T.M. (2005), Extending the supply chain: Integrating operations and marketing in the online grocery industry, Journal of Operations Management, Vol. 23, No. 6, pp. 642-661.

Boysen, N. (2010), Truck scheduling at zero-inventory cross docking terminals, Computers & Operations Research, Vol. 37, No. 1, pp. 32-41.

Bräysy, O., Gendreau, M. (2005a), Vehicle Routing Problem with Time Windows, Part I: Route Construction and Local Search Algorithms, Transportation Science, Vol. 39, No. 1, pp. 104-118.

Bräysy, O., Gendreau, M. (2005b), Vehicle Routing Problem with Time Windows, Part II: Metaheuristics, Transportation Science, Vol. 39, No. 1, pp. 119-139.

British Retail Consortium (2004), BRC Global Standard – Food, TSO, London, UK.

Broekmeulen, R. (1998), Operations management of distribution centers for vegetables and fruits, International Transactions in Operational Research, Vol. 5, No. 6, pp. 501-508.

Brown, G., Keegan, J., Vigus, B., Wood, K. (2001), The Kellogg company optimizes production, inventory, and distribution, Interfaces, Vol. 31, No. 6, pp. 1-15.

Buckley, M., Cowan, C. McCarthy, M. (2007), The convenience food market in Great Britain: Convenience food lifestyle (CFL) segments, Appetite, Vol. 49, No. 3, pp. 600-617.

Campbell, A.M., Savelsbergh, M. (2006), Incentive schemes for attended home delivery services, Transportation Science, Vol. 40, No. 3, pp. 327-341.

Carter, M.W., Farvolden, J.M., Laporte, G., Xu, J. (1996), Solving an integrated logistics problem arising in grocery distribution, INFOR, Vol. 34, No. 4, pp. 290-306.

Chapman, P.A. (2010), Reducing product losses in the food supply chain, in: Mena, C., Stevens, G. (Eds.), Delivering performance in food supply chains, Woodhead Publishing Limited, Cambridge.

Chen, H.-K., Hsueh, C.-F., Chang, M.-S. (2009), Production scheduling and vehicle routing with time windows for perishable food products, Computers & Operations Research, Vol. 36, No. 7, pp. 2311-2319.

Chen, Z.-L. (2010), Integrated production and outbound distribution scheduling: Review and extensions, Operations Research, Vol. 58, No. 1, pp. 130-148.

Chen, Z.-L., Vairaktarakis, G.L. (2005), Integrated scheduling of production and distribution operations, Management Science, Vol. 51, No. 4, pp. 614-628.

Cheong, Y. M., Ong, H. L., Huang, H. C. (2002), Modeling a vehicle routine problem for a soft drink distribution company, Asia-Pacific Journal of Operational Research, Vol. 19, No. 1, pp. 17-34.

Chinander, K.R. (2001), Aligning accountability and awareness for environmental performance in operations. Production and Operations Management, Vol. 10, No. 3, pp. 276-291.

Chung, H.K., Norback, J.P. (1991), A clustering and insertion heuristic applied to a large routing problem in food distribution, The Journal of the Operational Research Society, Vol. 42, No. 7, pp. 555-564.

Cordeau, J.-F., Pasin, F., Solomon, M.M. (2006), An integrated model for logistics network design, Annals of Operations Research, Vol. 144, No. 1, pp. 59-82.

Crainic, T.G., Laporte, G. (1997), Planning models for freight transportation, European Journal of Operational Research, Vol 97, No. 3, pp. 409-438.

Custódio, A.L., Oliveira, R.C. (2006), Redesigning distribution operations: a case study on integrating inventory management and vehicle routes design, International Journal of Logistics: Research and Applications, Vol. 9, No. 2, pp. 169-187.

Dabbene, F., Gay, P., and Sacco, N. (2008b), Optimisation of fresh-food supply chains in uncertain environments, Part II: A case study. Biosystems Engineering, Vol. 99, No. 3, pp. 360-371.

Dabbene, F., Gay, P., Sacco, N. (2008a), Optimisation of fresh-food supply chains in uncertain environments, Part I: Background and methodology, Biosystems Engineering, Vol. 99, No. 3, pp. 348-359.

Dalgaard, P., Buch, P., Silberg, S. (2002), Seafood Spoilage Predictor – Development and distribution of a product specific application software, International Journal of Food Microbiology, Vol. 73, No. 2-3, pp. 343-349.

Dantzig, G.B., Ramser, J.H. (1959), The truck dispatching problem, Management Science, Vol. 6, No. 1, pp. 80-91.

De Angelis, V., Mecoli, M., Nikoli, C., Storchi, G. (2007), Multiperiod integrated routing and scheduling of World Food Programme cargo planes in Angola, Computers & Operations Research, Vol. 34, No. 6, pp. 1601-1615.

De Koster, M.B.M. (2002), Distribution structures for food home shopping, International Journal of Physical Distribution & Logistics Management, Vol. 32, No. 5, pp. 362-380.

Del Castillo, E., Cochran, J.K. (1996), Optimal short horizon distribution operations in reusable container systems, Journal of the Operational Research Society, Vol. 47, No. 1, pp. 48-60.

Derigs, U., Gottlieb, J., Kalkoff, J., Piesche, M., Rothlauf, F., Vogel, U. (2010), Vehicle routing with compartments: Applications, modelling and heuristics, OR Spectrum, article in press, doi: 10.1007/s00291-010-0194-3.

Dobson, P.W., Clarke, R., Davies, S., Waterson, M. (2001), Buyer power and its impact on competition in the food retail distribution sector of the European Union, Journal of Industry, Competition and Trade, Vol. 1, No. 3, pp. 247-281.

Dupuy, C., Botta-Genoulaz, V. Guinet, A. (2005), Batch dispersion model to optimise traceability in food industry, Journal of Food Engineering, Vol. 70, No. 3, pp. 333-339.

Duran (1987), A large mixed integer production and distribution program, European Journal of Operational Research, Vol. 28, No. 2, pp. 207-217.

Eastham, J.F., Ball, S.D., Sharples, L. (2001), The catering and food retail industries: a contextual insight, in: Eastham, J.F., Sharples, L., Ball, S.D. (eds.), Food Supply Chain Management, Elsevier Butterworth Heinemann, Oxford, UK, Chapter 1, pp. 3-20.

Ekşioğlu, S., Jin, M. (2006), Cross-Facility Production and Transportation Planning Problem with Perishable Inventory, Lecture Notes in Computer Science, Vol. 3982, pp. 708-717.

Engelund, E.H., Breum, G., Friis, A. (2009), Optimisation of large-scale food production using lean manufacturing principles, Journal of Foodservice, Vol. 20, No. 1, pp. 4-14.

European Parliament and Council (2002), General Principles and requirements of Food Law, Regulation (EC) No 178/2002, Official Journal of the European Communities, Vol. 1.2.2002, pp. L31/1-L31/24.

Evans, S.R., Norback, J.P. (1984), An heuristic method for solving time-sensitive routeing problems, Journal of the Operational Research Society, Vol. 35, No. 5, pp. 407-414.

Evans, S.R., Norback, J.P. (1985), The impact of a decision-support system for vehicle routeing in a foodservice supply situation, Journal of the Operational Research Society, Vol. 36, No. 6, pp. 467-472.

FAO (2003), Codex Alimentarius: Food Hygiene Basic Texts, 3rd ed, Joint FAO/WHO Food Standards Programme, Rome, Italy.

Faulin, J. (2003a), Applying MIXALG procedure in a routing problem to optimize food product delivery, OMEGA – The International Journal of Management Science, Vol. 31, No. 5, pp. 387-395.

Faulin, J. (2003b), Combining linear programming and heuristics to solve a transportation problem for a canning company in Spain, International Journal of Logistics: Research and Applications, Vol. 6, No. 1-2, pp. 17-27.

Federgruen, A., Prastacos, G. Zipkin, P.H (1986), An allocation and distribution model for perishable products, Operations Research, Vol. 34, No. 1, pp. 75-82.

Federgruen, A., Zipkin, P. (1984), A combined vehicle routing and inventory allocation problem, Operations Research, Vol. 32, No. 5, pp. 1019-1037.

Fritz, M., Schiefer, G. (2008), Food chain management for sustainable food system development: A European research agenda, Agribusiness, Vol 24, No. 4, pp. 440-452.

Fritz, M., Schiefer, G. (2009), Tracking, tracing, and business process interests in food commodities: A multi-level decision complexity, International Journal of Production Economics, Vol. 117, No. 2, pp. 317-329.

Gelders, L.F., Pintelon, L.M., Van Wassenhove, L.N. (1987), A location-allocation problem in a large Belgian brewery, European Journal of Operational Research, Vol. 28, No. 2, pp. 196-206.

Geoffrion, A., Graves, C.W. (1974), Multicommodity distribution system design by Benders decompositions, Management Science, Vol. 20, No. 5, pp. 822-844.

Ghiani, G., Laporte, G., Musmanno, R. (2004), Introduction to Logistics Systems Planning and Control, John Wiley & Sons, Ltd.

Giannakourou, M.C., Taoukis, P.S. (2003), Application of a TTI-based distribution management system for quality optimization of frozen vegetables at the customer end, Journal of Food Science, Vol. 68, No. 1, pp. 201-209.

Golden, B.L., Magnanti, T.L., Nguyen, H.Q. (1977), Implementing vehicle routing algorithms, Networks, Vol. 7, No. 2, pp. 113-148.

Goyal, S.K., Giri, B.C. (2001), Recent trends in modeling of deteriorating inventory, European Journal of Operational Research, Vol. 134, No. 1, pp. 1-16.

Groothedde, B., Ruijgrok, C., Tavasszy, L. (2005), Towards collaborative, intermodal hub networks: A case study in the fast moving consumer goods market, Transportation Research Part E, Vol. 41, No. 6, pp. 567-583.

Grunert, K.G. (2005), Food quality and safety: consumer perception and demand, European Review of Agricultural Economics, Vol. 32, No. 3, pp. 369-391.

Gu, J., Goetschalckx, M., McGinnis, L.F. (2007), Research on warehouse operation: A comprehensive review, European Journal of Operational Research, Vol. 177, No. 1, pp. 1-21.

Hartwell, H.J., Edwards, J.S.A., Symonds, C. (2006), Foodservice in hospital: development of a theoretical model for patient experience and satisfaction using one hospital in the UK National Health Service as a case study, Journal of Foodservice, Vol. 17, No. 5-6, pp. 226-238.

Hauschild, M., Dreyer, L.C, Jørgensen, A. (2008), Assessing social impacts in a life cycle perspective – Lessons learned, CIRP Annals – Manufacturing Technology, Vol. 57, No. 1, pp. 21-24.

Hauschild, M., Jeswiet, J., Alting, L. (2005), From life cycle assessment to sustainable production: Status and perspectives, CIRP Annals – Manufacturing Technology, Vol. 54, No. 2, pp. 535-555.

Higgins, A., Beashel, G., Harrison, A. (2006), Scheduling of brand production and shipping within a sugar supply chain, Journal of the Operational Research Society, Vol. 57, No. 5, pp. 490-498.

Hill, C.A., Scudder, G.D. (2002), The use of electronic data interchange for supply chain coordination in the food industry, Journal of Operations Management, Vol. 20, No. 4, pp. 375-387.

Hobbs, E.J. (2006), Liability and traceability in agri-food supply chains, in: Ondersteijn, C.J.M., Wijnands, J.H.M., Huirne, R.B.M., Van Kooten, O. (eds), Quantifying the Agri-Food Supply Chain, Springer, Berlin, Chapter 7, pp. 85-100.

Hoffman, J.M., Mehra, S. (2000), Efficient consumer response as a supply chain strategy for grocery businesses, International Journal of Service Industry Management, Vol. 11, No. 4, pp. 365-373.

Hsu, C.I., Hung, S.F., Li, H.C. (2007), Vehicle routing problem with time-windows for perishable food delivery, Journal of Food Engineering, Vol. 80, No. 2, pp. 465-475.

Hu, X., Wang, Z., Huang, M., Zeng, A.Z. (2009), A computer-enabled solution procedure for food wholesalers' distribution decision in cities with a circular transportation infrastructure, Computers & Operations Research, Vol. 36, No. 7, pp. 2201-2209.

Huddleston, P., Whipple, J., Mattick, R.N., Lee, S.J. (2009), Customer satisfaction in food retailing: Comparing specialty and conventional grocery stores, International Journal of Retail & Distribution Management, Vol. 37, No. 1, pp. 63-80.

Hutchins, M.J., Sutherland, J.W. (2009), The role of the social dimension in life cycle engineering, International Journal of Sustainable Manufacturing, Vol. 1, No. 3, pp. 238-250.

Hwang, H.-S. (1999), A food distribution model for famine relief, Computers & Industrial Engineering, Vol. 37, No. 1-2, pp. 335-338.

Ioannou, G. (2005), Streamlining the supply chain of the Hellenic sugar industry, Journal of Food Engineering, Vol. 70, No. 3, pp. 323-332.

ISO (2005), ISO 22000:2005 - Food Safety Management Systems, International Organization for Standardization, Geneva, Switzerland.

James, S.J., Evans, J., James, C. (2008), A review of the performance of domestic refrigerators, Journal of Food Engineering, Vol. 87, No. 1, pp. 2-10.

James, S.J., James, C. (2010), Advances in the cold chain to improve food safety, food quality and the food supply chain, in: Mena, C., Stevens, G. (Eds.), Delivering performance in food supply chains, Woodhead Publishing Limited, Cambridge.

James, S.J., James, C., Evans, J.A. (2006), Modelling of food transportation systems - A review, International Journal of Refrigeration, Vol. 29, No. 6, pp. 947-957.

Jansen, D.R., Van der Vorst, G.A.L., Van Weert, A. (1998), Multi-compartment distribution in the catering supply chain, International Transactions in Operational Research, Vol. 5, No. 6, pp. 509-517.

Jansen, D.R., Van Weert, A., Beulens, A.J.M., Huirne, R.B.M. (2001), Simulation model of multi-compartment distribution in the catering supply chain, European Journal of Operational Research, Vol. 133, No. 1, pp. 210-224.

Jayaraman, V. (1998), Transportation, facility location and inventory issues in distribution network design, International Journal of Operations & Production Management, Vol. 18, No. 5, pp. 471-494,

Jones, P., Comfort, D, Hillier, D., Eastwood, I. (2005), Corporate social responsibility: a case study of the UK's leading food retailers, British Food Journal, Vol. 107, No. 6, pp. 423-435.

Karaesmen, I.Z., Scheller-Wolf, A., Deniz, B. (2011), Managing perishable and aging inventories: Review and future research directions, in: Kempf, K., Keskinocak, P., Uzsoy, R. (Eds.), Planning Production and Inventories in the Extended Enterprise: A State of the Art Handbook, International Series in Operations Research and Management Science, Vol. 151, Kluwer Academic Publishers, to appear.

Kleindorfer, P.R., Singhal, K., Van Wassenhove, L.N. (2005), Sustainable Operations Management, Production and Operations Management, Vol. 14, No. 4, pp. 482-492.

Klose, A., Drexl, A. (2005), Facility location models for distribution system design, European Journal of Operational Research, Vol. 162, No. 1, pp. 4-29.

Köksalan, M., Süral, H. (1999). Efes beverage group makes location and distribution decisions for its malt plants, Interfaces, Vol. 29, No. 2, pp. 89-103.

Köksalan, M., Süral, H., Kirca, Ö. (1995), A location-distribution application for a beer company, European Journal of Operational Research, Vol. 80, No. 1, pp. 16-24.

Le Blanc, H.M., Cruijssen, F., Fleuren, H.A., De Koster, M.B.M. (2006), Factory gate pricing: An analysis of the Dutch retail distribution, European Journal of Operational Research, Vol. 174, No. 3, pp. 1950-1967.

Lee, H.L., Whang, S. (2000), Information sharing in a supply chain, International Journal of Technology Management, Vol. 20, No. 3-4, pp. 373-387.

Lehtonen, M. (2004), The environmental-social interface of sustainable development: Capabilities, social capital, institutions, Ecological Economics, Vol. 49, No. 2, pp. 199-214.

Levén, E., Segerstedt, A. (2004), Polarica's wilde berries: An example of a required storage capacity calculation and where to locate this inventory, Supply Chain Management: An International Journal, Vol. 9, No. 3, pp. 213-218.

Lowe, T.J., Preckel, P.V. (2004), Decision technologies for agribusiness problems: A brief review of selected literature and a call for research, Manufacturing & Service Operations Management, Vol. 6, No. 3, pp. 201-208.

Mattson, B., Sonesson, U. (2003) Environmentally-Friendly Food Production, Woodheart Publishing Limited, Cambridge.

Meixell, M.J., Gargeya, V.B. (2005), Global supply chain design: A literature review and critique, Transportation Research Part E, Vol. 41, No. 6, pp. 531-550.

Melo, M.T., Nickel, S., Saldanha-da-Gama, F. (2009), Facility location and supply chain management – A review, European Journal of Operational Research, Vol. 196, No. 2, pp. 401-412.

Mercer, A., Tao, X. (1996), Alternative inventory and distribution policies of a food manufacturer, Journal of the Operational Research Society, Vol. 47, No. 6, pp. 755-765.

Mikkelsen, B.E., Beck, A.M., Lassen, A. (2007), Do recommendations for institutional food service result in better food service? A study of compliance in Danish hospitals and nursing homes from 1995 to 2002-2003, European Journal of Clinical Nutrition, Vol. 61, No. 1, pp. 129-134.

Miller, D. (2009), Food product traceability: New challenges, new solutions, Food Technology, Vol. 63, No. 1, pp. 32-36.

Min, H., Jayaraman, V., Srivastava, R. (1998), Combined location-routing problems: A synthesis and future research directions, European Journal of Operational Research, Vol. 108, No. 1, pp. 1-15.

Moin, N.H., Salhi, S. (2007), Inventory routing problems: A logistical overview, Journal of the Operational Research Society, Vol. 58, No. 9, pp. 1185-1194.

Mula, J., Peidro, D., Díaz-Madroñero, M., Vicens, E. (2010), Mathematical programming models for supply chain production and transport planning, European Journal of Operational Research, Vol. 204, No. 3, pp. 377-390.

Nagy, G., Salhi, S. (2007), Location-routing: Issues, models and methods, European Journal of Operational Research, Vol. 177, No. 2, pp. 649-672.

Nahmias, S. (1982), Perishable inventory theory: A review, Operations Research, Vol. 30, No. 4, pp. 680-708.

Osvald, A., Stirn, L.Z. (2008), A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food, Journal of Food Engineering, Vol. 85, No. 2, pp. 285-295.

Pamuk, S., Köksalan, M., Güllü, R. (2004), Analysis and improvement of the product delivery system of a beer producer in Ankara, Journal of the Operational Research Society, Vol. 55, No. 11, pp. 1137-1144.

Panozzo, G., Cortella, G.(2008), Standards for transport of perishable goods are still adequate? Connections between standards and technologies in perishable foodstuffs transport, Trends in Food Science and Technology, Vol. 19, No. 8, pp. 432-440.

Panozzo, G., Minotto, G., Barizza, A.(1999), Transport and distribution of foods: Today's situation and future trends, International Journal of Refrigeration, Vol. 22, No. 8, pp. 625-639.

Pooley, J. (1994), Integrated production and distribution facility planning at Ault Foods, Interfaces, Vol. 24, No. 4, pp. 113-121.

Prastacos, G.P. (1984), Blood inventory management: An overview of theory and practice, Management Science, Vol. 30, No. 7, pp. 777-800.

Privé, J., Renaud, J., Boctor, F., Laporte, G. (2006), Solving a vehicle-routing problem arising in soft-drink distribution, Journal of the Operational Research Society, Vol. 57, No. 9, pp. 1045-1052.

Raab, V., Bruckner, S., Beierle, E., Kampmann, Y., Petersen, B., Kreyenschmidt, J. (2008), Generic model for the prediction of remaining shelf life in support of cold chain management in pork and poultry supply chains, Journal on Chain and Network Science, Vol. 8, No. 1, pp. 59-73.

Raafat, F. (1991), Survey of literature on continuously deteriorating inventory models, Journal of the Operational Research Society, Vol. 42, No. 1, pp. 27-37

Reiner, G., Trcka, M. (2004), Customized supply chain design: Problems and alternatives for a production company in the food industry. A simulation based analysis, International Journal of Production Economics, Vol. 89, No. 2, pp. 217-229

Rijgersberg, H., Tromp, S., Jacxsens, L., Uyttendaele, M. (2010), Modeling logistic performance in quantitative microbial risk assessment, Risk Analysis, Vol. 30, No. 1, pp. 20-31.

Rochat, Y., Semet, F. (1994), A tabu search approach for delivering pet food and flour in Switzerland, Journal of the Operational Research Society, Vol. 45, No. 11, pp. 1233-1246.

Rodrigues, C.M.A., Della Lucia, C.M., Azeredo, R.M.C., Cota, A.M., Santana, A.M.C., Pinheiro-Sant'Ana, H.M. (2010), Control of vitamin C losses in vegetables prepared at a food service, Food Control, Vol. 21, No. 3, pp. 264-271.

Rong, A., Akkerman, R., Grunow, M. (2009), An optimization approach for managing fresh food quality throughout the supply chain, International Journal of Production Economics, article in press, doi: 10.1016/j.ijpe.2009.11.026.

Rong, A., Grunow, M. (2010), A methodology for controlling dispersion in food production and distribution, OR Spectrum, article in press, doi: 10.1007/s00291-010-0210-7.

Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H, Nakamura, N., Shiina, T. (2009), A review of life cycle assessment (LCA) on some food products, Journal of Food Engineering, Vol. 90, No. 1, pp. 1-10.

Rusdiansyah, A., Tsao, D. (2005), An integrated model of the periodic delivery problems for vending-machine supply chains, Journal of Food Engineering, Vol. 70, No. 3, pp. 421-434.

Rushton, A., Croucher, P., Baker, P. (2006), The Handbook of Logistics and Distribution Management, 3rd ed., Kogan Page, London, UK.

Salin, V., Darmasena, S., Wong, A., Luo, P. (2006), Food Product Recalls in the U.S., 2000-2003, Journal of Food Distribution Research, Vol. 37, No. 1, pp. 150-153.

Saunders, C., Barber, A., Taylor, G. (2006), Food miles – Comparative energy/emissions performance of New Zealand's agriculture industry, AERU Research Report No. 285, Agribusiness & Economics Research Unit (AERU), Lincoln University, Lincoln, New Zealand.

Schneeweiss. C. (2003), Distributed decision making – a unified approach, European Journal of Operational Research, Vol. 150, No. 2, pp. 237-252.

Schwägele, F. (2005), Traceability from a European perspective, Meat Science, Vol. 71, No. 1, pp. 164-173.

Semet, F, Taillard, E. (1993), Solving real-life vehicle routing problems efficiently using tabu search, Annals of Operations Research, Vol. 41, No. 4, pp. 469-488.

Shapiro, J.F. (2007), Modeling the Supply Chain, 2nd ed., Duxbury-Thomson, Belmont, CA.

Sim, S., Barry, M., Clift, R., Cowell, S.J. (2007), The relative importance of transport in determining an appropriate sustainability strategy for food sourcing. International Journal of Life Cycle Assessment, Vol. 12, No. 6, pp. 422-431.

Smith, B.G. (2008), Developing sustainable food supply chains, Philosophical Transactions of the Royal Society B, Vol. 363, No. 1492, pp. 849-861.

Smith, D., Sparks, L. (2004), Temperature controlled supply chains, in: Bourlakis, M., Weightman, P. (eds.), Food Supply Chain Management, Blackwell Publishing, Oxford, UK, Chapter 12, pp. 179-198.

Tarantilis, C.D., Ioannou, G., Prastacos, G. (2005), Advanced vehicle routing algorithms for complex operations management problems, Journal of Food Engineering, Vol. 70, No. 3, pp. 455-471.

Tarantilis, C.T., Kiranoudis, C.D. (2001), A meta-heuristic algorithm for the efficient distribution of perishable foods, Journal of Food Engineering, Vol. 50, No. 1, pp. 1-9.

Tarantilis, C.T., Kiranoudis, C.D. (2002), Distribution of fresh meat, Journal of Food Engineering, Vol. 51, No. 1, pp. 85-91.

Taylor, E. (2008a), HACCP for the hospitality industry: History in the making, International Journal of Contemporary Hospitality Management, Vol. 20, No. 5, pp. 480-493.

Taylor, E. (2008b), A new method of HACCP for the catering and food service industry, Food Control, Vol. 19, No. 2, pp. 126-134.

Taylor, E., Taylor, J. (2008), A new method of HACCP for hospitality: from concept to product, International Journal of Contemporary Hospitality Management, Vol. 20, No. 5, pp. 524-541.

Tayur, S., Ganeshan, R., Magazine, M. (1999), Quantitative Models for Supply Chain Management, Springer.

Terreri, A. (2009), Preventing the next product recall, Food Logistics, Vol. 111, March 2009, pp. 20-25.

Trienekens, J., Zuurbier, P. (2008), Quality and safety standards in the food industry, developments and challenges, International Journal of Production Economics, Vol. 113, No. 1, pp. 107-122.

Turenne, J. (2009), Sustainability in food service, in: Baldwin, C. (ed.), Sustainability in the food industry, Wiley-Blackwell and IFT Press, Ames, Iowa, USA, Chapter 10, pp. 225-238.

Twinn, F. (2007), Energy reduction becomes a priority, Food Manufacture, Vol. 82, No. 3, pp. 41-42.

Van Asselt, E.D., Meuwissen, M.P.M., Van Asseldonk, M.A.P.M., Teeuw, J., Van der Fels-Klerx, H.J. (2010), Selection of critical factors for identifying emerging food safety risks in dynamic food production chains, Food Control, Vol. 21, No. 6, pp. 919-926.

Van der Vorst, J.G.A.J., Beulens, A.J.M., Van Beek, P. (2000), Modelling and simulating multi-echelon food systems, European Journal of Operational Research, Vol. 122, No. 2, pp. 354-366.

Van der Vorst, J.G.A.J., Tromp, S.O., Van der Zee, D.J. (2009), Simulation modelling for food supply chain redesign; integrated decision making on product quality, sustainability and logistics, International Journal of Production Research, Vol. 47, No. 23, pp. 6611-6631.

Van Donk, D.P., Akkerman, R., Van der Vaart, J.T. (2008), Opportunities and realities of supply chain integration: The case of food manufacturers, British Food Journal, Vol. 110, No. 2, pp. 218-235.

Van Vliet, A., Boender, C.G.E., Rinnooy Kan, A.H.G. (1992), Interactive optimization of bulk sugar deliveries, Interfaces, Vol. 22, No. 3, pp. 4-14.

Vasileiou, K., Morris, J. (2006), The sustainability of the supply chain for fresh potatoes in Britain, Supply Chain Management: An International Journal, Vol. 11, No. 4, pp. 317-327.

Villegas, F.A., Smith, N.R. (2006), Supply chain dynamics: Analysis of inventory vs. order oscillations trade-off, International Journal of Production Research, Vol. 44, No. 6, pp. 1037–1054.

Wang, X., Li, D., Li, L. (2009a), Adding value of food traceability to the business: A supply chain management approach, International Journal of Services Operations and Informatics, Vol. 4, No. 3, pp. 232-258.

Wang, X., Li, D., O'Brien, C. (2009b), Optimisation of traceability and operations planning: An integrated model for perishable food production, International Journal of Production Research, Vol. 47, No. 11, pp. 2865-2886.

Wang, X. Li, D., O'Brien, C., Li, Y. (2010), A production planning model to reduce risk and improve operations management, International Journal of Production Economics, Vol. 124, No. 2, pp. 463-474.

Watson-Gandy, C.D.T., Dohrn, P.J. (1973), Depot location with van salesmen – A practical approach, OMEGA – The International Journal of Management Science, Vol. 1, No. 3, pp. 321-329.

WCED (1987), Our Common Future (World Commission on Environment and Development, Bruntland Commission), Oxford University Press, Oxford.

Weber, C.L., Matthews, H.S. (2008), Food-miles and the relative climate impacts of food choices in the United States, Environmental Science & Technology, Vol. 42, No. 10, pp. 3508-3513.

White, L., Lee, G.J. (2009), Operational research and sustainable development: Tackling the social dimension, European Journal of Operational Research, Vol. 193, No. 3, pp. 683-692.

Wilson, T. (2007), The ‘food miles’ fallacy, Institute of Public Affairs Review, Vol. 59, No. 2, pp. 41-43.

Wognum, P.M., Bremmers, H., Trienekens, J.H., Van der Vorst, J. G.A.J., Bloemhof, J.M. (2010), Systems for sustainability and transparency of food chains – Current status and challenges, Advanced Engineering Informatics, article in press, doi:10.1016/j.aei.2010.06.001.

Wouda, F.H.E, Van Beek, P., Van der Vorst, J.G.A.J, Tacke, H. (2002), An application of mixed-integer linear programming models on the redesign of the supply network of Nutricia Dairy & Drinks Group in Hungary, OR Spectrum, Vol. 24, No. 4, pp. 449-465.

Wright, O.R.L., Connelly, L.B., Capra, S. (2006), Consumer evaluation of hospital foodservice quality: an empirical investigation, International Journal of Health Care Quality Assurance, Vol. 19, No. 2, pp. 181-194.

Zanoni, S., Zavanella, L. (2007), Single-vendor single-buyer with integrated transport-inventory system: Models in the case of perishable goods, Computers & Industrial Engineering, Vol. 52, No. 1, pp. 107-123.

Zeng, L., Ong, H. L., Ng, K. M., Liu, S. B. (2008), Two composite methods for soft drink distribution problem, Advances in Engineering Software, Vol. 39, No. 5, pp. 438-443.

Zhang, G., Habenicht, W., Spieß, W.E.L. (2003), Improving the structure of deep frozen and chilled food chain with tabu search procedure, Journal of Food Engineering, Vol. 60, No. 1, pp. 67-79.

Zoryk-Schalla, A.J., Fransoo, J.C., De Kok, T.G. (2004), Modeling the planning process in advanced planning systems, Information & Management, Vol. 42, No. 1, pp. 75-87.