A Review of Quantitative Models for Sustainable Food Logistics Management: Challenges and Issues

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Abstract

The need to further improve food quality and reduce food waste leads to increased attention for the development of Food Supply Chain Management (FSCM), which considers intrinsic characteristics of food supply chains besides traditional supply chain management (SCM) objectives such as cost and responsiveness. Growing consciousness of society towards sustainable development brings additional objectives to the food supply chains and the fast evolution of sustainable development results in the development of a new fast-growing concept: Sustainable Food Supply Chain Management (SFSCM). In response to these developments, researchers have developed various decision support tools that can be used for handling progressively increasing complexity along the alteration process from SCM to FSCM and now to SFSCM. In this study, we have reviewed literature on sustainable food logistics management to identify logistical key issues and relevant quantitative modelling challenges. The evaluation of the reviewed papers shows that towards obtaining sustainability together with considering intrinsic characteristics of food supply chains, there is a gap between the needs of the practice and the current available methods. In this study, we have also presented improvement opportunities for future developed models by revealing the aforementioned missing points.

Keywords: *: Food logistics management, Sustainability, Quantitative models, Key performance indicators, Literature review*

1 Introduction

Food Supply Chains (FSCs) are composed of organizations, which are producing and distributing vegetable or animal-based products to consumers (van der Vorst et al., 2005). Due to food related diseases (e.g. EHEC, BSE) and globalisation of food production, consumers are becoming more aware of the origin of their food, leading to a growing interest in traceability, freshness and quality of what they have bought. At the same time, product assortments are widened by producers for satisfying the consumer's broadening needs resulting in more complicated lot sizing decisions and increasing transportation costs. Moreover, current projections show a continued increase in world population. The aforementioned developments can be given as some of the main reasons why Food Supply Chain Management (FSCM) has become an important issue in both public and business agendas. It requires a different management approach that considers intrinsic characteristics of food products and processes besides traditional SCM objectives such as cost and responsiveness. Over the last few decades, scholars and practitioners have put more emphasis on FSCM than ever before. In addition to that, recently FSCs are confronted with another trend, sustainability, that necessitates new/advanced approaches in FSCM. Sustainability is meeting the needs of people who are living today without causing damage to the future generations (Linton et al., 2007) and even aims to improve the quality of life for generations to come, not only for the existing people (Bloemhof, 2005). Driving factors for sustainability can be listed as current legislation, public interest or competitive opportunity (Linton et al., 2007). Sustainable development deals with balances between ecological, economic and social processes at the level of society in the long term (Aiking and Boer, 2004). That means, it stresses the importance of key issues which are closely related with human well-being and the natural environment. Therefore, the quality of the product that is served by companies to customer needs to be competitive, socially fair, environmentally safe and profitable, besides being produced efficiently (Kepler, 2004). The fast evolution of sustainable development changes the goals in almost every SC including FSCs and makes conventional FSC strategies inappropriate leading to the development of a new fast-growing concept: Sustainable Food Supply Chain Management (SFSCM).

The major factors that have contributed to the increased interest in this area are raising consciousness on sustainable system dynamics and, related with that, governments change regulations by enacting strict rules on food safety and sustainability problems to impose firms on taking necessary precautions against the social and environmental impacts of their operations. In terms of sustainability, companies operating in the agriculture and the food sector are confronted with: (1) accelerating environmental and social impact assessment policy and standards such as HACCP, BRC or ISO22000 enacted by governments; (2) emerging concept of extended producers responsibility supporting the shift from "cradle to grave" to "cradle to cradle" perspective (Neto et al., 2009) imposed from either governments or influential private institutions and (3) gradually increasing discussions brought to the agenda by the society on pursuing life without compromising future generation's rights to live .

Unsurprisingly, this alteration from traditional SCM to FSCM and now to SFSCM improves the complexity of SCs and results in more challenging logistics management; especially since, the aforementioned developments have stimulated companies and researchers to consider multiple performance indicators. Companies have to invest in a redesign of their logistics network to increase responsiveness, improve food quality, reduce food waste and improve sustainability and transparency. As a result, the traditional performance indicator “cost” is replaced by the emerging Triple Bottom Line (TBL) concept in which Profit, People and Planet are the drivers towards performance (van der Vorst et al., 2005). It is clear that this change evokes the need for an integrated approach that links supply chain decisions to the three pillars of sustainability.

Sustainability in itself is not a new research area and much literature is devoted to this subject. However, FSC systems are complex comprising a wide diversity of products with different characteristics and quality management requirements, enterprises, dynamic interactions and markets making the decisions concerning the FSCs such as production, distribution decisions more challenging. Therefore, quantitative models are often used to support management decision making in analysing scenarios and deciding on effective redesigns of the chain. Up to now, literature lacks an overview of the state of the art concerning these aspects.

The main aim of this study is to identify logistical key issues and modelling challenges in sustainable food logistics management. We have conducted a literature review on quantitative studies concerning sustainable food logistics management. We have chosen a broad scope of quantitative studies with various types of FSCs, with varying objectives and concerns to ensure general comprehension of modelling types, sustainable system dynamics and also approaches handling product quality decay and waste. Our focus is on the inter organizational chain logistics necessary to improve food quality and sustainability, so we do not so much elaborate on processes like growing, harvesting, processing etc. This review comprises comparisons of selected studies with respect to various factors such as included performance indicators, environment, product and model characteristics as well as sustainability, transparency and quality concerns.

2 Research Methodology

In this study we mainly focus on quantitative models about food logistics management. However, we also consult some qualitative studies about FSCs to develop the discussion and to understand related logistical key issues more clearly. Our literature search is carried out within well-known databases such as ISI Web of Knowledge and EBSCO and followed by reference and citation analyses to find related contributions. The following search criteria were employed: *sustainable food logistics management, food supply chain production and distribution planning, food supply chain quantitative models, sustainability in food supply chains, food safety/security issues in food supply chains.*

Framework of this study (see Fig.1) comprises three aspects: (1) identifying logistical demands from practice (logistical key issues), (2) current available methods, and (3) needs for new/advanced models (quantitative modelling challenges). Using this framework, we try to determine key modelling challenges for sustainable food logistics management.

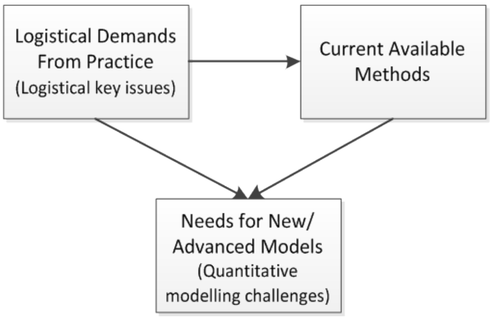

Figure 1. Logistical key issues and modelling challenges in SFSCs

Different than two other literature review studies about quantitative models in FSCs (Ahumada and Villalobos, 2009a) and (Akkerman et al., 2010) in which sequentially the field of production and distribution planning for agri-foods and food distribution management for various FSCs is discussed, we place emphasis on sustainability and present more detailed information with respect to related models. By putting forward main performance indicators considered in quantitative models, we generate a structured linkage between the practical needs and the current modelling literature.

2.1 Logistical Demands From Practice (Logistical key issues)

Currently, there is a global and interconnected system in food industry that has various complex relationships for the logistics management of food products, because of consumers' concerns related to food safety scandals and globalization of food production (Trienekens and Zuurbier, 2008). Also, food security is still a considerable problem a.o. due to the growing population which is projected to reach 9Bn by 2050 (Global Food Security, 2012) that necessitates emphasis on the reduction of food waste. In FSCs reaching the right customer (higher revenue) at the right level of quality, with the appropriate remaining shelf life and with the proper routing through the chain are crucial factors for solidifying and maintaining competitive advantage (Ahumada and Villalobos, 2011). However, this claim needs to be extended when sustainability concerns are involved in decision making. Thereby, the ultimate goal in a sustainable FSC is ensuring customer satisfaction with the most efficient/effective way possible while being aware of the impacts of operations on the environment and society. In this study, considering the related literature we aim to cover the core issues in sustainable food logistics management in three groups: (1) cost reduction and improved responsiveness, (2) improved food quality and a reduction of food waste, and (3) improved sustainability and transparency. These groups sequentially can also be regarded as phases towards SFSCM.

2.1.1 Cost reduction and improved responsiveness (SCM phase)

Cost and responsiveness issues are the two main traditional concerns in SCs. In today's food sector consumers demand high quality food in various innovative forms throughout the year with a competitive price ((Apaiah and Hendrix, 2005); (Trienekens and Zuurbier, 2008)). Thereby, SCM aims to achieve better customer service with less cost while satisfying the various requirements of other stakeholders in the chain ((van der Vorst and Beulens, 2002); (van der Vorst et al., 2005)). Besides, compared to the past, food industries head more towards international markets to the aim of sourcing necessary products for their operations and serving products. This changing system leads to the need of advanced models and tools for planning the SC operations (Mula et al., 2010) and global coordination and optimization of geographically dispersed facilities (Brown et al., 2001) to reduce operations' costs. Apparently, problems in FSCs are more sophisticated than in the past (Bilgen and Ozkarahan, 2007) and companies in the food industry focus mainly on cost reduction, especially in the current economic crises.

Another major concern, establishing SC responsiveness, has two main dimensions; one of them is the time between placing and receiving an order and the other one is how quickly companies respond to customers' unique and rapidly changing needs. Responsiveness is key to maintaining customer satisfaction and customer service in the food industry. In Gunasekaran et al. (2008) the key factors for forming a responsive SC are stated as follows: timely information sharing, shortening the total cycle time, coordinating the workflow at different echelons of the SC, good decision support systems, reducing lead times for information and materials flows, integrating information about operations, reducing redundant echelons, and flexible capacity. There is also a trade-off between the cost of the SC (efficiency) and its responsiveness, resulting in discussions on the position of the customer order decoupling point (van der Vorst et al., 2005). On one hand increased product diversity and competition leads to decrease in inventories to reduce inventory costs; on the other hand keeping more inventory always guarantees responding quickly to consumers. So, FSCs try to maintain a reasonable balance between these two decision areas: reducing cost versus improving responsiveness.

2.1.2 Improved food quality and a reduction of food waste (FSCM phase)

Food quality and waste issues are the two main triggers for the transition from the SCM to the FSCM which has additional challenges and complexity compared to traditional SCM. In FSCs, there is a continuous change in the quality of the food product starting from the time the raw material leaves the grower (or e.g. the slaughter for meat products) to the time the product reaches the consumer (Dabbene et al., 2008). Perishable products have a shorter shelf life[1] than non-perishables and meet two criteria: (1) high rate of deterioration at ambient storage conditions and requiring specific storage conditions to slow the deterioration rate, (2) an obsolescence date of the product such that reordering for the products with the same date is impractical (e.g. newspapers and (bi)weekly magazines can be considered perishables (van Donselaar et al., 2006)). These changes in product value make conventional SC strategies which do not take perishability into account inappropriate (Blackburn and Scudder, 2009). Perishable products require special management that can deal with additional challenges such as temperature controls, quality decay modelling or waste reduction methods. Besides, current FSCs are serving to consumers who are more concerned about food safety and security issues than ever before. Also, other stakeholders have growing concern on these issues leading to formation of global organizations dealing with food related problems, the Food and Agricultural Organ (FAO), the world health organ (WHO), both UN organs and the World Trade Organization

[1] The shelf life of a product is length of the time, starting from the day it is produced before the product considered unacceptable for consumption or become obsolete (Donselaar et al.,2006).

(WTO) (Trienekens and Zuurbier, 2008). These organizations aim at improvements in availability of and access to healthy food. Thereby, they have various missions such as setting norms and standards, providing technical support to countries or monitoring and assessing operations. Regarding perishability issue, van der Vorst et al. (2007; 2011) have proposed the innovative concept of Quality Controlled Logistics (QCL) and claimed that better SC design can be established, if product quality is tracked along the SC. Moreover, throughout the FSCs among the world, the food waste is progressively increasing. To give an example from the Netherlands, according to a fact sheet report (2010) of the Ministry of Economics, Agriculture and Innovation, in the agro chain annual loss is approximately 2,000 million € and this is 30% up to even 50% in some sectors. Of this, 10% to 20% is lost in production, 2% to 10% in industry and trade and 3% to 6% in the retail and out-of-home market. So, the world is still facing big problems related with the food industry which are waiting to be solved. Therefore, there is a growing need for special quantitative models which can tackle the perishability and waste problems in food logistics management.

2.1.3 Improved sustainability and transparency (SFSCM Phase)

Sustainability and transparency issues lead to the need for SFSCM for dealing with additional challenges and much more increased complexity compared to FSCM and SCM. Apart from the traditional complexity of the FSCs, sustainability concerns are rapidly growing in the field of OR/OM and FSCM. Kyoto Protocol, setting binding targets for industrialized countries can be given as the most outstanding and recent step of governments towards achieving sustainable development. EU is also a highly influential proponent of sustainability (Linton et al., 2007) and important EU regulations concerning sustainability are, The General Food Law (Regulation EC/178/2002) and The Waste Electrical and Electronic Equipment (WEEE) (Directive 2002/96/EC) (Bloemhof, 2005). Mainly related with the growing concern about the future, also the concept of sustainable SC design has emerged and aims to incorporate economic, environmental as well as societal decisions into SCs in the design phase ((Chaabane et al., 2012); (Wang et al., 2011)). Escalating sustainability consciousness of stakeholders in FSCs inevitably affects the decision making process and operations. That means an integrated approach linking SC decisions to the three pillars of sustainability (Chaabane et al., 2012) with quality consideration is necessary for companies. According to Seuring and Muller (2008) the pressures and incentives for sustainability in SCs (not only FSCs) are listed as follows: legal demands legislation, customer demands, response to stakeholders, competitive advantage, environmental and societal pressure groups, reputation loss. However, it is obvious that investments to improve environmental care need to be balanced against other investments (Wognum et al., 2011) or the social and environmental dimensions of SSCM must be undertaken with a clear and explicit recognition of the economic goals of the firm (Carter and Rogers, 2008).

Another key issue, transparency, has also growing impact on FSCs. Consumers want to get more insight in production processes as well as what happened to the product as it went through the SC (Vis, 2012). This places emphasis on especially the people and planet aspects of sustainability. In order to achieve transparency and tracking and tracing of products and services throughout the value chain, intensified integration and cooperation between the actors of the chain and improved monitoring of process activities (Fritz and Schiefer, 2008) is required.

2.2 Current Available Methods

In this section, the presentation of main characteristics of the existent models in literature is followed by a discussion about the performance indicators considered in these models for each of the aforementioned logistical key issues in the previous section.

2.2.1 Modelling Characteristics

Due to the recently growing attention to FSCM in the Operations Management (OM) literature (Akkerman et al., 2010) especially in the last decade, the number of studies on food logistics management is increasing. The existing models of food logistics management and their main characteristics are derived in Table 1. The aforementioned studies are investigated in terms of modelling type, decisions incorporated, linearity, solution method, containing uncertainty, decision planning horizon structure, transportation mode, existence of application with either real or hypothetical data and field of study.

Regarding that production, transportation and inventory management are the main logistical drivers (Chopra and Meindl, 2010) in a SC, the common objective of all models is improving the performance of the related food logistics system by aiding the decision making process. For these aforementioned problems, scholars have proposed various types of models: Mixed Integer Programming (MIP), Linear Programming (LP), Multi Objective Programming (MOP), Goal Programming (GP), Analytical and Simulation models. Different software programs have been used or approaches have been developed for obtaining solutions from the developed models. Depending on the complexity of the problem, in some studies scholars need to develop several heuristics for at least producing solutions that are close to the optimal solution. The reasons for facilitating from heuristic methods can be given as the impossibility or huge amount of time to obtain an optimal solution. Except for a few studies which have non-linear terms in their models, the focus is mostly on the use of linear models. Moreover, some models serve to the purpose of multi decision planning horizon, whereas some of them are developed for only single period decision planning. Mode of transportation assumption is also different in studies.

Most real FSC problems are characterized by various sources of uncertainties i.e. length of the order forecast horizon, information availability and data timeliness, decision policies used, supply, process and demand uncertainties (van der Vorst et al., 2000). However only a few studies such as (van der Vorst et al., 1998); (Azaron et al., 2008) are keen to challenge incorporating stochastic elements into their models. Besides, almost all of the proposed models are implemented in various FSCs either by considering collected real or generated hypothetical data.

2.2.2 Cost reduction and improved responsiveness

All of the quantitative models in reviewed literature (see Table 2) try to minimize the costs of various operations in food logistics management. Most of the confronted costs in quantitative models can be classified into four main groups: production, inventory, distribution and other costs. In this list the last item, other costs, represents costs which depend on the type of the food product such as milk collection, biomass drying or by-product credit. In some of the studies considering food quality decay ((Rong et al., 2011); (Blackburn and Scudder, 2009); (Ahumada and Villalobos, 2009b)), cooling, wastage and/or quality loss costs are handled within one or more of the main cost groups. Apart from the aforementioned main cost groups, Rong and Grunow (2010) incorporate dispersion costs of batches into the quantitative model to solve the trade-off between reducing production costs of the food products and reducing the concerns for food safety.

Different from other studies, Azaron et al. (2008) put emphasis on the minimization of the variance of the total cost and the minimization of the financial risk (the probability of not meeting a certain budget) besides cost minimization in a multi-objective model.

Except for a few studies ((Ahumada and Villalobos, 2009b); (Bilgen and Gunther, 2010); (Blackburn and Scudder, 2009); (van der Vorst et al., 2000)) in which there are strict deadlines such as a specific production lot that has to be finished up to a particular day or cycle time, FSC responsiveness is not explicitly mentioned in literature. However aiming for coordinating operations in related FSCs, it can be said that all these developed quantitative models also serve the purpose of increasing responsiveness with varying extent. Especially, forbidden stock-out possibilities in e.g. Rong et al. (2011), Akkerman et al. (2009) (see Table 1) can be regarded as a management approach to improve customer responsiveness. Apart from reducing operational costs, utilisation of transport carriers has also the potential to shorten cycle time for delivery to the customer. Moreover, stochastic quantitative models in literature have shortage costs to encourage satisfying customers' demand on time that can contribute to the improved responsiveness. The study of van der Vorst et al. (1998) refer to responsiveness by stating that systematically managing uncertainties in a SC is a next step towards creating responsive SCs.

Apart from those studies referring responsiveness, Blackburn and Scudder (2009) brought in Marginal Value of Time (MVT) rate to measure the cost of a unit time delay in the SC and divided the FSC into two segments (a ''responsive'' segment in which product deterioration rates are high and an ''efficient'' segment with lower deterioration rates), modelling each of them separately. They came up with an important result that the decisions in each segment of the SC do not need to be coordinated to achieve SC optimization.

2.2.3 Improved food quality and a reduction of food waste

The perishability problem, sometimes even leading to food waste in FSCs, is too important to ignore and affects many operations along the chain. In response to that growing practical need, attempts have been made to incorporate quality decay and waste of the product into quantitative models in food logistics management (see Table 2). The general aim of these studies is approaching real life situations in FSCs as much as possible.

Most of the models in literature such as Zanoni and Zavanella (2007); Eksioglu and Jin (2006) assume that the quality of products diminishes linearly and deemed useless after a specific time period. That means as long as products are above the pre-specified minimum levels, they are regarded as acceptable and quality of the products do not make difference in terms of market price or cost. Thereby, the model does not penalize the late delivery unless it is above of the pre-specified quality level. However, because of quality decays either part of the purchased goods cannot be sold on the market or can be sold with a lower price than the best market price (Osvald and Stirn, 2008). To avoid these problems and to encourage the freshness of products, a few studies ((Ahumada and Villalobos, 2009b); (Ahumada and Villalobos, 2011); (Osvald and Stirn, 2008)) consider the cost of inventory lost while being transported by including that cost to the objective function. Besides, rather than assuming simple linear decay, Rong et al. (2011) use a quantitative quality decay model based on the Arrhenius equation[2].

Among the studies which handle the perishability problem in their models, some studies such as Rong and Grunow (2010) and van der Vorst et al. (2009) also try to include temperature controls of the products for determining the best temperatures throughout the chain (see Table 2). In these studies, quality decays occur in products depending on the temperature

[2] The Arrhenius equation is a simple, but remarkably accurate, formula for the temperature dependence of the reaction rate constant, and therefore, rate of a chemical reaction (Wikipedia, 2012; Chang, 1981)

levels. That means that the magnitude of quality change at different temperature levels is assumed to be known in advance as a parameter. Different than the other studies, Akkerman et al. (2009) claim that enthalpy[3] level control is easier than temperature controls and include enthalpy level tracking to their models besides temperature controls.

A few of the studies in literature, You et al. (2011), Rong et al. (2011), Akkerman et al. (2009), van der Vorst et al. (2009) and Wang et al. (2010) (see Table 2), has referred to the potential food waste problem. Among these studies, You et al. (2011) and Rong et al. (2011), explicitly incorporate the food waste problem into their models. In these aforementioned studies, products that lose their suitable freshness are discarded and food waste or waste disposal costs are incurred. Besides, in the simulation model of Vorst et al. (2009) product waste is added as a performance indicator.

2.2.4 Improved sustainability and transparency

Despite the fact that sustainability is not a new concept, the study in this fields is regarded as in its infancy period by many scholars (Linton et al., 2007). The reviewed literature also supports that argument by having only a small number of studies dealing with sustainable development (see Table 2) from the researched perspective. The studies which take into account the new emerging sustainability goals, try to deal with environmental and/or societal concerns besides economic objectives.

Reviewed literature shows that in terms of environmental perspective, GHG emission rates, energy usage and water use indicators and in terms of societal perspective fat content of products and number of accrued jobs are used in the quantitative models of food logistics management.

All of the studies considering GHG emissions try to manage a single indicator in terms of carbon dioxide–equivalent emissions (CO2-equiv/year) or carbon dioxide emissions (CO2/year) and aim to coordinate good distribution. The environmental impact is expressed as kg CO2 per mile travelled. The other environmental impact indicator energy use in the models relates to the various operations in FSCs such as refrigeration, heating, lighting or machine use and expressed as MJ per second/per ton km. The common aim of the studies incorporating energy use is reducing the energy consumption throughout the chain while keeping up operations. The consumption of an important natural resource, water, is also considered in a few studies e.g. (Ahumada and Villalobos, 2009b) with the aim of controlling water use in related chains.

In literature only one study (Oglethorpe, 2010) has a target to reduce the fat content (expressed as kg) of the products. This attempt can be regarded as societal objective since fat content of products has potential to affect the health of people in negative way. Besides, in that study and in other one (You et al., 2011) the number of accrued jobs, which is expressed as hours and full-time equivalent job per year respectively, is aimed to be increased as a social dimension.

[3] Enthalpy reflects the energy stored in the product and enthalpy changes are mainly based on the heat transfer between a food product and its surrounding environment, based on characteristics of the product and the environment in which it is located (Akkerman et al., 2009).

Table 1.
Main Characteristics of Quantitative Studies in Food Logistics Management

	Model Type	Decisions	Linear vs Non-Linear	Solution Method	Stochastic vs Deterministic	Stochastic element	Multi vs Single period	Multi vs Single mode transportation	Application	Real vs Hypothetical	Field of Study
Gelders et al. (1987)	MIP	PT	L	Fortran	D	N	S	S	Y	R+H	Large brewery
Zuo et al. (1991)	MIP	PT	L	MPSX/MIP packages, FORTRAN, Heuristic	D	N	S	S	Y	R	Corn
van der Vorst et al. (1998)	Simulation	PTI	U	U	S	Demand, lead time	U	U	Y	R	U
van der Vorst et al. (2000)	Simulation	PTI	U	U	S	U	U	U	Y	R	Chilled salads
Brown et al. (2001)	MIP	PTI	L	Heuristic	D	N	M	S	Y	R	Cereal and convenience foods
Gebresenbet and Ljungberg (2001)	Analytical	PTI	U	Route LogiX	D	N	U	U	Y	R	Agriculture
Tarantilis and Kiranoudis (2002)	Analytical	T	U	Mic.Visual C++, Heuristic	D	N	S	S	Y	R	Meat
Wouda et al. (2002)	MIP	PT	L	U	D	N	S	S	Y	R	Dairy
Apaiah and Hendrix (2005)	LP, Network	PT	L	GAMS	D	N	S	M	Y	R	Pea-based novel protein foods
Entrup et al. (2005)	MIP	PI	L	ILOG's OPL, Cplex 8.1	D	N	M	N	Y	R	Yoghurt
Eksioglu and Jin (2006)	MIP-Network flow	PTI	L	Cplex 9, heuristic	D	N	M	S	Y	H	U
Higgins et al. (2006)	MIP	PTI	L	Fortran 95, Heuristic	D	N	M	S	Y	R	Sugar
Ahuja (2007)	MIP	PTI	NL	Cplex 7.0, Greedy heuristic	S	Demand	M	S	Y	H	U
Bilgen and Ozkarahan (2007)	MIP	PTI	L	ILOG OPL Studio 3.7 CPLEX 8.0	D	N	M	M	Y	R	Wheat
Zanoni and Zavanella (2007)	MIP	PTI	L	Cplex 6.6, Heuristic	D	N	M	S	Y	H	U
Azaron et al. (2008)	MOP	PTI	NL	Goal attainment technique-LINGO	S	Demand, supply, costs	S	S	Y	H	Wine
Dabbene et al. (2008)	Analytical	PTI	NL	A specific optimisation algorithm	S	Chain behaviour	M	S	Y	R	Beef
Osvald and Stirn (2008)	Analytical	PT	L	Heuristic	D	N	S	M	Y	H	Vegetables
Ahumada and Villalobos (2009b)	MIP	PTI	L	AMPL- Cplex 10	D	N	M	M	Y	H	Pepper-tomatoes
Akkerman et al. (2009)	MIP	PTI	L	U	D	N	M	S	N	N	Meal elements
Blackburn and Scudder (2009)	Analytical	PT	U	U	D	N	S	M	Y	R	Melons and sweet corn
van der Vorst et al. (2009)	Simulation	PTI	U	ALADIN TM	S	Product quality	M	M	Y	R	Pineapples
Bilgen and Gunther (2010)	MIP	PTI	L	ILOG's OPL 6.1-Cplex 11.2	D	N	M	M	Y	H	Fruit juices and soft drinks
Oglethorpe (2010)	GP	PT	U	MS Excel Solver	D	N	U	S	Y	R+H	Pork
Rong and Grunow (2010)	MIP	PTI	L	Cplex 10.2, Heuristic	D	N	M	S	Y	H	U
Wang et al. (2010)	MIP	PTI	NL	Heuristic	D	N	M	U	Y	R	Cooked meat-bakery
Ahumada and Villalobos (2011)	MIP	PTI	U	Cplex	D	N	M	M	Y	H	Bell peppers and tomato
Bosona and Gebresenbet (2011)	Analytical	PT	U	GIS- Route LogiX	D	N	U	S	Y	R	Local food producers
Rong et al. (2011)	MIP	PTI	L	ILOG'sOPL-Cplex 10.2	D	N	M	M	Y	R	Bell peppers
Yan et al. (2011)	Analytical	PTI	U	U	D	N	S	S	Y	H	U
You et al. (2011)	MOP	PTI	L	E-constrained method, Cplex 12	D	N	M	M	Y	R	Cellulosic, Ethanol sector
Zucchi et al. (2011)	MIP	PT	L	Gen. Alg. Mod. Sys. 22.5 with Cplex	D	N	M	S	Y	R	Beef
P:Production, T:Transportation, I:Inventory, U:Unspecified, N:None, L:Linear, NL: Nonlinear, S:Stochastic, D:Deterministic, M:Multi, S:Single, Y:Yes, N:No, R:Real, H:Hypothetical											

The studies in literature which take into account transparency, focus on traceability of the product along the chain. Bilgen and Gunther (2010) emphasize a need in FSCs that demand need to be assigned to daily delivery periods rather than weeks because of short replenishment cycles and this situation necessitates tracing the completion of production lots on a daily time scale. They introduced auxiliary binary decision variables, so-called heaviside variables, which indicate that the specific production lot has been finished on a specific line up to a particular day. Rong and Grunow (2010) a handle different problem and support the idea that traceability systems must be complemented with suitable production and distribution planning approaches. In their model, they have a parameter called batch ID for each production batch which consists of the information about batch number, product type, production time, and production location. With this information they have tried to determine the number of batches (setups), the batch sizes and which batches are delivered to which retailers in each period. In another study (Rong et al., 2011), the developed model traces product batches of different quality throughout the production and distribution network.

2.3 Needs for New/Advanced Models (Quantitative Modelling Challenges)

The reviewed literature on sustainable food logistics management shows that the food industry needs more advanced models for the entire chain to support business decisions and capture SC dynamics (Dabbene et al., 2008).

The assumptions of almost all studies in the literature rely on a completely deterministic environment. From the perspectives of ease of development (complexity) or solvability of the developed models, researchers' approach to the chain problems can be understandable. However in the real world most of the chain members in the food industry are confronted with various uncertainties with respect to such as demand, supply or production amounts. Thereby, for getting close to the real life situation it is good to incorporate variation possibility of several parameters into the FSC quantitative models.

One of the main concerns of FSCs, perishability, usually has been taken roughly into consideration in quantitative models. The major reason for mishandling is measuring quality decay is not easy since it can be dependent on many parameters according to the food product and requires technological tracking systems. It is obvious that if more sensitive and detailed quality decay analyses considering environmental or intrinsic conditions are made on related products, more reliable results can be obtained by integrating them into the models.

Another finding that can be drawn from the reviewed papers is that research into SC sustainability has so far received insufficient attention in literature. In response to the growing concerns on sustainable development, the future models should aid decision makers while considering also the environmental and societal repercussions of the chain operations. In order to develop new eco-innovative quantitative models, firstly the impacts of various chain operations to the environment or society should be clearly determined. Life Cycle Assessment Analyses (LCA) serves to that purpose of assessment of impacts associated with all the stages of a product's life from-cradle-to-grave. After determining the crucial impact categories (the key performance indicators) for lessening their magnitudes and pursuing operations in a sustainable way, researchers can incorporate them into the quantitative models and search for the improvement opportunities.

Table 2.
Performance Indicators in Food Logistics Management

	Gelders et al. (1987)	Zuo et al. (1991)	van der Vorst et al. (1998)	van der Vorst et al. (2000)	Brown et al. (2001)	Gebresenbet and Ljungberg (2001)	Tarantilis and Kiranoudis (2002)	Wouda et al. (2002)	Apaiah and Hendrix (2005)	Entrup et al. (2005)	Eksioglu and Jin (2006)	Higgins et al. (2006)	Ahuja (2007)	Bilgen and Ozkarahan (2007)	Zanoni and Zavanella (2007)	Azaron et al. (2008)	Dabbene et al. (2008)	Osvald and Stirn (2008)	Ahumada and Villalobos (2009b)	Akkerman et al. (2009)	Blackburn and Scudder (2009)	van der Vorst et al. (2009)	Bilgen and Gunther (2010)	Oglethorpe (2010)	Rong and Grunow (2010)	Wang et al. (2010)	Ahumada and Villalobos (2011)	Bosona and Gebresenbet (2011)	Rong et al. (2011)	Yan et al. (2011)	You et al. (2011)	Zucchi et al. (2011)
Cost reduction and improved responsiveness																																
Various Supply Chain Costs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Variance of the total cost																X																
Financial risk																X																
Responsiveness (Order Cycle Time of the SC)			X	X															X		X		X									
Marginal Value of Time (MVT)																					X											
Forbidden stock-out possibility							X			X	X	X		X	X				X	X			X		X	X			X	X	X	
Utilisation of transport carriers			X	X		X	X								X			X										X				
Improved food quality and a reduction of food waste																																
Quality decay tracking			X	X	X					X	X		X		X		X	X	X	X	X	X			X	X	X	X	X	X	X	
Temperature controls						X											X			X	X	X			X	X	X	X	X			
Enthalpy level controls																				X												
Food Waste																				X		X				X			X		X	
Improved sustainability and transparency																																
GHG emission rates						X														X		X		X				X			X	
Energy usage																				X		X		X								
Water use																			X					X							X	
Fat content of products (health impacts)																								X								
Number of accrued jobs																								X							X	
Tracing batches																							X		X	X		X	X			

Traceability aids to reveal knowledge and make it transparent so that it is visible to all stakeholders. Thereby, having traceability systems to track different characteristics of the products from production to consumer helps to improve the transparency of the whole chain. Similar to sustainability, traceability receives insufficient attention in literature (Rong and Grunow,2010). However, the increased availability of the information with new control systems on the origin or physical condition of the product along the chain, has potential to improve development of future models.

To conclude, adoption of sustainability concerns with respect the product together with intrinsic characteristics of FSCs such as perishability and transparency are prerequisites for the success of quantitative models in sustainable food logistics management.

3 Conclusion

FSCM is in general a complex process owing to the intrinsic characteristics of FSCs and fast moving and highly competitive food sector. In addition to that FSCs are recently confronted with sustainable development trend. Regarding that, the need for adding sustainability concerns into the FSCM, results in much more complicated and challenging decision making process. Inevitably, food logistics systems are also affected from this alteration process starting from traditional SCM to SFSCM. In this paper, we have reviewed the quantitative studies on food logistics management while pointing out the aforementioned alteration process. Besides, we have also consulted from some qualitative studies. We have given special focus on logistical key issues and current available methods to identify quantitative modelling challenges in sustainable food logistics management. The core issues in sustainable food logistics management have been investigated in three groups: (1) cost reduction and improved responsiveness, (2) improved food quality and a reduction of food waste, and (3) improved sustainability and transparency. As a result, the quantitative studies on food logistics management have been evaluated in terms of modelling characteristics and performance indicators considered for each of the aforementioned logistical key issues. The conclusions drawn from this work affirm that the research on sustainable food logistics management is developing according to the needs of the food industry. The arguable point is about its adequacy of aiding decision making process and capturing SC dynamics. It is important to highlight that currently the literature is insufficient to respond to those practical needs. Generally, the intrinsic characteristics of food products are not handled properly in the studies. The majority of the works reviewed even do not contemplate on sustainability problems, the sustainability concerns find place only in a few recent studies. After this review, we come up with a conclusion that the new/advanced models that take into consideration of demands from practice are required for sustainable food logistics management. It is believed that this study has potential to provide perspectives on future efforts of sustainable food logistics system modelling.

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