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A Review on Quantitative Models for Sustainable Food Logistics Management

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ABSTRACT

The last two decades food logistics systems have seen the transition from a focus on traditional supply chain management to food supply chain management, and successively, to sustainable food supply chain management. The main aim of this study is to identify key logistical aims in these three phases and analyse currently available quantitative models to point out modelling challenges in sustainable food logistics management (SFLM). A literature review on quantitative studies is conducted and also qualitative studies are consulted to understand the key logistical aims more clearly and to identify relevant system scope issues. Results show that research on SFLM has been progressively developing according to the needs of the food industry. However, the intrinsic characteristics of food products and processes have not yet been handled properly in the identified studies. The majority of the works reviewed have not contemplated on sustainability problems, apart from a few recent studies. Therefore, the study concludes that new and advanced quantitative models are needed that take specific SFLM requirements from practice into consideration to support business decisions and capture food supply chain dynamics

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

1 Introduction

Food Supply Chains (FSCs) are composed of organizations that produce and distribute vegetable or animal-based products to consumers. Due to food related diseases (e.g. EHEC, BSE) and globalisation of food production (Nepstad *et al.*, 2006), consumers have become more aware of the origin and nutritional content of their food. This leads to a growing interest in traceability, freshness and quality of products. At the same time, producers expand product assortments to satisfy consumer's broadening desires. This results in more complicated lot sizing decisions and increased transportation costs. An expected continuous increase in world population brings forward another important concern, food security, regarding the availability of food in different parts of the world. The aforementioned developments explain why *Food Supply Chain Management* (FSCM) has become an important issue in both public and business agendas.

In addition to traditional *Supply Chain Management* (SCM) objectives, such as cost reduction and responsiveness improvement, FSCM requires a different management approach that also considers intrinsic characteristics of food products and processes (Van der Vorst *et al*., 2011). Over the last few decades, scholars and practitioners have emphasized FSCM more than ever before. Additionally, FSCs just as other supply chains have recently been confronted with another trend, a request for sustainability, necessitating new and advanced approaches in FSCM. Sustainability is improving the quality of life not only for the current generation but also for the future generations (Brundtlandt, 1987). Sustainable development deals with balancing between ecological, economic and social impacts at the level of society in the long term (Aiking and Boer, 2004). This means that it stresses the importance of key issues closely related to human welfare and the natural environment. Therefore, a product needs to be socially fair and environmentally friendly in addition to being produced efficiently, competitively and profitably (Kepler, 2004). The fast evolution of sustainable development changes the goals in almost every supply chain (SC) including FSCs and makes traditional strategies inappropriate. This has led to the development of a new fast-growing concept: *Sustainable Food Supply Chain Management* (SFSCM) (c.f. Seuring and Muller, 2008; Ahumada and Villalobos, 2009a).

The major factors contributing to the increased interest in SFSCM are: raising consciousness of the importance of sustainable system dynamics and, related to that, changing regulations set by governments that enact strict rules on food safety and sustainability issues. The main aim of these legislations is to impose firms taking necessary precautions against any negative social and environmental impacts of their operations. Companies operating in the agriculture and food sector are confronted with the following: (1) accelerating environmental and social impact assessment policies and standards such as HACCP, BRC or ISO22000 enacted by governments; (2) the emerging concept of extended producer responsibility supporting the shift from "cradle to grave" to "cradle to cradle" perspective (Quariguasi Frota Neto *et al.*, 2009) pushed by either governments or influential private institutions, and (3) gradually increasing preoccupation in society to live well without compromising future generation's rights to prosper.

Unsurprisingly, this progression from traditional SCM to FSCM and now to SFSCM increases the complexity of supply chains and results in more challenging logistics management. As defined by the Council of Supply Chain Management Professionals: "*Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements*" [[1]] . The aforementioned developments have stimulated companies and researchers to consider multiple Key Performance Indicators (KPIs) such as cost, perishability and sustainability in food logistics management (FLM) projects. Companies often have to invest in a redesign of their logistics network to manage those KPIs simultaneously. As a result, the traditional performance indicator "cost" is replaced by the emerging triple bottom line concept in which Profit, People and Planet are the simultaneous drivers towards performance (Van der Vorst *et al.*, 2005). It is apparent that this change evokes the need for an integrated approach that links food supply chain (FSC) logistics decisions to the three pillars (economic, environmental and social pillars) of sustainability (Chaabane *et al.*, 2012) and at the same time manage product quality; an approach called sustainable food logistics management (SFLM).

Sustainability in itself is not a new research area and much literature is devoted to this subject (e.g. Klassen and Whybark (1999)). However, FSC systems are complex, comprising a wide diversity of products with different characteristics and quality management requirements, enterprises, dynamic interactions and markets. This makes logistics decisions concerning FSCs such as production, inventory and distribution decisions more challenging. Quantitative models can support management decision making in these areas. At present the literature lacks an overview of the state of the art concerning these models on SFLM (Akkerman *et al.*, 2010).

The main aim of this study is to identify key logistical aims, analyse currently available quantitative models and point out modelling challenges in SFLM. We conduct an academic literature review on quantitative studies in FLM that includes journal articles and books. Primary (e.g. research articles) and Secondary Sources (e.g. literature reviews) concerning Operations Research and Operations Management disciplines are used. Quantitative studies published within the past 25 years are covered and also qualitative studies are consulted to broaden the discussion and to understand key logistical aims more clearly. Literature search is carried out within well-known databases, Thomson Reuters (formerly ISI) Web of Knowledge, Google Scholar, EBSCO, and followed by reference and citation analyses to find related contributions. The following search criteria are employed: SFLM, FSC production planning, FSC distribution planning, FSC quantitative models, sustainability in FSCs, food safety/security issues in FSCs, transport management in FSCs.

Previous literature review studies have also focussed on FSCs and/or sustainability (Ahumada and Villalobos, 2009a; Akkerman *et al.*, 2010; James *et al.*, 2006; Seuring and Muller, 2008). Among these studies, only Akkerman *et al.*, (2010) consider both FSCs and sustainability issues together. However, in contrary to this study, we cover the contributions considering the development from SCM to FSCM towards SFSCM. Furthermore, we present detailed information with respect to key logistical aims and related models to generate a structured linkage between the practical requirements and the current modelling literature using the KPIs and logistics system scope issues considered in models.

The rest of the paper is organized as follows. Section 2 describes the key logistical aims in SFLM. Section 3 discusses the currently available quantitative models in related literature. Section 4 presents the quantitative modelling challenges. Finally, section 5 provides the conclusions of this study.

2 Key Logistical Aims

In this section, we cover the key logistical aims in SFLM in three groups: (1) cost reduction and improved responsiveness (SCM phase), (2) improved food quality and reduction of food waste (FSCM phase), and (3) improved sustainability and traceability (SFSCM phase). As it is shown, these groups can also be regarded as sequential phases towards SFSCM. We also discuss the drivers and enablers of the key logistical aims to provide the potential research intentions in the different phases (Table 1). Additionally, we present generic logistics system scope issues of each phase that need to be considered in quantitative models to adequately manage the related key logistical aims. Discussing the drivers and enablers, and the generic logistics system scope issues, allows us to evaluate and assess respectively the KPIs and the logistics system scope of the models in the further sections.

2.1 Cost reduction and improved responsiveness

Cost reduction and responsiveness improvement aims are the two main traditional concerns in SCM. SCM aims for better customer service with less cost while satisfying the requirements of other stakeholders in the chain (Van der Vorst and Beulens, 2002; Van der Vorst *et al.*, 2005). Cost refers to the total global network costs from the source of supply to its final point of consumption [*]. Cost reduction and control efforts have been already a central focus in many sectors. However, economic crises and ongoing globalisation have boosted the importance of achieving lowest cost in almost all supply chains including FSCs. Unlike the past, food industries are heading towards international markets for sourcing necessary products for their operations and serving products. The (compulsory) network extension for facilitating economies of scale increases complexity in FSCs. This results in problems that are more sophisticated than in the past (Bilgen and Ozkarahan, 2007). Automation resulting in more efficient processes enables companies to some extent to cope with these problems. Nevertheless, the changing system still leads to the need of advanced models and tools for planning SC operations (Mula *et al.*, 2010). Additionally, global coordination and optimization of geographically dispersed facilities is necessary (Brown *et al.*, 2001) to quickly and accurately determine the distribution options and costs (Chopra, 2003; Simchi-Levi *et al.*, 2009).

The second major concern, establishing improved SC responsiveness, has two main dimensions: the time between placing and receiving an order, and how quickly companies respond to the dynamics of the global marketplace such as customer's unique and rapidly changing needs, new product introductions and new sourcing opportunities (Beamon, 1998; Fisher, 1997). Responsiveness and flexibility are key issues to maintain customer satisfaction in the food industry (Lambert and Cooper, 2000). Nowadays consumers ask for more product variety and high frequent deliveries with short lead times that forces fast production in small batches. Also, demand uncertainty has increased due to increased product variety and

[*] http://www.clm1.org/digital/glossary/glossary.asp

competition. Gunasekaran *et al.* (2008) state that the key factors for forming a responsive SC are: timely information sharing, shortening the total cycle time, coordinating the workflow, implementing good decision support systems, reducing lead times, integrating information about operations, reducing redundant echelons and creating flexible capacity. In parallel, new ICT tools that facilitate more advanced information exchange (Cachon and Fisher, 2000) and collaboration (Christopher and Juttner, 2000) help companies to improve their responsiveness. Companies are also confronted with trade-offs 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; Van Donk, 2001). On one hand, increased product diversity and competition leads to a make to order production system with a decrease in inventories to reduce inventory costs; on the other hand producing to stock and keeping more inventory (buffer/safety) in the SC guarantees quick customer response. Therefore, FSCs have the challenge to maintain a reasonable balance between these two issues: reducing cost versus improving customer service.

The literature review identified a number of generic logistics system scope issues that need to be considered while managing the aforementioned key logistical aims of the SCM phase (see Table 1). In terms of network design, crucial issues are: the roles and the types of operations performed in facilities, locations of facilities, capacities allocated to each facility, markets that facilities will serve and sources that will feed facilities (Chopra and Meindl, 2010). Additional generic issues identified are (see Table 1): (i) distribution channel choice among several distribution options, (ii) outsourcing possibility, (iii) operations excellence with respect to time, quantity and invoice, (iv) strategic inventory positions choice, (v) transportation alternatives and constraints (e.g. time windows, number of vehicles, capacity of carriers), (vi) production choices (e.g. workforce scheduling, multiple product handling, batch size consideration), (vii) incorporation of uncertainty and (viii) use of information technologies (e.g. Geographic Information System or Wireless Sensor Network).

2.2 Improved food quality and reduction of food waste

Addition of food quality and food waste concerns to the key logistical aims of SCM phase triggers the transition from SCM to FSCM. Nowadays, consumers ask for safe and high quality products with a competitive price throughout the year (Apaiah and Hendrix, 2005; Trienekens and Zuurbier, 2008). Increasing attention on food safety shows that health consciousness of consumers has been increasing. In FSCs, the quality of the product continuously changes starting from the time the raw material leaves the grower (or the slaughter for meat products) to the time the product reaches the consumer (Dabbene *et al.*, 2008). This quality change (often degradation) necessitates keeping track of and preserving perishable product quality along the FSC to increase its freshness. These changes in product value make conventional SC strategies, not taking perishability into account, inappropriate (Blackburn and Scudder, 2009). Perishable products require management approaches and models that can cope with additional challenges such as temperature controls, quality decay or waste reduction methods (Hafliðason *et al.*, 2012; Van Donselaar *et al.*, 2006). Technological improvements (e.g. temperature controlled facilities and trucks) enable FSCs to manage food quality throughout the chain. Van der Vorst *et al.* (2011; 2007) propose the innovative concept of Quality Controlled Logistics (QCL) and claim that the establishment of better FSC designs depends on the availability of real time product quality information and the use of that information in advanced logistics decision making along the chain. Apart from this work, also other studies in literature are devoted to the special planning of perishable food products (Adachi *et al.*, 1999; Entrup *et al.*, 2005; Tarantilis and Kiranoudis, 2001). Additionally, consumers have started to desire more convenient products that require minimal preparation such as ready to eat or just heating before eating. This tendency also requires special attention in FSCM.

The second major concern, reducing food waste, deals with preventing or reducing food spoilage in FSCs. Throughout the FSCs among the world, food waste is progressively increasing because of the mismanagement of perishable food products. Consumers' desire for high quality products with long shelf lives also contributes to the increase of food waste. Due to being close to best before dates, many products are lost in FSCs without reaching the consumers as consumers are not willing to buy them. For example, the annual loss in the agro chain from the Netherlands 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 [†].

The relevant logistics system scope covers the generic issues that need to be considered while managing the aforementioned key logistical aims of FSCM phase. Generic issues regarding SCM phase need to be considered beforehand. The additional issues commonly related with the specific characteristics of FSCM phase (given in Table 1) are: (i) batch homogeneity controls along the chain, (ii) dynamic inventory

[†] www.minlnv.nl/txmpub/files/?p_file_id=2001236

management that tracks the quality of products, (iii) dynamic control of goods flow that adopts conditions and logistics to optimize market fulfilment (e.g. redirecting products to other markets having lower quality requirements), (iv) cold chain management that considers temperature or enthalpy controlled carriers, depots, (v) multiple temperature consideration for multiple products, (vi) product interferences consideration (e.g. bananas produce ethylene that accelerates the ripening process of other fruits), (vii) monitoring temperature history for accurate quality predictions, (viii) customer requirements consideration for specific markets, (ix) use of specific quality decay models, and (x) waste management that considers spoilages.

2.3 Improved sustainability and traceability

Addition of sustainability and traceability concerns to the key logistical aims of the FSCM phase leads to the need for a new approach, SFSCM. The Kyoto Protocol setting binding targets for industrialized countries can be given as a recent step of governments towards achieving sustainable development [‡]. The European Union is also an influential proponent of sustainability (Linton *et al.*, 2007). Consciousness of consumers towards environmental and societal issues put pressure on companies to use sustainable practices, since world population is growing, climates are changing and natural resources are depleting. Also, nutritional content of products (Helms, 2004), increased child labour and employment conditions are under discussion as societal issues. Seuring and Muller (2008) summarize the pressures and incentives for sustainability in supply chains (not only for FSCs) as follows: legislations, customer demands, response to stakeholders, competitive advantage, pressure groups and reputation loss. As a consequence, increasing sustainability awareness of stakeholders (Bettley and Burnley, 2008a) inevitably affects the (logistics) decision making process and operations in FSCs. As such, 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). However, it is obvious that the environmental and social dimensions of SFSCM must be undertaken with a clear and explicit recognition of the economic goals of the firm (Carter and Rogers, 2008; Wognum *et al.*, 2011).

The second key logistical aim, improving traceability, 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 moves through the SC (Mogensen *et al.*, 2009). This places emphasis on especially the people and planet aspects of sustainability. Legislations from governments or pressures from non-profit organizations aim to stimulate improved SC visibility in FSCs. A good traceability system can contribute to improved transparency by offering specific information regarding product and related processes to consumers (Fritz and Schiefer, 2009; Wognum *et al.*, 2011). Additionally, Fritz and Schiefer (2008) stress the importance of intensified cooperation and collaboration between the actors of the chain and improved monitoring of activities to achieve transparency and tracking and tracing of products and services throughout the value chain. This integration and monitoring can be enhanced with the use of new ICT tools to redirect the pattern of logistics operations[§].

The relevant logistics system scope covers the generic issues that needs to be considered while managing the aforementioned key logistical aims of SFSCM phase. Generic issues regarding the SCM and the FSCM phase need to be considered beforehand. The additional issues commonly related with the specific characteristics of SFSCM phase (given in Table 1) are: (i) use of impact assessment tools (e.g. Life Cycle Assessment Analysis (LCA) assesses impacts of operations associated with all stages of a product's life starting from-cradle-to-grave), (ii) sustainable food production consideration (e.g. using efficient machines that can reduce water use consumption or choosing production locations considering deforestation, land use issues), (iii) sustainable inventory management consideration (e.g. controlling energy use of cooling stocks in facilities (Akkerman *et al.*, 2010)), (iv) sustainable food transportation management consideration (e.g. considering GHG emissions, fuel consumptions of different transportation modes, new energy sources such as biofuels or noise, air pollution caused by vehicles (Dekker *et al.*, 2012)), and (iv) traceability possibility of products for improving transparency in FSCs (e.g. use of safety focused traceability systems).

[‡] http://unfccc.int/kyoto_protocol/items/2830.php
[§] http://www.internationaltransportforum.org/pub/pdf/02LogisticsE.pdf

Table 1.
Key logistical aims in SFLM

Phase	Key aims	Drivers & Enablers	Explanation of Key Aims	Logistics System Scope Issues	Literature
SCM phase	Cost reduction	Economic crisis resulting in low prices Globalisation resulting in world-wide competition Automation resulting in more efficient processes	The ability to minimize total global network costs from the source of supply to its final point of consumption.	Network design, Distribution channel choice, Outsourcing, Operational excellence, Inventory positions choice, Transportation alternatives and constraints, Production choices, Incorporation of uncertainty, Use of information technology.	(Beamon, 1998) (Cachon and Fisher, 2000) (Christopher and Juttner, 2000) (Chopra, 2003) (Chopra and Meindl, 2010) (Fisher, 1997) (Gunasekaran *et al.*, 2008) (Lambert and Cooper, 2000) (Simchi-Levi *et al.*, 2009)
	Improved responsiveness	Demand for more product variety, high frequent deliveries with short lead times and small batches Increased demand uncertainty New ICT tools that facilitate more advanced information exchange	The ability to have a flexible and robust system that satisfies customer orders in time and responds quickly to the dynamics of the global marketplace. Additionally, to cooperate and collaborate with the other supply chain members in a way that facilitates movement of information in timely, reliable and accurate manner.		
FSCM phase	Improved food quality	Demand for safe and high quality food products Health consciousness of consumers Year round availability of food Demand for more convenience products Technological improvements	The ability to control product quality in the supply chain and deliver high quality food products in various forms to final consumers by incorporating product quality information in logistics decision making.	**All the above +** Homogeneity controls, Dynamic inventory management, Dynamic control of goods flow, Cold chain management, Multiple temperature consideration for multiple products, Product interferences consideration, Monitoring temperature history, Customer requirements consideration, Use of specific quality decay models, Waste management.	(Akkerman *et al.*, 2010) (Blackburn and Scudder, 2009) (Dabbene *et al.*, 2008) (Hafliðason *et al.*, 2012) (Trienekens and Zuurbier, 2008) (Van der Vorst *et al.*, 2000) (Van der Vorst *et al.*, 2007) (Van der Vorst *et al.*, 2011) (Van Donselaar *et al.*, 2006)
	Reduction of food waste	Demand for high quality products with long shelf lives Increased food security concerns Pressure from global organizations	The ability to collaborate in the supply chain network to reduce food that is discarded or lost uneaten because the quality has deteriorated.		
SFSCM phase	Improved sustainability – Environmental concerns	Growth of world population Climate change Limited natural resources Escalating sustainability awareness	The ability to reduce environmental impacts (e.g. GHG emission, energy use, water use, air pollution, deforested land, land availability and noise) of operations and to facilitate new energy sources such as biofuels.	**All the above +** Use of impact assessment tools, Sustainable food production consideration, Sustainable inventory management consideration, Sustainable transportation management consideration, Traceability possibility of products.	(Bettley and Burnley, 2008b) (Chaabane *et al.*, 2012) (Dekker *et al.*, 2012) (Fritz and Schiefer, 2009) (Helms, 2004) (Linton *et al.*, 2007) (Nepstad *et al.*, 2006) (Wang *et al.*, 2011) (Wognum *et al.*, 2011)
	Improved sustainability – Societal concerns	Increased child labour Employment Escalating sustainability awareness	The ability to reduce societal impacts (e.g. nutritional content of products, employment opportunities, farm income) of operations.		
	Improved traceability	Recent food crises Legislation	The ability to have complete visibility of all relevant product and process characteristics in the chain allowing to track and trace products throughout all stages in a supply chain.		

3 Currently Available Quantitative Models on (S)FLM

After identifying key logistical aims and related generic logistics system scope issues, this section focuses on quantitative models for FLM and SFLM. Following the paper selection method given in section 1, 36 relevant papers were selected that were used for the analysis. First, we present the main characteristics of the reviewed models (Table 2), followed by an analysis of the KPIs (Table 3) and logistics system scope issues (Table 4) considered in the models for each of the key logistical aims.

3.1 Modelling Characteristics

In recent years Operations Management and Operations Research literature has shown a growing interest in FSCM (Akkerman *et al.*, 2010). Correspondingly, the number of studies using food logistics models is increasing. In this study, we investigate the quantitative models with respect to the main characteristics (Table 2) summarized below:

Modelling type: Researchers develop various types of models to facilitate the decision making process and enable companies' operations to be carried out in a systematic way. The distribution of model types used in the batch of 36 papers are as follows: (i) Mixed Integer Programming (54% of all models), (ii) Analytical (20%), (iii) Simulation (11%), (iv) Linear Programming (6%), (v) Multi Objective Programming (6%), and (vi) Goal Programming (3%).

(Non)linearity: Except for a few studies that have non-linear terms in their models, most researchers use linear models. Investigating extensions of the same approach to nonlinear cost structures (Ahuja, 2007) or building a different approach for tackling with dynamic problems (Dabbene *et al.*, 2008) are reasons to include nonlinear terms.

Solution approaches and tools: Apart from standard software programs (e.g. Cplex, Lindo), various heuristics have been developed to solve the models. Complexity of the problem (Eksioglu and Jin, 2006), large problem instances (Ahuja, 2007) or possibility to generate fast solutions (Rong and Grunow, 2010) lead researchers to consider heuristic approaches.

Application area: Almost all contributions have case studies. FSCs such as meat, dairy, and fruit are taken as application areas. *Real vs. Hypothetical:* Proposed models are implemented either by considering real or hypothetical data

Table 2.
Main characteristics of quantitative models in (S)FLM

	Model Type	(Non) Linearity	Solution Approaches and Tools	Application Area	Real vs. Hypothetical
(1) Gelders *et al.* (1987)	MIP	L	Fortran	Large brewery	R+H
(2) Zuo *et al.* (1991)	MIP	L	MPSX/MIP packages, Fortran, Heuristic	Corn	R
(3) Van der Vorst *et al.* (1998)	Simulation	U	U	U	R
(4) Van der Vorst *et al.* (2000)	Simulation	U	U	Chilled salads	R
(5) Brown *et al*. (2001)	MIP	L	Heuristic	Cereal and convenience foods	R
(6) Gebresenbet and Ljungberg (2001)	Analytical	U	Route LogiX	Agriculture	R
(7) Jansen *et al.* (2001)	Simulation	U	Arena	Catering	R
(8) Tarantilis and Kiranoudis (2002)	Analytical	U	Mic.Visual C++, Heuristic	Meat	R
(9) Wouda *et al.* (2002)	MIP	L	U	Dairy	R
(10) Apaiah and Hendrix (2005)	LP	L	Gams	Pea-based novel protein foods	R
(11) Ioannou (2005)	LP	L	Lindo, Excel solver	Sugar	R
(12) Eksioglu and Jin (2006)	MIP	L	Cplex 9, Heuristic	U	H
(13) Higgins et al. (2006)	MIP	L	Fortran 95, Heuristic	Sugar	R
(14) Ahuja (2007)	MIP	NL	Cplex 7.0, Greedy heuristic	U	H
(15) Bilgen and Ozkarahan (2007)	MIP	L	ILOG's OPL - Cplex 8.0	Wheat	R
(16) Hsu *et al.* (2007)	MIP	L	Several Algorithms	Lunch box	H
(17) Zanoni and Zavanella (2007)	MIP	L	Cplex 6.6, Heuristic	U	H
(18) Azaron *et al.* (2008)	MOP	NL	Goal attainment technique-Lingo	Wine	H
(19) Dabbene *et al.* (2008)	Analytical	NL	A specific optimisation algorithm	N	N
(20) Osvald and Stirn (2008)	Analytical	L	Heuristic	Vegetables	H
(21) Ahumada and Villalobos (2009b)	MIP	L	AMPL - Cplex 10	Pepper-tomatoes	H
(22) Akkerman *et al.* (2009)	MIP	L	U	N	N
(23) Blackburn and Scudder (2009)	Analytical	U	U	Melons and sweet corn	R
(24) Chen *et al.* (2009)	MIP	NL	Mic.Visual C++ 6, Lingo 10.0	U	N
(25) Van der Vorst *et al.* (2009)	Simulation	U	ALADIN TM	Pineapples	R
(26) Bilgen and Gunther (2010)	MIP	L	ILOG's OPL - Cplex 11.2	Fruit juices and soft drinks	H
(27) Oglethorpe (2010)	GP	U	MS Excel Solver	Pork	R+H
(28) Rong and Grunow (2010)	MIP	L	Cplex 10.2, Heuristic	U	H
(29) Wang *et al.* (2010)	MIP	NL	Heuristic	Cooked meat-bakery	R
(30) Ahumada and Villalobos (2011)	MIP	U	Cplex	Bell peppers and tomato	H
(31) Bosona and Gebresenbet (2011)	Analytical	U	GIS- Route LogiX	Local food producers	R
(32) Rong *et al.* (2011)	MIP	L	ILOG's OPL - Cplex 10.2	Bell peppers	R
(33) Yan *et al.* (2011)	Analytical	U	U	U	H
(34) Zucchi *et al.* (2011)	MIP	L	Gen. Alg. Mod. Sys. 22.5 with Cplex	Beef	R
(35) You *et al.* (2012)	MOP	L	E-constrained method, Cplex 12	Cellulosic, Ethanol sector	R
(36) Zanoni and Zavanella (2012)	Analytical	L	U	Fried potato	R

MIP: Mixed integer programming, LP: Linear programming, MOP: Multi objective programming, GP: Goal programming, U:Unspecified, N:None, L:Linear, NL: Nonlinear, R:Real, H:Hypothetical

3.2 Models for cost reduction and improved responsiveness

The reviewed literature shows that total logistics cost incurred and variance of the total logistics cost are the main KPIs considered in models aimed at cost reduction (Table 3). All quantitative studies try to redesign logistics operations with the aim of minimizing SC costs in the food logistics system. Costs can be classified as production, inventory, distribution and other costs. Other costs represent food-specific costs such as milk collection, biomass drying or by-product credit costs. Additionally, authors (Ahumada and Villalobos, 2009b; Blackburn and Scudder, 2009; Rong *et al.*, 2011) regard costs of food quality decay, cooling, wastage and product loss as part of the main cost groups. Apart from the main cost groups, Rong and Grunow (2010) also incorporate batch dispersion costs into their model to solve the trade-offs between reducing production costs of products and reducing the concerns for food safety. Distinct from other studies, Azaron *et al.* (2008) also adopt the minimization of the variance of the total cost into a multi-objective model to increase the robustness of the model.

According to the literature review, the following KPIs are considered in models to improve responsiveness: on-time delivery, late delivery, missed sales, order cycle time (lead time) and transport carriers utilised (Table 3). Most models in literature aim to ensure on-time delivery of customer orders using deterministic assumptions and known demand without incorporating uncertainty (Table 4). Constraints on production time are discussed by Ahumada and Villalobos (2009b) and Bilgen and Gunther (2010), including strict deadlines such as a specific production lot that has to be finished up to a particular day or maximum order cycle time. Moreover, Van der Vorst *et al.* (2000) emphasise shortening cycle times (lead times) and increasing the execution frequency of business processes.

Researchers use different approaches for managing the late deliveries and missed sales found in models under stochastic assumptions. Some examples are (1) keeping track of percentage delivered on agreed time (Jansen *et al.*, 2001), (2) considering losses in goodwill for violation of delivery time (Chen *et al.*, 2009) and (3) number of missed sales caused by stock-outs (Van der Vorst *et al.*, 1998). Regarding late deliveries, Blackburn and Scudder (2009) also introduce the Marginal Value of Time (MVT) rate to measure the cost of a unit time delay in a SC. This means that researchers want to control backorders or missed sales that lead to decreased responsiveness. Opposite to this, Dabbene *et al.* (2008) consider cost of earliness from early delivering to demand points as this may lead to stocking problems. In literature time windows constraints are set for managing the challenges of late or early deliveries (Chen *et al.*, 2009; Osvald and Stirn, 2008).

Another KPI, order cycle time (lead time), refers to the time that elapses from the moment an order is placed to the moment ordered goods are received (Van der Vorst *et al.*, 1998). Researchers incorporate lead time into models by considering parameters such as transportation distances (e.g. Gebresenbet and Ljungberg (2001), Osvald and Stirn (2008)), required transportation times (e.g. Hsu *et al.* (2007), Dabbene *et al.* (2008)) or required production times (e.g. Wang *et al.* (2010)).

Utilisation of transport carriers can also improve responsiveness by shortening cycle times for customer deliveries. Gebresenbet and Ljungberg (2001) consider empty driving, load capacity utilization level in terms of volume and motor idling times during stoppage. Moreover, Akkerman *et al.* (2009), and Gebresenbet and Ljungberg (2001) refer to the contribution of transport utilization on environmental impact in terms of CO_2 emissions.

Researchers put logistics system scope boundaries in accordance with the logistics problem under consideration and their objectives. Logistics system scope issues considered in quantitative models for SCM phase are presented in Table 4. Our analysis is as follows:

- Production, transportation and inventory, which are the main logistical drivers in a SC (Chopra and Meindl, 2010), can be regarded as main modelling decisions. Most studies use an integrated approach of production, transportation and inventory management with the aim of generating synergy, building an integrated view and improving the efficiency of all interrelated processes (Eksioglu, 2002; Mula *et al.*, 2010).
- In quantitative models the main question to be answered in terms of production is: how much to produce in each production plant? Apart from that, a few studies incorporate decisions such as workers required in a specific period for cultivating product (Ahumada and Villalobos, 2009b) or available labour restrictions (Ahumada and Villalobos, 2011) as workforce scheduling issues. Additionally, some studies manage multiple products with the same model (e.g. Brown *et al.* (2001), You *et al.* (2012)). Researchers also consider batch size/setup number decisions to get more insight in the problem (e.g. Rong *et al.* (2011), Wang *et al.* (2010)). Furthermore, a few studies incorporate production facility location decisions into their models (e.g. Gelders *et al.* (1987), Zucchi *et al.* (2011)).

- ❖ The foremost issue in terms of transportation is determining transportation amounts in each channel. In response to the evaluation of multi-mode transportation networks, some studies consider different transportation alternatives such as road, train, air simultaneously (e.g. Apaiah and Hendrix (2005), Bilgen and Ozkarahan (2007)). These kinds of models offer decision makers more flexibility and ease of cost minimization and on-time delivery opportunities while managing the whole network. In addition to that, dual sourcing (e.g. Ioannou (2005), Zuo *et al.* (1991)), transhipment between facilities (e.g. Wouda *et al.* (2002)) and indirect shipments (e.g. Higgins *et al.* (2006), Tarantilis and Kiranoudis (2002)) are also possible.
- ❖ A few studies incorporate stochastic elements into their models. Demand (e.g. Ahuja (2007)), lead time (e.g. Van der Vorst *et al.* (2000)), supply and costs (e.g. Azaron *et al.* (2008)), and SC behaviour (e.g. Dabbene *et al.* (2008)) are the stochastic elements considered in the studies.

3.3 Models for improved food quality and reduction of food waste

The reviewed literature shows that degraded food quality, temperature level changes and enthalpy level changes are the KPIs considered in models for the key logistical aim of improved food quality (Table 3). The problem of perishability, sometimes even leading to food waste, affects almost all operations along the FSCs. Entrup *et al.* (2005) give an example to illustrate this challenge. Increasing yoghurt freshness requires producing as close as possible to the demand date. At best, each product is produced daily. However, this type of production causes smaller lot sizes and higher costs, since significant set-up costs occur in yoghurt production. For these kinds of effects, attempts have been made to incorporate product quality decay in food logistics models (Table 3). The aim of these studies is coping with the quality decay challenge while managing the logistics operations.

Most studies in literature, such as Zanoni and Zavanella (2007); Eksioglu and Jin (2006), assume that product quality diminishes linearly and is deemed useless after a specific time period. This means that as long as products are above the pre-specified minimum levels, they are regarded as acceptable. Additionally, the model does not penalize the product deliveries with a short remaining shelf life. However, either part of the purchased goods cannot be sold on the market or only with a lower price because of continuous quality degradation (Osvald and Stirn, 2008). To avoid these problems and to encourage the freshness of deliveries, a few studies consider the cost of inventory lost while being transported (Ahumada and Villalobos, 2009b; Ahumada and Villalobos, 2011; Osvald and Stirn, 2008). Additionally, Van der Vorst *et al.* (2009) measure the product quality when the product arrives at the retail store as a KPI by checking the remaining selling time at the retail outlet. Moreover, rather than assuming simple linear decay, for instance Rong *et al.* (2011) use a quantitative quality decay model based on the Arrhenius equation, which is a remarkably accurate formula for the temperature dependence (Chang, 1981), to manage quality changes.

Among the studies that handle the perishability problem in their models, some studies (e.g. Rong and Grunow (2010) and Van der Vorst *et al.* (2009)) also include temperature control of the products to determine optimal temperature settings in a supply network (Table 3). In these studies, product quality decays depend on the temperature levels. This means that the magnitude of quality change for alternative temperature conditions is assumed to be known in advance as a parameter. Moreover, Akkerman *et al.* (2009) state that enthalpy level control is easier than temperature controls. Therefore, they include enthalpy level tracking to their models in addition to temperature control.

According to the literature review, the KPI considered in models to improve the key logistical aim of food waste reduction is food waste occurred (Table 3). A few of the studies in literature refer to the potential food waste problem (Table 3). Among those studies, You *et al.* (2012) and Rong *et al.* (2011) explicitly integrate the food waste calculations into their models. In these aforementioned studies, products that lose their suitable freshness are discarded and food waste or waste disposal costs are incurred.

Logistics system scope issues considered in quantitative models for the FSCM phase are presented in Table 4. Our analysis is as follows:

- ❖ In order to manage continuous quality change in FSCs, quality tracking possibility is considered and incorporated into the models (e.g. Eksioglu and Jin (2006), Yan *et al.* (2011)). This consideration unsurprisingly affects the logistics decisions, because of shelf life constraints (Ahumada and Villalobos, 2011; Rong *et al.*, 2011).
- ❖ Studies that track quality and consider inventory decisions mostly employ dynamic inventory management. This allows them to manage a real-time inventory system (Van der Vorst *et al.*, 2000) that tracks the quality levels of inventories in each period (Ahumada and Villalobos, 2011).
- ❖ Some studies consider temperature or enthalpy controlled carriers or depots (e.g. Akkerman *et al.* (2009), Blackburn and Scudder (2009)). This leads them to consider additional factors such as energy

usage rates of those carriers or additional costs. Additionally, only Bosona and Gebresenbet (2011) attempt to manage multiple products by considering different temperature levels.

- Different quality decay models are used depending on the specifications of the related product (e.g. Hsu *et al.* (2007), Dabbene *et al.* (2008)), in order to manage perishable products more efficiently.
- Although handling quality decay, most studies assume that products are delivered before spoilage. However, a few studies incorporate possibility of quality fall below the minimum levels that results in food waste (e.g. Van der Vorst *et al.* (2009)). In addition to that, one study (You *et al.*, 2012) also considers waste treatment units.

3.4 Models for improved sustainability and traceability

For the key logistical aim of improved sustainability, the reviewed literature shows that GHG emitted, fuel consumed, energy used and water used (as environmental dimensions), and nutritional content of products (health impacts) and number of accrued jobs (as societal dimensions) are the KPIs considered in the models (Table 3). Although sustainability is not a new concept for both business world and society, research in this field is regarded as in its infancy period by scholars (Linton *et al.*, 2007). Our literature review also supports that argument as we found only a small number of quantitative studies dealing with SFLM (Table 3). Studies that consider the new emerging sustainability goals in FLM attempt to deal with the above mentioned environmental and/or societal concerns in addition to economic objectives.

All of the studies (see Table 3) measure GHG emissions by a single indicator in terms of either carbon dioxide emissions (CO_2/year) (e.g. Akkerman *et al.* (2009)) or carbon dioxide-equivalent (CO_2, CH_4, and NO_x) emissions (CO_2-eq/year) (e.g. You *et al.* (2012)) (Table 4). The common aim of these studies is controlling and reducing the CO_2 emitted to the environment from the logistical operations. Vehicles during transportation (Gebresenbet and Ljungberg, 2001; Van der Vorst *et al.*, 2009) or processes related with production management such as blending, drying, storing (You *et al.*, 2012) can be given as examples for those logistical operations that cause CO_2 emissions (Table 4). For instance, Gebresenbet and Ljungberg (2001) consider transport distance, speed, load, road conditions with respect to slope and motor idling time. The related environmental impact is expressed in kg CO_2 per mile travelled or per product. You *et al.* (2012) point to the importance of life cycle stages of products to be included in emission rates estimations. For this reason, they integrate LCA analysis with multi objective optimization.

Energy use in models, usually expressed in MJ per second/per ton km, relates to operations in logistics system. Those models either focus on energy consumption from maintaining temperature (e.g. Zanoni and Zavanella (2012)) or operations such as heating, lightening or machine use (e.g. Oglethorpe (2010)) (Table 4). The common aim of the studies is reducing the energy consumption throughout the chain while maintaining operations (Table 3). Additionally, Oglethorpe (2010) links the energy use with emission calculations by assuming that energy use of processing operations equals a specific amount of CO_2 emission per kg of output. A few studies also include controlling the consumption of water, an important natural resource, in the chain (Table 3) using water restriction constraints (Ahumada and Villalobos, 2009b; You *et al.*, 2012). As a final environmental KPI, only Bilgen and Ozkarahan (2007) consider fuel consumed during logistics operations. They take fuel consumption as one of the transportation cost input among others i.e. hire cost of vehicle, government charges.

In literature, only two studies aim to manage nutritional contents of products. Apaiah and Hendrix (2005) consider protein content and Oglethorpe (2010) consider fat content of products. In addition, in (Oglethorpe, 2010; You *et al.*, 2012), the number of accrued jobs, which is expressed as hours and full-time equivalent jobs per year respectively, is used as a societal objective.

According to the literature review, batches traced is the KPI considered in models to improve the key logistical aim of improved traceability (Table 3). Bilgen and Gunther (2010) emphasize a need in FSCs to assign demand to daily delivery periods rather than weeks because of shortened replenishment cycles and quicker replenishment times. For this reason, they stress that completion of production lots has to be traced on a daily time scale. They introduce auxiliary binary decision variables, which indicate that the specific production lot has been finished on a specific line up to a particular day. Rong and Grunow (2010) work on a different problem and support the idea that traceability systems have to be complemented with suitable production and distribution planning approaches. They include a parameter called batch ID to their models, allowing the model to get information on batch number, product type, production time, and production location for each product. They aim to determine the number of batches, the batch sizes and which batches are delivered to which retailers in each period with this information.

Logistics system scope issues considered in quantitative models for SFSCM phase are presented in Table 4. Our analysis is as follows:

- Except for one study (You *et al.*, 2012), researchers do not use any tool such as LCA for defining more accurately the related environmental and societal impacts of logistics operations. This results in omitting or mishandling effects of some operations to the environment and/or society.
- Although fuel consumption rate is one of the most important competitive factors in logistics management, it is not modelled. Only one study (Bilgen and Ozkarahan, 2007) implicitly mention fuel consumption. Apparently, models consider fuel consumption calculations under the total transport cost, however this leads to losing the chance to assess explicitly the amount of fuel used which is crucial in terms of environmental sustainability.
- Societal issues are less addressed than environmental issues in quantitative models. The main reason for this is the challenge of measurement and quantification of societal issues.

Some studies (e.g. Ahuja (2007), Rong et al. (2011)), assume that models can trace product batches of different quality throughout the logistics network

Table 3. Key performance indicators in (S)FLM

			1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SCM Phase	Cost reduction and improved responsiveness	Total logistics costs incurred	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Variance of the total logistics cost																		✓																		
		On-time delivery	✓	✓				✓		✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Late delivery				✓			✓							✓		✓		✓	✓				✓	✓	✓											
		Missed sales			✓		✓																															
		Order cycle time (lead time)			✓	✓	✓	✓	✓	✓						✓		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
		Transport carriers utilised			✓	✓		✓	✓	✓									✓			✓											✓					
FSCM Phase	Improved food quality and reduction of food waste	Degraded food quality			✓	✓								✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓
		Temperature level changes																✓			✓			✓	✓		✓			✓	✓	✓	✓	✓				✓
		Enthalpy level changes																						✓														
		Food waste occurred																									✓				✓			✓			✓	
SFSCM Phase	Improved sustainability and traceability	GHG emitted						✓																✓			✓		✓								✓	
		Energy used																✓						✓			✓		✓									✓
		Water used																					✓						✓								✓	
		Fuel consumed															✓																					
		Nutritional content of products										✓																	✓									
		Number of accrued jobs																											✓								✓	
		Batches traced			✓	✓								✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓

*Numbers refer to studies listed in Table 2.

Table 4. Logistics system scope issues of quantitative models in (S)FLM

			1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SCM Phase	Cost reduction and improved responsiveness	Production amounts	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Production capacity		✓		✓	✓				✓	✓	✓		✓	✓	✓			✓	✓		✓	✓	✓							✓	✓	✓		✓	✓	
		Workforce scheduling																					✓									✓						
		Multiple product			✓	✓	✓	✓	✓		✓	✓			✓		✓		✓				✓			✓		✓				✓	✓				✓	
		Batch size/setup number				✓								✓											✓		✓	✓		✓	✓			✓	✓			✓
		Production facility location determination	✓								✓									✓													✓			✓	✓	
		Transportation amounts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Transportation capacity		✓		✓		✓	✓	✓	✓				✓	✓	✓	✓	✓		✓	✓			✓	✓		✓	✓			✓	✓				✓	
		Multi-mode transportation										✓					✓						✓		✓		✓					✓		✓			✓	
		Dual sourcing possibility		✓			✓					✓	✓				✓						✓				✓			✓		✓	✓	✓		✓	✓	
		Transhipment possibility between facilities					✓				✓		✓																									
		Indirect shipment possibility	✓	✓				✓	✓	✓					✓		✓	✓				✓				✓		✓										
		Inventory levels			✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓		✓	✓	✓		✓	✓		✓	✓
		Inventory storage capacity in facilities											✓		✓	✓					✓		✓	✓				✓						✓			✓	
		Incorporation of uncertainty			✓	✓			✓							✓		✓		✓	✓					✓	✓											
FSCM Phase	Improved food quality and reduction of food waste	Quality tracking possibility			✓	✓								✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓		✓	✓
		Dynamic inventory management			✓	✓								✓		✓		✓	✓		✓		✓				✓			✓	✓	✓		✓	✓		✓	✓
		Temperature or enthalpy controlled carriers, depots																✓			✓			✓	✓		✓			✓	✓	✓	✓	✓				✓
		Multiple temperature for multiple products																															✓					
		Use of specific quality decay models																✓			✓				✓		✓			✓		✓		✓				✓
		Possibility of quality fall below the minimum level																									✓				✓			✓			✓	
		Waste treatment units																																			✓	
SFSCM Phase	Improved sustainability and traceability	LCA analyses																																			✓	
		Emissions from transportation						✓																✓			✓		✓								✓	
		Emissions from other operations (e.g. production, storing.)																									✓		✓								✓	
		CO^2 emissions						✓																✓			✓		✓									
		CO^2-equivalent (CO^2, CH^4, and NO^x) emissions																																			✓	
		Fuel consumption															✓																					
		Energy consumption for maintaining temperature																✓						✓			✓		✓									✓
		Energy consumption for heating, lightning and ext.																											✓									
		Water use																					✓						✓								✓	
		Product content consideration										✓																	✓									
		Employment consideration																											✓								✓	
		Traceability possibility of products			✓	✓								✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓

*Numbers refer to studies listed in Table 2.

4 Quantitative Modelling Challenges

Section 2 first identified key logistical aims and related generic logistics system scope issues in FLM (Table 1). Then, section 3 analysed currently available quantitative models with respect to their general characteristics (Table 2), KPIs (Table 3) and relevant logistics system scope issues (Table 4). In this section, we aim to point out modelling challenges based on the assessment of the above mentioned models.

Most literature studies rely on a completely deterministic environment (Table 4). This assumption allows decision makers to achieve 100% on-time delivery (Table 3). Researchers have not shown yet interest in late deliveries or missed sales, which are crucial KPIs of logistics management in terms of improving responsiveness (Table 3). This approach is understandable since deterministic models can be developed and solved relatively easy. However, in the real world most SC members in the food industry are confronted with several uncertainties i.e. information availability and data timeliness, supply, process and demand uncertainties (Van der Vorst *et al.*, 2000) (Table 1). Therefore, deterministic assumptions do not fully capture the complexity of real world problems, which might hinder their applicability. For instance, a model with deterministic demand will allow inventory reductions. Assuming no demand variation will result in minimized cost solutions by reducing inventory levels. However, SC responsiveness requires adaptation to changes in customer demand or in the marketplace, so attention should be paid to incorporating variabilities in the model's relevant logistics system scope issues. In addition to that, companies need to evaluate trade-offs between cost and responsiveness, so losses in goodwill or costs of time delays should be carefully studied.

One of the main concerns of FSCs, continuous quality degradation, appears in almost two third of all reviewed literature with an increasing rate in recent years (Table 3, 4). The challenge of including food quality decay shows itself in models. Most models roughly take product perishability into account by using linear quality decay models, solely depending on time. However, increasing customer concerns on food safety necessitates more sensitive and detailed quality decay models that consider the intrinsic product conditions. In response to that, only a limited number of researchers employ quality decay models that explicitly include product parameters, time, and environmental factors (Table 4). Integrating those kinds of quality models into the logistics models will enhance the value of models, since they will provide more reliable results to the decision makers. Furthermore, almost no researchers show interest in the food waste problem, occurring at almost all stages of the FSC (Table 3). Incorporating the option that product quality falls below the minimum level will help these models to approach real life problems and issues much better than before.

So far, research in sustainable logistics has received insufficient attention (Table 3,4). Approximately, only one third of the studies has environmental or societal repercussion considerations. As expected, the researchers' tendency to incorporate sustainability into logistics models has increased in recent years, but this has been insufficient. Only a few models incorporate sustainability KPIs into their models but ignore other relevant indicators (Table 3) and/or logistics system scope issues (Table 4). For instance, in terms of GHG emission reduction, researchers mostly focus on CO_2 emissions (Table 4). However, integrating also other GHGs such as methane (CH_4), nitrous oxide (N_2O) and fluorinated gases will improve the applicability of the proposed solutions [*]. Furthermore, the use of environmental and societal impact assessment analyses such as LCA has a huge potential to improve the validity of the sustainable logistics models (Table 1). After determining the key impact categories and relevant logistics system scope issues for reducing negative repercussions of operations on the environment and society, researchers can incorporate them into models and search for the improvement opportunities.

Most literature studies propose single objective models for the related logistical problems in FSCs (Table 2). However, real life problems consist of multi objectives, which are in conflict with each other. For instance, it is common to see attempts, which are either obligatory or voluntary due to carbon taxes or environmental awareness, for decreasing GHG emissions from logistics operations. Unsurprisingly, those attempts in either case come at a cost to companies. The challenge is managing the additional objective of reducing emission levels together with SC cost. It is also possible to give other examples incorporating multi-goals such as cost vs. responsiveness, cost vs. quality, quality vs. sustainability. These examples present the necessity of multi objective perspectives in logistics models and researchers could use multi objective programming models to deal with such cases.

Finally, determining the system boundary is a careful job in FLM. If the target of a model is to improve the sustainability performance of logistics operations, the proposed solutions should also satisfy economic expectations of stakeholders. This means that the ideal model for SFLM generally should incorporate all of

[*] http://www.epa.gov/climatechange/emissions/index.html#ggo

the key logistical aims that are explained in detail in the previous sections (Table 1). A few attempts to simultaneously deal with challenges regarding the three phases (SCM, FSCM and SFSCM) have been found in literature. However, those attempts have not fully captured the relevant KPIs and logistics system scope issues (Table 3, 4). Even, we have observed that some logistics system scope issues (outsourcing possibility, product interferences consideration, Table 1) are not handled by any of the quantitative models. Thereby, performances of the proposed models can be improved by incorporating more KPIs and more logistics system scope issues related to the problem.

5 Conclusion

FSCM is in general a complex process owing to the intrinsic characteristics of food product and processes of FSCs and the fast moving and highly competitive food sector. Especially in last years, in addition to the existing challenges, FSCs have been confronted with the increased attention for sustainable development. Many drivers such as legislation, customers' awareness and non-profit organizations' pressure have pushed companies to seek ways to reduce their environmental and societal impacts. Unsurprisingly, addition of sustainability concerns into the FSCM decision making process has made it more complicated and challenging than before. Inevitably, food logistics systems are also affected by the progress starting from traditional SCM to FSCM and now further progressing to SFSCM.

In this paper, we have reviewed quantitative studies in FLM in a structured way. To the best of our knowledge, this is the first literature review on SFLM that has covered the contributions considering the development from SCM to FSCM towards SFSCM. We can conclude from this work that the research on SFLM has been developing according to the needs of the food industry. The number of studies that consider KPIs and logistics system scope issues regarding recent needs of the food sector has been increasing. However, are these studies adequate to aid decision making process and capture FSC dynamics? We highlight that current FLM literature is insufficient to respond to these practical needs. Generally, the intrinsic characteristics of food products and processes have not been handled properly in the studies. The majority of the works reviewed have not contemplated on sustainability problems, apart from a few recent studies. To conclude, new and advanced models for SFLM are needed that take specific requirements from practice into consideration to support business decisions and capture FSC dynamics. Better logistics models can improve food quality and safety, availability of food, and create sustainable and efficient business networks, which are the main issues faced by stakeholders in FSCs.

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