Accepted Manuscript

Agribusiness Supply Chain Risk Management: A Review of Quantitative Decision Models

Golnar Behzadi, Michael Justin O'Sullivan, Tava Lennon Olsen, Abraham Zhang

PII: S0305-0483(16)30274-2
DOI: 10.1016/j.omega.2017.07.005
Reference: OME 1804

To appear in: *Omega*

Received date: 2 June 2016
Revised date: 25 June 2017
Accepted date: 8 July 2017

Highlights

- Providing the first literature review of risk management models specifically for agribusiness supply chains.
- Focusing on specific sources of uncertainty in agribusiness industries.
- Providing new implications and further directions for developing the research in the context of agribusiness supply chain risk management.
- Providing the first literature review of risk management models specifically for agribusiness supply chains.

Agribusiness Supply Chain Risk Management: A Review of Quantitative Decision Models

Golnar Behzadi*[a], Michael Justin O'Sullivan[a], Tava Lennon Olsen[b], Abraham Zhang[c,d]

[a] *Department of Engineering Science, Faculty of Engineering, The University of Auckland, Auckland 1010, New Zealand*
[b] *Information Systems and Operations Management, Business School, The University of Auckland, Auckland 1010, New Zealand*
[c] *Auckland University of Technology (AUT) Business School, AUT, Auckland 1010 New Zealand*
[d] *Department of Management Systems, University of Waikato Management School, Hamilton 3240, New Zealand*

Abstract

Supply chain risk management is a large and growing field of research. However, within this field, mathematical models for agricultural products have received relatively little attention. This is somewhat surprising as risk management is even more important for agricultural supply chains due to challenges associated with seasonality, supply spikes, long supply lead-times, and perishability. This paper carries out a thorough review of the relatively limited literature on quantitative risk management models for agricultural supply chains. Specifically, we identify robustness and resilience as two key techniques for managing risk. Since these terms are not used consistently in the literature, we propose clear definitions and metrics for these terms; we then use these definitions to classify the agricultural supply chain risk management literature. Implications are given for both practice and future research on agricultural supply chain risk management.

Keywords: Agribusiness supply chain, risk management, robust, resilient

1. Introduction

In the past two decades, supply chain risk management (SCRM) has emerged as an important research topic [1]. Several reasons are behind this development: 1) globalization has made supply chains longer and more complex; consequently, supply chains are now exposed to more risks and have become more vulnerable; 2) the lean management philosophy has become widely implemented in many industries; this philosophy advocates waste elimination/minimization and embraces just-in-time production/logistic; although it improves supply chain efficiency, the removal/reduction of redundancies has resulted in greater supply chain vulnerability under adverse events; and 3) the world has paid increasing attention to the many supply chain disruptions that have been caused by catastrophic events (e.g., [2, 3, 4, 5]).

Agribusiness plays an indispensable role in the world's economy as a key source of food supplies. Agribusiness products have three specific characteristics that make risk management for agribusiness supply chains (ASCs) more complicated when compared to risk management for typical manufacturing supply chains. These characteristics are seasonality, supply spikes (sometimes referred to as "bulkiness"), and perishability. Dealing with seasonality requires planning as growth is seasonal whereas consumption is throughout the year. Further, most agricultural products have long supply lead times that cannot be easily altered against nature. Harvesting and post-harvest activities, including packing, processing, storage, and transportation, can be very demanding because of supply spikes. Furthermore, there is often significant time pressure on post-harvest activities as most agricultural products are perishable. Also, because of the perishability, there is a need for specific handling, storage, and inventory management. If not properly managed, a delay in transportation may cause substantial loss of product value.

In addition to product specific characteristics, risk management is important for ASCs because they often involve more sources of uncertainties than manufacturing supply chains [6]. In an ASC, the supply process is related to biological production (food crops, meat, etc.), which is affected by weather variability (e.g., droughts), disease (e.g., Psa kiwifruit disease), and pests (e.g., locusts). Such factors imply that both harvest levels and harvest times are subject to uncertainties. In addition, these factors can impact on the quality of the produce. In particular, in the processing stage, there are special risks associated with food quality and food safety (e.g., botulism risks). These uncertainties make ASCs more vulnerable than typical manufacturing supply chains. Furthermore, recent practices in agribusiness have added to the complexity of ASCs, thus making the application of risk management strategies more critical [7]. Such practices include the use of new marketing strategies (e.g., in product differentiation/proliferation) and the interlinked design of global supply chains [7].

This paper fills a gap in the literature by providing a review of quantitative models for ASC risk management. Our focus is on risks at the supply chain level, and related risk management methodologies for ASCs that foster resilience and robustness, terms that we will carefully define. We review different quantitative risk management (RM) approaches that provide resilience and robustness for a variety of agricultural products. As pointed out by [3] and [1], there are a lot of inconsistencies in the meanings of SCRM terms. One contribution of this review is to suggest metrics for resilience and robustness.

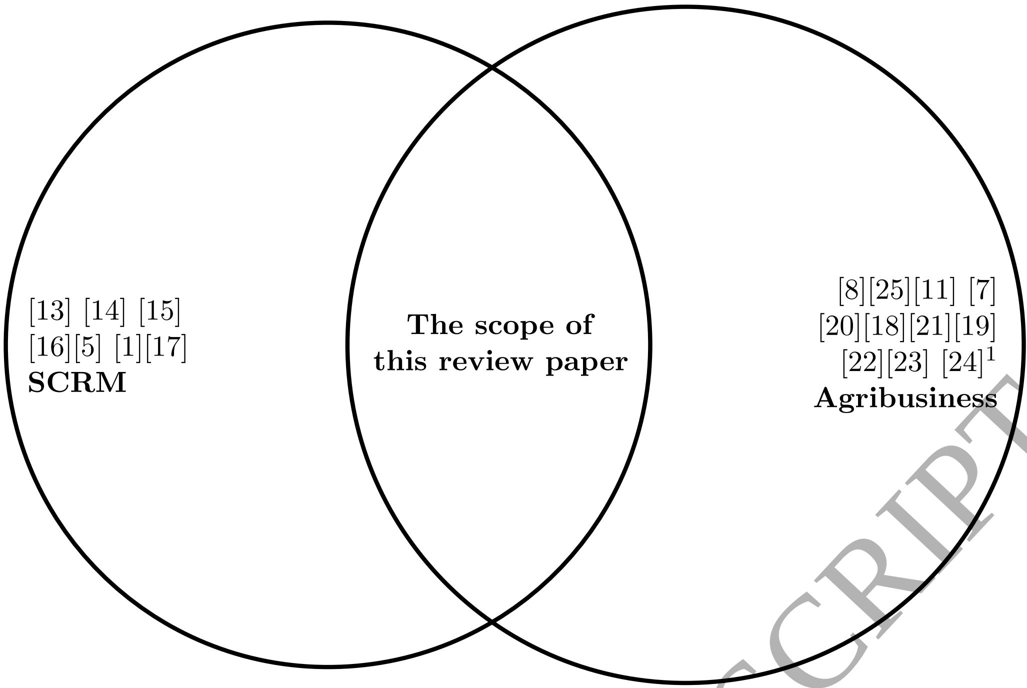
The remainder of this paper is organized as follows. Section 2 outlines the scope of our review in Agribusiness Supply Chain Risk Management (ASCRM) and reviews related survey papers. The key concepts and terms in this review are defined in Section 3. Section 4 classifies the available modeling studies in ASCRM according to different aspects of product type, risk types, risk measures, and RM strategies (i.e., robustness and resilience). In this section, modeling approaches are further analyzed for different types of agricultural products. At the end of Section 4, a specific overall summary of the section is provided that identifies gaps in the research literature. The paper is concluded in Section 5 by proposing directions for future research.

2. Literature

Applications of quantitative models in agricultural problems date back to the 1950s and have been addressed widely in the literature [8, 7]. Modeling approaches in agribusiness have been predominantly used for problems related to transportation, distribution, harvesting, facility location, and farm planning (e.g., [9, 10, 11, 12]), with a specific focus on farm planning problems. Key considerations in agricultural problems (i.e., yield, harvest time, demand, etc.) are influenced by different sources of uncertainty such as weather conditions, animal or crop diseases, and price variability. Although, as described in the following, there are separate and extensive review studies on both quantitative risk management and agribusiness models, we are not aware of any review paper thus far on SCRM models in agribusiness, which is the topic of our review.

Articles [13], [14], [15], [16], [5], [1], and [17] reviewed the bulk of the quantitative SCRM literature, mostly in the context of manufacturing industries. Agribusiness decision models have been reviewed in the areas of production, harvesting, and distribution [8, 7, 18, 19], facility locations [11], supply-side resource utilization [20], ASC planning challenges [21], and operational issues that result in post-harvest waste [22]. Further, [23] reviewed quantitative ASC models in the contexts of: planting, harvesting, production, distribution, and inventory; [24] extended the review of agribusiness problems (in the context of supply chains) in considering factors of uncertainty. However, neither of the review papers discuss risk management strategies, so cannot be considered as reviews of SCRM. Thus, as depicted in Figure 1, to the best of our knowledge, there is no review specific to quantitative models in the joint area of SCRM and agribusiness. As mentioned above, this overlap will be covered by our review paper.

Figure 1: Venn diagram on the research gap in literature reviews/survey papers



Note that risk management is not new to agribusiness planning. For instance, [26, 27] introduced the basic concepts of risk management in agriculture. Further, [25] reviewed farm decision-making under risk from several aspects such as utility functions, farmer risk preferences, and response approaches to both short-term and long-term uncertainty. However, the main concern of these aforementioned studies was farm level risks and uncertainties, whereas we have focused on risks at the supply chain level.

We reviewed papers from different journals in Operations Management (OM), Operations Research (OR), Supply Chain Management (SCM), and agriculture. We searched the Scopus database using combinations of keywords including "risk management," "quantitative risk management," "supply chain," "operations research," and "agribusiness". In addition, we went through all the papers surveyed in the review papers from Figure 1 for SCRM papers with an agribusiness application (left hand side survey papers) and agribusiness papers that focused on SCRM (right-hand-side survey papers). We defined supply chain broadly as any paper that modeled multiple locations or firms.

We believe [28], published in 1993, is the first quantitative study in the field of agribusiness that considered risks in supply chains, although without directly referring to the term "supply chain."

[1] Article [24] reviews agribusiness problems in supply chain structures and includes uncertainty attributes; however, as risk management strategies have not been clearly discussed in this review, the review has not been categorized under the SCRM section.

Before that, risks in agribusiness had only been discussed at the farm level (see [26]). Article [28] studied a vegetable processing supply chain problem with two echelons that consider production, trimming, and processing decisions under uncertain climatic factors. In contrast with [28], most of the reviewed papers after 2000 have explicitly referred to the term supply chain in their studies.

As 1993 appeared to us to be a late date for a first study, we carried out further research on the timing of the field. The term "supply chain management" appears to have first been used in an interview in the Financial Times in 1982 [29]. However, the concept of multi-echelon inventory control was addressed well before the introduction of "supply chain management (SCM)" [29]. Our search on "multi-echelon" and "agribusiness" yielded no RM papers earlier than [28]. It appears that when a flurry of articles and books came out on the subject of SCM in the mid-1990s, the concept began to be used in other fields of study, such as agribusiness. However, a recent review on SCRM indicates that the concept of risk management has still received noticeably less attention in the field of agribusiness and biological sciences compared to fields such as engineering, decision sciences, and business [1]. The latter statement has been supported by the findings of our review that particularly focused on agribusiness supply chain risk management studies. Table 1 lists the main issues addressed in the literature of quantitative SCRM modeling in agribusiness from 1993 until the present, ordered by decreasing publication date.

Table 1: Summary review of the literature in quantitative ASC risk management

Reference	Issue addressed
[30]	Single-period, multi-product food production planning model (with applications in cocoa/wheat/palm oil/corn/soybean supply chains) that maximizes the expected profit of the processing firm by determining the procurement policy under fixed proportional production.
[31, 32]	Handling model for an export-oriented Canadian wheat supply chain that provides safety and quality assurance under minimum farmers' total cost including cost of: loss at test point, contamination penalty, and risk control effort.
[33]	Supermarket-farmer coordination model in an agricultural commodity supply chain that distributes the profit and improves its effectiveness.
[34]	Supply planning model for linseed oil processor in a polymers production supply chain that maximizes the expected profit under raw material quantity/quality and market demand uncertainty.
[35]	Buyer-backup supplier coordination model that maximizes the expected profit by determining the buyer firm's reserve quantity and the backup supplier's installed capacity in a single-period (short-life) food supply chain.
[36]	Multi-period capacity management model that maximizes the expected revenue of an agri-food processor (the palm oil mill) by determining processing/storage capacity investments for the first period and periodic inventory decisions for the following periods.
[37]	Production, transportation, and marketing model that minimizes the expected total cost of production by determining the delivery waiting time for the final product and the processing time of production in a perishable fresh-crop supply chain.
[38]	Post-harvest logistics management model for respiring, deteriorating fresh crops that maximizes the total expected inventory and shortage costs, by determining proper lot-sizes for finished products in RTIs (return transport items) and selling price during the deterioration process, under a stochastic lead-time of receiving RTI from buyer, in a closed-loop supply chain.
[39]	Aggregate production planning for a frozen orange juice supply chain that minimizes the total cost of supply, inventory, and shortage under uncertainty in citrus juice acidity specification.
[40]	Production planning model for a biofuel supply chain that maximizes expected profit by determining purchasing, processing, and production decisions.
[41]	Robust supply chain design model applied in an agricultural (rice) supply chain that maximizes expected profit and minimizes the ratio of performance deviation to a variation of uncertain parameters by determining supply chain flow and location decisions.
[42]	Single-period farming, procurement, and process planning model that maximizes expected profit in the processing firm by determining proper ordering quantities of all sources and their corresponding processing rates in a cocoa production supply chain.
[43], [44]	Multi-period operational production and distribution planning model in a crop (i.e., tomato and bell pepper) supply chain that maximizes the growers' expected profits during harvest under uncertainty by making a trade-off between freshness and cost.[43] extends [44] by considering various sources of uncertainty, particularly on a crop's price and yield.
[45]	Multi-objective stochastic model for a hydrocarbon bio-refinery supply chain that minimizes the annual cost and financial risk by determining network design, technology selection, production investment, and planning decisions.
[46]	Closed-loop supply chain design model with applications in both food and high-tech manufacturing industries that minimizes the total supply chain cost under uncertainty associated with purchase costs and demand.
[47]	Fuzzy network design in a consumable vegetable oil supply chain that minimizes the total transportation cost and labor sources under probabilistic warehousing or refinery capacities and market demand.
[48]	Tactical planning model for an olive oil supply chain that maximizes expected profit by determining farm areas and best seeding times.

Summary review of the literature in quantitative ASC risk management continued

Reference	Issue addressed
[49]	Single-period multi-product meat supply chain design model that maximizes the packer's expected profit, plant utilization, and animal non-uniformity given procurement, processing, and production decisions.
[50]	Production planning model for multi-period, multi-product (perishable/powder) dairy supply chain that maximizes the expected profit by determining the optimal sales policy.
[51]	Single-period production planning model that maximizes the expected return by determining the optimal amount of space to be leased for production and the quantity of olives to be provided from external sources under yield and yield-dependent cost uncertainties in a Turkish olive oil supply chain.
[52]	Investment and production planning model in a single-period biofuel supply chain that maximizes the expected profit by determining investment decisions in a processing plant and flow decisions along the supply chain.
[53]	Robust aggregate production planning model that minimizes the total cost of production, staffing, inventory, transportation, and shortage and maximizes the customers' satisfaction in a wood and paper production supply chain under uncertainty associated with cost parameters and demand.
[54]	Inventory model under supplier-retailer collaboration on demand forecasting in a perishable agri-food supply chain that maximizes the expected profit by determining an optimal replenishment policy.
[55]	Robust optimization model for harvest planning in a grape (wine) supply chain under yield (harvest productivity) uncertainty that maximizes the expected profit by determining the optimal labor assignments at different harvest-blocks and times.
[56]	Enterprise decision model (i.e., to join to or form a co-op) in a dairy supply chain that maximizes the expected income of farmers by determining co-op decisions (about size, conditions, and product quantity), production, and shipment planning.
[57]	Winery allocation model in a wine supply chain that maximizes the expected profit composed of sales and salvage value minus total production, packaging, and storage costs under demand uncertainty.
[58]	Contract model between a large seed supplier and multiple retailers in a seeds supply chain that maximizes the expected total channel of profit by determining contract parameters that result in supply chain coordination.
[59]	Inventory model for perishables in a fresh vegetable supply chain that maximizes expected profit by determining the optimal planting batch in each harvest period.
[60]	Robust multi-site, medium-term production planning model that minimizes the expected total cost for the producer including costs of production, labor, workforce change, shipment, and inventory by determining shipment, inventory, sale, and labor decisions in a cotton/silk (lingerie) supply chain.
[61]	Production planning model for a premium-brand tomato supply chain that maximizes the expected profit and meets the minimum service level by balancing overage cost, especially related to perishability, and underage cost of lost customers.
[62]	Capacity management and logistic network design model for an export fruit supply chain that maximizes throughput by determining the optimal flow between nodes and investigating the possibility of a capacity extension.
[63]	Production planning and scheduling model in a multi-commodity fruits/juices (apples and pears) supply chain that maximizes the expected sales' income by determining storage, process, and sales policies.
[64]	Investment management in a concord grape and juice production supply chain that minimizes the expected total cost of underage and overage through a trade-off between overinvestment and lack of capacity by determining the optimal pressing rates.
[65]	Single long-period (two-year) production planning model that maximizes expected sales in an olive oil supply chain by determining optimal leased farms and the production policy.

Summary review of the literature in quantitative ASC risk management-further continued

Reference	Issue addressed
[66, 67]	Sequential two-period newsvendor harvest/inventory planning model in a hybrid seed-corn supply chain that maximizes the margin by determining the number of acres in each period (in the 2003 version the model has been extended to multi-product production planning).
[68]	Production planning model in an Ilium flower supply chain that maximizes the expected total revenue by determining quantities of varieties of bulbs and flowers in each stage of the supply chain.
[69]	Facility location/allocation model that minimizes the expected production and transportation costs under a green production scheme, uncertain daily demand, and scenarios of supply failures in a dairy (raw milk) supply chain.
[70]	Medium-range horizon multi-period production planning model in a tomato supply chain that minimizes the total packing cost for the packing plant and the penalty cost for the delayed harvest.
[28]	Multi-period production model in a vegetable processing supply chain that minimizes the total harvest and production cost and meets capacity and market limitations by determining harvesting, flow, processing, and logistics decisions.

As demonstrated in Table 1, quantitative agricultural risk models have been discussed in various contexts of farm management, production management, scheduling, and pest/disease management for supply chains in different crops/livestock. The following characterizes this work further and highlights gaps for future research.

3. Agribusiness SCRM Classification Terms

In this section, we identify the key concepts of our review in agribusiness supply chain risk management (ASCRM). In particular, we describe different aspects that have been discussed in the reviewed papers, which include: product types, risk types, and approaches to the modeling and management of risk. In Section 4, we use these aspects to classify the papers in Table 1.

3.1. Agribusiness Supply Chain Product Types

An agribusiness supply chain encompasses all components of a "farm-to-fork" process for a given food product; these include various stages related to supply, production, post-harvest, storage, processing, distribution, and linkages between components. Thus, the basic concepts are similar to manufacturing supply chains. However, the additional characteristics of ASCs (as described in Section 1, especially perishability) can make ASCs relatively more complex.

ASCs can be classified into different classes by the types of products produced. Some agricultural food products are referred to as crops (and sometimes agri-food crops) and include products obtained directly from plants. Other agricultural products such as cattle, meat, or seafood are known as livestock.

The livestock category also includes dairy products (e.g., milk, cheese) and non-food products (e.g., wool, hair, silk). Importantly, both livestock products and crops are either perishable or long-life. For example, fruits, fresh vegetables, and meat products are perishable. However, wheat and wool are considered to be long-life. Perishable crops can be further classified into respiring or non-respiring products and perishable livestock is divided into three classes of fresh, chilled, and frozen products. Within agri-foods, respiring crops and fresh livestock products are extremely prone to risk because of their particular biological characteristics. In Figure 2, we illustrate the classification of different products within ASCs.

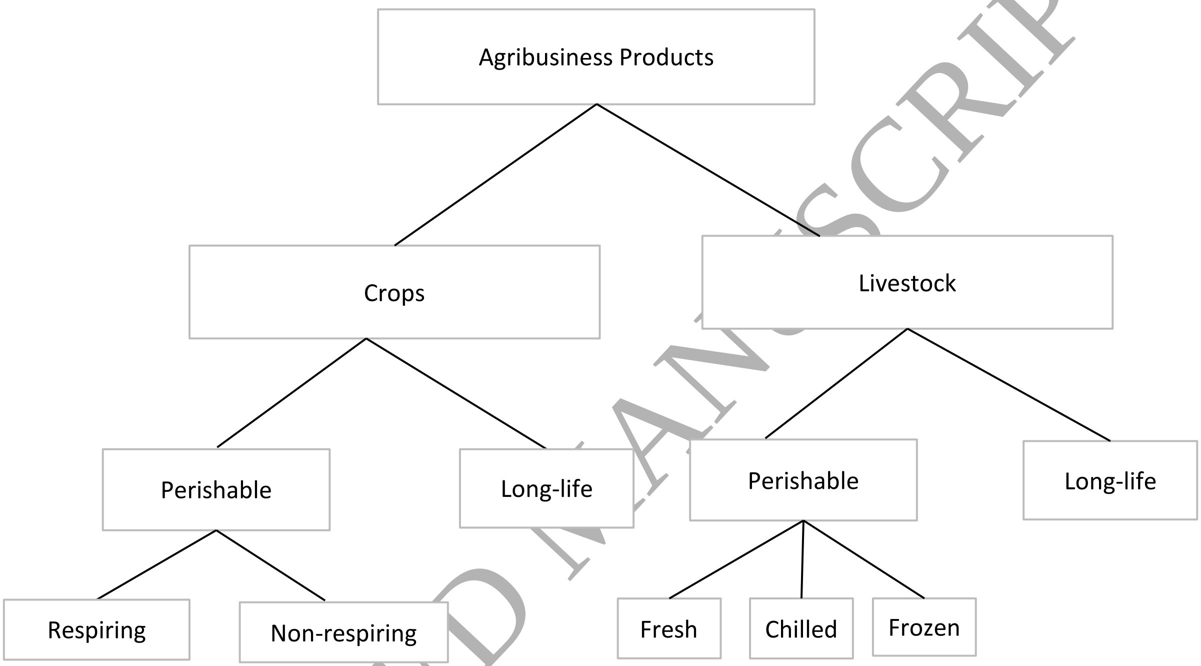


Figure 2: Product classification of ASCs

Although crops and livestock are common product classifications for ASCs (e.g., in [6]), from a modeling standpoint, agricultural products can be classified as perishable or long-life because models that include perishability are often quite different from those that do not. Within the perishable category, there are second-order characteristics, such as respiring versus non-respiring (for crops) and fresh versus chilled/frozen (for livestock, e.g. meat), that can also be considered when modeling perishability. In Section 4, we will divide the literature into long-life and perishable products. First, in the following subsections, we highlight the modeling differences between these two categories.

3.1.1. Long-life Agricultural Products

The basic modeling difference between long-life and perishable agricultural products is that models in the category of long-life agriculture products are usually considered in multiple periods over a long time horizon. Studies in the context of risk management for long-life agricultural products are aimed at a variety of decisions such as crop planning, harvest and cultivation scheduling, capacity investment, production planning of processed foods, food handling, and facility location. Two recent representative examples of such work include [32] and [30].

Article [32] studied a handling problem for an export-oriented Canadian wheat supply chain that considers safety and quality issues. They developed a supply chain model to determine appropriate testing strategies by minimizing the farmer's total costs including the cost of loss at a test point, a contamination penalty, and a risk control effort under risks of a farmers' misrepresentation of data and technological failure. They proposed a simulation approach in the context of ASC with detailed assumptions including assumptions on an individual farmer's behavior.

A second example of an ASC risk model in the context of long-life agriculture is provided by [30]. They investigate a capacity management problem in a palm oil supply chain. The model is developed as a multi-period supply chain that maximizes the expected revenue of an agri-food processor (the palm oil mill) through a dynamic stochastic programming approach with a series of two-stage models. The optimal solution is found by determining processing/storage capacity investment decisions in the first period, and making inventory decisions under yield and price uncertainties in the remaining periods. Their model compares three capacity portfolios that address processing dominated, storage dominated, and mixed processing policies.

3.1.2. Perishable Agricultural Products

Risk management approaches for perishable agriculture products require particular consideration because of the additional level of vulnerability associated with perishability. A simple approach to deal with perishability and short lifecycles is newsvendor modeling (i.e., through a single-period inventory management model). One recent representative example of such modeling is [49], who discuss procurement strategies in a beef supply chain in order to minimize the packer's expected cost under yield and demand uncertainty. They studied mixed spot and contract strategies under single period planning. The newsvendor model is used to reflect the perishability of beef products. Under the optimal solution, the expected total cost of the beef packer is minimized by determining procurement, processing, and production decisions.

Perishability can also be modeled over multiple periods by considering estimation approaches on the remaining shelf-life/freshness of the agricultural products at risk. Such models are capable of tracing the impact of a disruptive event or risk from one planning period to another. However, shelf-life/perishability modeling considerations increase the complexity of the proposed mathematical models.

A recent example of a multi-period model is [37]'s study of a fresh fruit producer that sells to local and international markets under known (Make-To-Order: MTO) or uncertain (Make-To-Stock: MTS) demands and transportation disruptions. In this problem, the international market is more profitable but has the risk of transportation failures. Such failures affect both unfinished (ordered, not yet processed), and finished (processed, not yet delivered) products. Indeed, the waiting time until delivery is an important threat for perishable products. Thus, the key decision is whether to wait or to sell the finished product in the local market at a discounted price. However, for unfinished products, the decision is made on whether to slow down or change the process to adjust to a suitable delivery time. These decisions are made to prevent perishability and loss, and ultimately, minimize the expected total cost of the production system.

3.2. Supply Chain Vulnerability and Risk

Supply chain vulnerability is "the propensity of risk sources and risk drivers to outweigh risk mitigation strategies, thus causing losses and adverse supply chain consequences" [71]. Hence, vulnerability is a "function of certain supply chain characteristics such as supply chain density, complexity, and node criticality" that affects both the probability and the severity of supply chain risks [72]. The latter definition highlights varying origins of vulnerability and risk. Vulnerability is a concept that depends on the characteristics of the underlying supply chain, and risk is an external threat [5]. Thus, vulnerability management could result in both reducing the probabilities of being affected by various risks and the levels of their impact.

In ASC problems, risks and vulnerabilities have been discussed in various contexts such as yield, cost (supply-side), and price (demand-side) variability for different agricultural products. Perishability, as a key ASC characteristic, can impact on all these uncertainties; for instance, price can be affected by changes in perishability. Generally speaking, there are two categories of risk events: high probability low consequence (HPLC) events versus low probability high consequence (LPHC) events [73]. HPLC events are often referred to as business-as-usual risks. LPHC events are risks that stem from severe disruptions to normal practices. Many types of agribusiness risks (e.g., pests) can be seen in both varieties of HPLC (e.g., mild infestations) and LPHC (e.g., locust swarms). HPLC and LPHC events are both important as they can both occur in various supply chains. Hence, both types of risk need to be considered in ASCRM approaches. However, most studies focus on only one of these risks. One exception is [74] who define supply delay uncertainty (i.e., delayed supply that is still available within the time horizon – HPLC) and supply shortage disruption (i.e., supply that is not available within the time horizon – LPHC) in a dynamic supply portfolio selection problem.

In addition to these two categories, different types of risks may be further defined. Article [75] defines five regular types of risks: 1) supply; 2) process; 3) demand; 4) intellectual property; and 5) behavioral, political, and social. In a similar vein, [76] characterizes risks as: risks which are internal to the firm, namely process and control risks; risks which are external to the firm, but internal to the supply chain: demand or supply risks; and, finally, external risks related to the environment. While all of these risks are relevant to agribusiness, operational and disruption risks of supply/demand are particularly pertinent. This criticality stems from the additional vulnerability in agribusiness supply/demand-related elements such as supply quantity, cost, quality, market demand, price, etc.

According to [77], supply-side risks can be further categorized into five forms: 1) disruptions; 2) yield uncertainty; 3) capacity uncertainty; 4) lead-time uncertainty; and 5) input cost parameter uncertainty. In ASCs, yield and lead-time uncertainty are particularly important (often as business as usual risks). However, severe variations in either yield or lead time (or both) represent disruptions and need to be planned for as such. For example, uncertain factors such as weather conditions regularly affect crop yields, but unusual weather conditions (e.g., a hurricane) can produce an extremely low yield, which represents a disruption rather than a normal yield uncertainty.

Article [78] describes food supply risks in the following contexts: product contamination and recall, loss of access due to terrorism, loss of access due to protests, loss of site, reduced capacity (e.g., production capacity shortfalls when sites are compromised), loss of people, loss of supplier, and reduced contractual cover in the event of a service failure or general shortage. According to [79], terrorist threats to food supply are very real and current threats have significant global consequences. Pests and diseases could also be considered as another source of risk. As an example, in the case of kiwifruit, supply has been disrupted by Pseudomonas syringae pv. actinidiae (Psa) a bacterial disease of kiwifruit vines that caused disruptions to worldwide kiwifruit production (e.g., Italy in 1992/2008 and New Zealand in the early 2010s) [80].

Further supply risks can stem from the failure or unavailability of some inexpensive items. For instance, shortage of a cheap tool in a manufacturing industry may damage production and results in a significant loss in supply chains. These kinds of risks are referred to as hidden risks [81]. In agribusiness, the massive use of industrial agriculture (i.e., large, highly specialized farms with large inputs of fossil fuels, pesticides, and other chemicals derived from oil) can be considered a hidden risk. In fact, most of the costs from industrial agriculture have been ignored in short-term calculations of performance, but serious long-term consequences for the agribusiness system as a whole include damage to natural systems and increasing health risks [82].

In contrast to supply risks, agricultural demand risks can be viewed in terms of market and price uncertainty, e.g., in processed agricultural foods [49, 42]. Demand risks stem fundamentally from the variable and unpredictable expectations in markets as highlighted in the review by [83]. In addition, demand uncertainty may relate to major disruptions (e.g., by LPHC events). For instance, demand risks such as market/brand failure may result in demand disruptions. Moreover, demand-side risks could stem from supply-side risks, especially when supply risks are related to safety issues that may significantly impact the perceptions of the public and their associated demand (e.g., recently, concerns for the safety of milk powder produced by Fonterra in the botulism scare of 2014 led to massive product recalls and cast a shadow on the reputation of the entire NZ dairy industry) [84].

In summary, both supply-side and demand-side risks are crucial in agribusiness. Given the natural uncertainty in ASCs and the severe impacts of disruptions on ASCs, demand and supply disruptions need a particular focus. Section 4 classifies the risks considered in the reviewed papers as supply and demand side risks.

3.3. Supply Chain Risk Management

Broadly speaking, a risk management process includes the following steps: 1) risk identification; 2) risk assessment; 3) decision analysis (i.e., how decisions are affected by risks under different scenarios); 4) mitigation; and 5) contingency planning [75]. In the initial steps, the risk identification and assessment process should be comprehensive enough to evaluate all types of risks, including hidden risks, because of their possible disruptive impacts on the supply chain (as described in Subsection 3.2). A comprehensive risk assessment may be achieved through a vulnerability map that maps the probable catastrophic events with their associated likelihoods and consequences [81].

In [75]'s definition of a structured evaluation process for implementing a risk-related strategy, the final two steps of the risk management process (i.e., Steps 4 and 5) recognize two main groups of SCRM strategies; these are mitigation (i.e., proactive/ pre-disruption strategies) and contingency strategies (i.e., reactive/ post-disruption strategies). Article [4] suggests that both preparation (i.e., mitigation) and first response (i.e., contingency strategies) are critical in minimizing the total impacts of risk in supply chains.

Article [85] divides risk mitigation strategies into three categories: inventory control (e.g., ordering and stocking decisions); sourcing (e.g., dual sourcing, product substitution); and acceptance. The acceptance strategy, i.e., not protecting against disruption, is considered when the cost of dealing with a disruption outweighs losses from the disruption (assuming cost is the main objective). Article [86] investigates optimal mitigation strategies for perishable products, i.e., when inventory control is not a possible option for mitigation because of the perishability concerns. In this case, one of the possible mitigation strategies is supplier diversification (i.e., routinely sourcing from multiple suppliers). Article [49] proposes a mitigation strategy for diversifying procurement from both contract and spot markets in a beef supply chain under optimal portfolio management decisions (i.e., procurement, processing, and production decisions). Although diversifying the supply sources is a common mitigation strategy under supply risks, it may not be effective when other objectives rather than cost or profit are considered. In particular, [87] considers an integrated supply and scheduling problem with a mixed integer bi-objective model and shows that, given a service-oriented model (i.e., when service level maximization is prioritized), a diversified supply strategy is less attractive than in the cost-oriented model given local and regional supply disruptions.

In contrast with what has been explained so far about mitigation strategies, the default strategy after risk materializes is reactive (i.e., contingency planning). This is particularly necessary when a supply chain operates without any concern about risks on a daily basis, but utilizes contingency plans (e.g., "fall back" suppliers or routes) when a disruption occurs. Reactive and contingency planning have been claimed to be critical in minimizing the crossover from risk management to crisis and event management [88, 89]. Article [86] discusses two approaches in contingency risk management: contingency sourcing (i.e., switching to backup suppliers) and demand switching (i.e., rerouting between demand markets or encouraging customers to buy an alternative product–product substitution) after a disruption takes place. Article [89] provides a qualitative framework for contingency risk management in the case of food supply chains. In doing so, they focus on six measures: the speed of response, communication, escalation, resource and fund availability, multi-partner collaboration, and leadership. In their study, speed of response (i.e., a measure of flexibility) varies according to the degree of risk impact on food safety.

In total, from a practical standpoint, sometimes reactive strategies are preferred. Although many researchers support proactive approaches in SCRM (see [90, 91, 92, 93, 78, 94]), there are notable gaps in the preparedness of organizations in practice as there is little investment into mitigation strategies [89]. One underlying reason for this lack of investment is related to justifying the cost of fixing problems that may never happen. In addition, proactive (mitigation) approaches focus on identifying and minimizing the impacts of the expected risks. Hence, these approaches require the use of predictive tools to identify risks, calculate probabilities of risks, and implement mechanisms for risk mitigation. In ASCs, due to their nature-based uncertainty, such predictions could be even harder to achieve [89].

Although studies in the context of SCRM often either address mitigation- or recovery-based strategies, in some studies both types of RM strategies have been considered; hence the optimal strategy could be varied given different problem settings [95]. For instance, a backup supplier strategy as a reactive strategy is addressed in [95] under supply capacity risks in an automotive supply chain problem. In [95], an alternative transportation capacity is also introduced as a recovery-based strategy. Article [95] studies mitigation strategies such as inventory holding (i.e., an increase in order-quantity) and additional warehouse or transportation capacity. As another example, [96] selects the primary supplier portfolio to mitigate possible suppliers' failures in advance; it also determines the selection of recovery suppliers (after disruption) to improve the service level, which is measured by both time and cost of recovery.

Mitigation and contingency risk management strategies are applied in supply chain problems through two modeling approaches, referred to as robust and resilient strategies. To define robust and resilient approaches in supply chains, we start by comparing these concepts to the well-known concept of leanness in a supply chain. As discussed in Section 1, lean supply chains provide great cost efficiency with minimum redundancy, except in cases of disruption. By definition, lean supply chains are also vulnerable. This is exactly in contrast to robust and resilient risk management strategies, which focus on decreasing the vulnerability of the network.

While not always used consistently in the literature, here we define robustness as an ability to withstand disruption with an acceptable loss of performance, whereas resilience is the potential to recover quickly from disruption. The key advantage of these definitions, as used here, is that robustness and resilience fit within the common overarching theme of risk management as described in [78]. In particular, robustness is a suitable capacity for managing business-as-usual risks (i.e., high probability, low impact risks), while resilience is suitable for disruption risks (i.e., low probability, high impact risks).

Robust strategies in the supply chain are considered as proactive and upfront RM options that mitigate risks and provide minimum variation in performance under disruption (e.g., [97, 98, 99, 14, 100, 101, 102]) that could be provided through approaches such as stochastic programming (e.g., [103, 104]) and robust optimization (e.g., [105, 106, 60]). In comparison, resilience is referred to as a post-disruption recovering capacity [107, 21, 108, 109], and stems from characteristics including flexibility, availability, velocity, and visibility [110]. Flexibility is a key measure in providing resilience that provides quick reactions to unforeseen circumstances [77]. Thus, time is an important component in the resilience concept. However, time-based resilience has received limited attention in the existing supply chain management literature (see [111] and [112] for examples). More details about robustness and resilience metrics will be discussed in Subsection 4.2.3.

3.4. Modeling Approaches for ASC Risk Management

In this section, we classify different mathematical modeling approaches for ASCRM. These modeling approaches have been selected according to their application in different agricultural problems. Our classification starts in Subsection 3.4.1 with the classical risk programming approach, called minimization of total absolute deviation, that has been used the most in farm planning problems. Other approaches to risk include game theory in Subsection 3.4.2, linear programming-based (LP) approaches (mixed-integer linear programming, multi-objective optimization, goal programming) in Subsection 3.4.3, stochastic programming, stochastic dynamic programming, and fuzzy optimization in Subsection 3.4.4, simulation in Subsection 3.4.5, robust optimization in Subsection 3.4.6, and other less common approaches in Subsection 3.4.7.

These modeling approaches are applied in ASC problems to adapt RM strategies including robustness and resilience under different types of operational and disruption risks as described in Subsection 3.3.

Most of the reviewed models in this section focus on business-as-usual uncertainty that is mitigated through robust strategies. The types of risks and the related RM strategies referred to through these models will be discussed further in Section 4.

3.4.1. MOTAD

Minimization of the total absolute deviation (MOTAD) provides an efficient frontier between expected profit and variance of the profit, under a quadratic programming (QP) model [113]. MOTAD is the most common approach in classical agriculture risk modeling, especially in problems such as crop planning. MOTAD minimizes the sum of negative deviations from a prefixed income target and was first introduced by [114] for the farm investment portfolio problem under return variability. Later, [115] suggested an extension to the [114] model in the form of either LP or QP instead of just QP.

Article [116] has developed a short-run crop planning model with MOTAD under cost, price, and yield uncertainty. The problem is formulated as a linear approximation to the original formulation. The risk programming portfolio model in the context of farm management has also been developed under some alternative distributional assumptions in the portfolio programming. This approach suggests a direct solution to the expected utility function of cropping activities under an average estimation of the farm-level situation [117]. Surprisingly, this old and common approach does not seem to have been applied to ASCs.

3.4.2. Game Theory

Game theory (GT) approaches address risk in two ways: 1) explicitly defining risk metrics and including these metrics in the game; and 2) creating coordination between players in a game, hence sharing and reducing risk for each player. According to [118]'s survey, game theory models were initially considered in agricultural problems as games that incorporate uncertainty in nature through a parametric game approach: one goal is optimized while the other is treated as a parametric constraint (e.g., minimizing the variance of the cropping pattern when the expected return is addressed as a parametric constraint). However, this classical GT approach to risk in agriculture was later criticized, for the reason that the applied decision criteria were incompatible with the principle of rational choice in their concerned case-studies [20]. Recently, game theory was applied in advanced food and agriculture studies, such as [33], which considers different coordination approaches between farmers and supermarkets under yield and demand uncertainties.

3.4.3. LP-based Approaches

There are different LP-based optimization methods used in modeling risk in agribusiness: goal programming (GP), multi-objective optimization (MOO), and mixed-integer linear programming (MILP). Before describing these methods, we give a brief, general description of LP models that are used in agribusiness studies.

LP is a method for the optimization of a linear objective function, subject to linear constraints [119]. LP is widely utilized in agribusiness models, mainly for the purpose of profit maximization under certainty in problems such as: land allocation, selecting cultivation techniques, labor or machinery allocation, production planning, cropping pattern selection, crop scheduling, and integrated production-distribution for seeding (e.g., [70, 69, 44]).

MILP is a generalization of an LP model where some of the variables are restricted to be integers [119]. In ASC problems in order to consider integer variables and capture failure scenarios (e.g., plant closure status via a binary variable), LP models have been extended to MILP models [69].

MOO is another optimization method that is used when more than one linear function needs to be optimized simultaneously [120]. GP is a branch of MOO that handles multiple, normally conflicting objectives (goals); then, each of these goals is given a pre-described target value and deviations from this set of target values are minimized [120]. While in LP and MILP methods the objective function is measured in one dimension, in GP goals with different priorities and weights that can be combined with each other in the objective function. There are a number of studies in the context of agriculture where LP models were extended to GP/MOO models to encompass risk attributes. In these models, performance (e.g., profit) maximization is not the only concern and risk minimization is considered as another objective, which is especially important in agricultural models. For instance, [121] develops crop planning as a GP model, with multiple objectives including risk avoidance, maintaining the minimum level of required food, and maximizing the farmer's profit.

3.4.4. Stochastic Programming/Stochastic Dynamic Programming

Uncertainty and risk can be captured by a stochastic programming (SP) approach, where right-hand-sides or coefficients related to the objective function/constraints, are uncertain. SP is a common approach in ASC models that seeks to model risks mainly in the category of business-as-usual uncertainty in parameters such as price, resource availability, and rainfall.

SP has various applications in agricultural problems that are described by the following representative examples. Article [122] develops an SP model for a cropping problem that considers a set of fresh vegetables with alternative harvesting schedules. In this model, variable weather (hence, indirectly yields), and prices are used to construct the random scenarios. Article [123] analyzes the capital structure and investment decisions in a farm problem by measuring liquidity risk, collateral risk, and credit-reserve risks via an SP formulation. Article [64] provides an SP model for a strategic harvest decision under uncertain crop size and harvest rates when both crop size and harvest rates are affected by weather volatility. Further, to support sequential decisions under realizations of supply and demand uncertainties, two-stage SP models have been applied in some recent studies in the context of agribusiness (e.g., [36] and [49] in the context of multi-product food production planning).

Considering uncertainty and risk parameters with decisions across different time periods has resulted in stochastic dynamic programming (SDP) approaches being used. Initially, SDP has been considered in agribusiness problems with possible periodic or repeated failures, e.g., a farm machinery replacement problem when machine failure is stochastic [124]. The earliest model of dynamic programming (DP) in the context of agriculture (crop planning) appears to be [125], which discussed periodic decisions on growing versus fallowing to determine sufficient levels of moisture in the soil during each growing period.

Some of the SDP applications in agricultural problems include: irrigation planning (under scarce water situations), cropping, and production planning. For example, [126] and [127] discuss the optimal water and capacity allocation model over time periods under uncertainty of different soil moisture level scenarios. In another example, SDP is applied in a periodic pest control problem when infected fractions of the plant are used to construct stochastic scenarios [128]. Recently, [36] discusses SDP models in a multi-period palm oil supply chain to provide optimal capacity management and suggest a periodic production plan.

In some other examples, the uncertainty incorporated in the optimization model relates to fuzzy parameters, e.g., frequently imprecise environmental uncertainties. Information about fuzzy parameters is often incomplete and/or unavailable over the problem horizon. In these circumstances, fuzzy set theory can be useful and has been used to incorporate uncertainty into RM models. The triangular function is one of the most common membership functions for describing fuzzy parameters and defines three possibilities for each fuzzy parameter. Article [47] defines a triangular membership function to capture fuzzy parameters for both supply-side and demand-side capacities in a vegetable oil supply chain problem.

3.4.5. Simulation

Simulation (SIM) has been mainly applied to scheduling/estimation problems in agriculture, e.g., harvest-time planning and transplant scheduling under uncertain ecological factors. Simulation approaches can be categorized as either multi-agent or system dynamics models.

In multi-agent models, the behavior of individuals (i.e., agents) is dictated by their schemata. According to [129], a schema is "a cognitive structure that determines what action the agent takes at time t, given its perception of the environment." System dynamics is another simulation-based approach to address the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, and time delays. The key difference of system dynamics, when compared with agent-based approaches, relates to the inclusion of structure in system dynamics versus the agents' rules in agent-based simulation [130]. In a recent study by [95], a system dynamics model is adopted for a multi-stage supply chain problem under network disruptions. Here, disruption scenarios are modeled through a continuous time function in the system dynamics model. Within the disruption scenarios, elements in the multi-stage supply chain are disrupted at different times and to varying extents. In fact, the network structure is dynamic where nodes and arcs may become unavailable for different durations. The model provides recovery policies by redirecting the material flow during the disruption. The optimal reconfiguration policies are determined by taking into account the performance impact of the disruption and the recovery costs.

Nevertheless, multi-agent simulation models are increasingly being used in agricultural resource problems, e.g., in socio-economic, environmental, and land-use problems as reviewed by [131]. Similarly, [132] and [133] studied planting problems by using a multi-agent simulation approach to provide biophysical estimation models under uncertainty.

Another application of simulation in the context of agriculture relates to food safety analysis. Articles [31, 32] discuss a multi-agent simulation model for a handling problem in a Canadian wheat supply chain under risk of farmer or technology failures to provide safety and quality assurance. Article [32] extended the static agent-based simulation model in [31] by proposing a corresponding dynamic approach that characterizes the wheat supply as a dynamic complex system. In such a dynamic wheat supply chain model, both farmers and handlers interact and respond to the unpredictable system changes over time. SIM is particularly useful in such a problem because the complex behavioral assumptions could not be inserted in a corresponding analytic model. Hence, the complexity of agribusiness problems encourages the use of simulation models to address the complex characteristics of ASCs more precisely. Article [32] compared solutions and policies generated using the SIM approach versus those generated by the alternative analytic model under restrictive assumptions about individual behavior. This study recognizes that although analytic and SIM approaches result in different solutions, in many respects, they reach similar conclusions on the proposed policy for test and quality control in the described case-study.

3.4.6. Robust Optimization

Article [105] used GP to perform robust optimization (RO), which involves two types of robustness: solution robustness and model robustness. In this approach, robustness is addressed proactively, i.e., “close” to optimal and “almost” feasible for all input scenarios. The RO model provided by [105] has been mainly applied to LP models. However, there is another type of RO introduced later by [134] that includes non-linear applications. Further, [135] provides a flexible adjustment in RO that reduces the level of conservatism related to suboptimal solutions for the nominal value in previous RO models (i.e., to ensure that the solution remains feasible and near optimal under all scenarios). The flexible adjustment in [135] is provided by considering ellipsoidal uncertainties, which involve solving the robust counterparts of the nominal problem in the form of conic quadratic problems (i.e., as a reasonable approximation to the complicated uncertainty set). This modified RO approach is called distributionally robust optimization. The distributional RO model sets up the first and second moments of the distribution as an uncertain parameter. One of the key factors in distributional RO is called the budget of uncertainty, which is the maximum number of parameters that can deviate from their nominal values and is especially used to mitigate demand uncertainty (e.g., in different customer zones).

RO has been applied to ASC problems recently in a limited context such as production planning, harvest planning, and facility location problems, mainly for long-life agricultural products [60, 55, 41]. In general, the key benefit of RO is to deal with uncertainty even if the actual information about uncertain parameters is limited, i.e., when SP could not be applied effectively (see [55]). Hence, it is expected to receive more attention in ASC modeling problems under examples of rare disruptions in this context.

3.4.7. Other Modeling Approaches

Safety-first models and chance constraints are among the other modeling approaches that have been applied in agricultural risk models, particularly in farm planning models under uncertainty, as described by [26, 27]. In safety-first models, the preference for safety as a measure of risk is satisfied first, and then decisions are made to maximize the profit. In the chance constraint formulation, the probability of the available resources is given by known distributions and the risk measure is forced to be above a satisfactory lower bound via the corresponding (chance) constraint.

3.5. Summary

In this section, we described the key concepts of the review related to both ASC and RM. We focused on ASCs by differentiating between the types of products and their different requirements in applying RM strategies. Under RM, attributes such as types of risks, strategies, and modeling approaches with particular applications in agribusiness have been discussed. The key aspects studied in this section form the basis for our classification approach to categorize the reviewed papers in Section 4.

4. ASCRM Paper Classification and Findings

In this section, we categorize the papers presented in Table 1 (in Section 2) using the concepts from Section 3. First, Subsection 4.1 describes the classification approach used in reviewing and categorizing these papers. Then, Subsection 4.2 presents the findings of the review by summarizing the results and providing specific implications/suggestions for future studies in the field of ASCRM.

4.1. Classification

In this section, we classify the papers that were initially identified in Table 1 according to the criteria depicted in Figure 3. These criteria were formally defined in Section 3. Figure 3 summarizes these criteria with the associated subsections from Section 3.

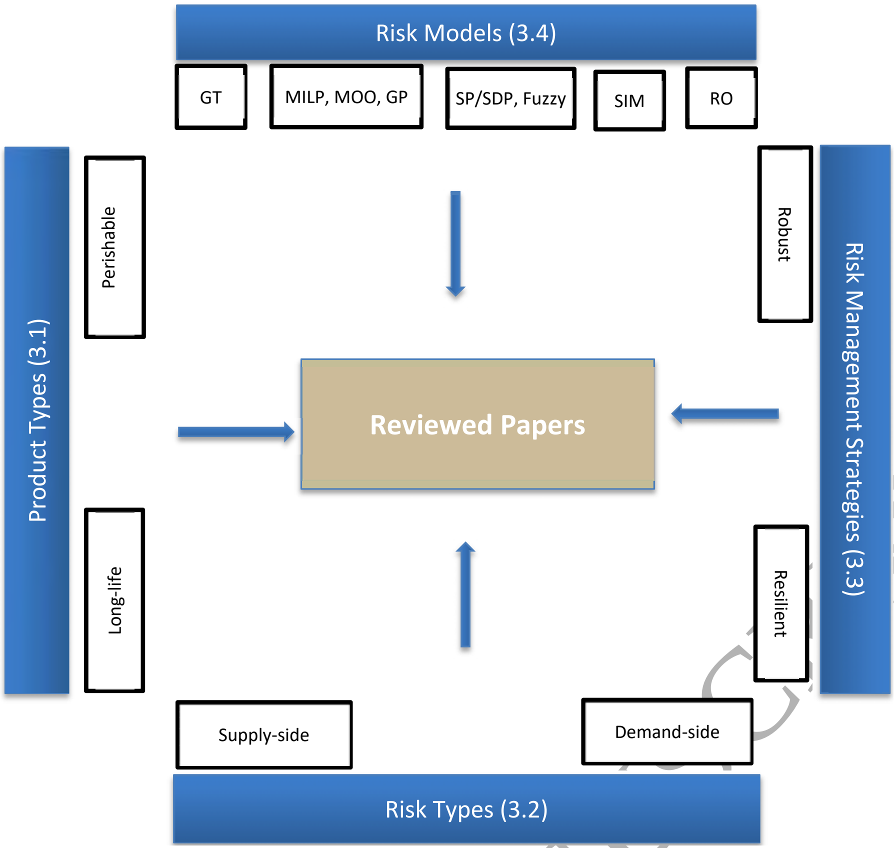


Figure 3: Classification of the reviewed papers

Figure 3 depicts a combination of aspects that we will use to classify the literature. According to the first criterion (i.e., 3.1 product type: long-life vs. perishable products), each paper is placed either in Table 2a or Table 2b. If the paper has been placed in Table 2b, the modeling/considerations towards perishability have also been briefly discussed in one column. Within Tables 2a and 2b the papers are categorized, through the associated columns, by other aspects (beyond perishability) of risk types (i.e., 3.2), modeling approach towards risk (i.e., 3.4), and an interpretation of whether the paper represents robust or resilient RM strategies (i.e., 3.3). Note that the concepts of robustness and resilience are interpreted for the reviewed papers based on the attributes and potential of their models and our given definitions for these terms, whether or not the terms are exactly used in the papers.

Table 2a: Detailed literature review on quantitative SCRM models for long-life agri-products

Author	Risk		Risk modeling	RM strategy (interpretation)		Remarks
	Supply-side	Demand-side		Resilient	Robust	
[31]	• Farmer's misrepresentation of quality in testing • Handlers' technology failures		SIM (static agent-based model)		✓	• Comparing results from simulation and analytic models
[32]	• Farmer's misrepresentation of quality in testing • Handlers' technology failures		SIM (dynamic agent-based model)		✓	• Comparing results from simulation and analytic models • [32] extends the study earlier provided in [31] by providing a dynamic agent-based model and addressing a comparison between the solution approaches in the analytical model with the corresponding simulation model
[33]	• Yield uncertainty		Game Theory		✓	• Providing an investment model using the Shapley value method
[30]	• Yield of fresh fruit palm bunch (under variable weather/ pest conditions) • Spot price uncertainty		SDP		✓	• Considering three capacity portfolio options: processing dominating, storage dominating, and mixed • Using SDP in a series of independent two-stage problems
[34]	• Raw material quantity • Raw material quality	• End-product price	Two-stage SP	✓		• Selection of the area for contract farming and reserved maximum amount for optional supply (stage 1) • Choosing whether to buy or not from the optional supply (stage 2) • Considering non-food application of renewable resources (instead of fossil resources) in polymers production
[40]		• End-product demand • Price of the end-product (geometric Brownian motion)	SP (Linear)		✓	
[41]	• Path based supply disruptions	• Demand size	RO (MILP)		✓	• Considering path-based variable • Considering different attitudes towards risk (i.e., risk neutral or risk-averse decision makers) • Evaluating the ratio of change in the normalized performance to the change in an uncertain parameter as a robustness measure • Considering robust optimization in [105] with the piece-wise linear method

Table 2a - Continued

Author	**Risk**		**Risk modeling**	**RM strategy (interpretation)**		**Remarks**
	Supply-side	Demand-side		Resilient	Robust	
[45]	• Feedstock Supply	• Biofuel demand	Two-stage SP		✓	• Providing a multi-objective stochastic model considering different attitudes towards risk (i.e., risk neutral or risk-averse decision makers) • Comparing risk measures of downside risk and $CVaR$ • Providing a trade-off between risk and performance measures
[47]	• Fuzzy supply-side capacities (in refinery and storage facilities)	• Fuzzy demand-side capacities (in refinery and storage facilities) • Fuzzy demand	Fuzzy multi-objective LP		✓	
[48]	• Maturation time • Harvest time • Yield	• Demand size	Two-stage SP		✓	• Considering both strategic and tactical decisions
[50]	• Milk supply		Multi-stage SP		✓	• Providing linear price-demand curve with dynamic outer approximation sampling • Selecting the planning horizon according to the maximum fixed storage time and ignoring deterioration during this time • Addressing uncertainty using an autoregressive model with random errors
[52]	• Biomass supply • Biomass cost	• Biomass demand • Biomass price	MILP		✓	• Comparing multiple design scenarios with a nominal design scenario as a robustness measure
[56]		• Demand (stochastic demand for each individual farmer)	SP		✓	• Comparing B2B and B2C strategies in a dairy supply chain
[53]	• Supply-side cost parameters	• Demand-side cost parameters • Demand size	Robust Optimization		✓	• Considering a multi-objective that minimizes total production costs and maximizes the customers' satisfaction by minimizing the sum of the maximum shortage in markets and periods • Solving MILP as a single objective by using the LP-metric method
[57]		• Demand (scenario-based)	Two-stage SP		✓	• Addressing seasonality of production in winery farms • Applying a postponement strategy in the finishing process (i.e., labeling and packaging) to mitigate risk of customized demand uncertainty

Table 2a - Continued

Author	Risk		Risk modeling	RM strategy (interpretation)		Remarks
	Supply-side	Demand-side		Resilient	Robust	
[58]		• Demand (uniform)	SP		✓	• Comparing between two incentive systems for the seed supplier • Recognizing different behavior of the problem in the seeds industry
[60]		• Demand uncertainty (market scenarios)	RO ([105] approach)		✓	• Analyzing solution robustness vs. model robustness as a robustness measure
[62]	• Supply scenarios		SP		✓	• Comparing between network algorithms such as augmenting path, pre-flow push, and successive shortest path • Prioritizing export in case of congestion
[68]	• Harvest	• Price	SP (Linear)		✓	• Selling in both daily auctions and future markets
[69]	• Scenarios of plant closure • Scenarios of additional restriction on green policy	• Demand size	MILP		✓	• Considering stock just for long shelf-life products • Deciding on the number of plants, locations, and allocation policies • Evaluating the impact of different supply chain design strategies such as regionalization, consolidation, product specialization, and process specialization in manufacturing plants to improve risk mitigation and performance
[70]	• Harvest time • Packing rate • Shortage cost		LP/ Fuzzy		✓	• Considering fuzzy type uncertainty related to the perception of the line supervisor; packing rate is set after visual inspection of the quality of arrived products
[28]	• Uncertain harvest (climatic factors)		Linear GP		✓	• Developing a multi-objective function to minimize cost, meet growing and processing capacities as well as market demand under different scenarios of harvest

Table 2b: Detailed literature review on quantitative SCRM models for perishable agri-products

Author	**Risk**		**Perishability modeling**	**Risk modeling**	**RM strategy (interpretation)**		**Remarks**
	Supply-side	Demand-side			Resilient	Robust	
[36]	• Input spot price	• Output spot price • Demand size uncertainty	Newsvendor model	Two-stage SP		✓	• Comparison between fixed proportional (cost-pooling), flexible (capacity-pooling), and dedicated production policies • Cost-pooling value of proportional production increases as correlated with the demand rate (when demand of one product is high and the other is low) • Considering input processing and output production capacity (stage 1), input processing levels within capacity (stage 2)
[35]	• Cheap unreliable supplier (Bernoulli disruption)	• Demand size uncertainty	Newsvendor model	Two-stage SP	✓		• Considering supply from an expensive emergency supplier for any demands above total capacity of primary and backup suppliers • Providing win-win coordination • Utilizing backup supplier as a resilience measure
[37]	• Export public transport failure		Shelf-life extension; exponential decaying cost	SP/SDP	✓		• Modeling perishability and disruption features simultaneously • Considering both static and dynamic models under MTO and MTS demands • Considering resilient backup strategy under harsh disruption scenarios
[38]	• Delay in returning transportation equipment (e.g. container) results in stock-out or deterioration		Impact on ripeness (lot-sizing model)	SDP		✓	• Considering backorder shortages • Modeling the impact of lot-size on deterioration of fresh produce under a ripening process with exponential RTI lead-time in an SDP
[39]	• Orange juice acidity specification	• Juice demand	Accepted bounds for quality specification (acidity) of juice	RO with uncertain acidity spec.		✓	• Forecasting fruit maturation curve by soluble solids in orange juice depending on environmental and orchard maintenance conditions • Mitigating supply-side uncertainty by considering two sourcing strategies including contract-based and spot-based (or short-term contracted) fruit • Processing of intermediary product (base-juice) in stage 1 and blending of the final juice in stage 2 after uncertainty realization
[42]	• Yield • Quality of the crop (impacts on production rate of the processing firm) • Open market supply cost		Newsvendor model	Two-stage SP		✓	• Concerning the impact of variable quality of the crop on the production rate

Table 2b - Continued

Author	Risk		Perishability modeling	Risk modeling	RM strategy (interpretation)		Remarks
	Supply-side	Demand-side			Resilient	Robust	
[46]	• Supply cost	• Demand size	Product warehousing limited life-time	Interval RO ([136])		✓	• Considering closed-loop (eco-friendly) supply chain • Customizing two-side applications (i.e., both in food and high-tech electronics industry)
[49]	• Yield (quantity) uncertainty	• Demand size uncertainty for standard/premium products	Newsvendor model	Two-stage SP		✓	• Proposing a price-based clearance • Suggesting the complementary use of both supply contract and spot markets to hedge market • Considering the fixed capacity in short/medium horizons
[51]	• Yield uncertainty • Yield-dependent trading cost	• Yield dependent trading selling price	Newsvendor model	Two-stage SP		✓	• Considering impacts of endogenous cost and fruit futures for a risk-averse decision maker • Deciding on the space to lease (before harvest) • Selection between one of the following (after harvest): – Converting the crop to the final product – Buying more from external growers – Selling some (or all) of the crop in the open market before processing
[44]	• Harvest maturity (quality) identified by color and firmness	• Open market price-sensitive demand	Yield color estimation in an acceptance interval of firmness, shelf-life, and quality	MILP		✓	• Modeling cost of rejected/discounted shipments for produce that first passed the quality threshold but have then been affected by quality change during supply chain stages • Applying a biological formulation to the expected quality
[43]	• Crop yield	• Crop price	See [44]	Two-stage SP		✓	• Considering both risk neutral and risk aversion objectives, i.e., expected profit and expected losses
[54]		• Demand size (normal)	Inventory deterioration (certain decaying rate)	SP		✓	• Considering supplier-retailer collaboration in forecasting demand
[55]	• Yield (harvest productivity)		Quality cost	RO (MILP model using [135])		✓	• Proposing two new robust approaches including aggregated modified robust and adversarial robust models
[59]		• Demand size • Demand arrival	• Fixed shelf-life-time (equal to the selling horizon) • Products' quality deterioration rate	QP (solved with heuristic)		✓	• Differentiating between fresh and unspoiled products • Considering customer choice in buying or not buying unspoiled products

Table 2b - Continued

Author	**Risk**		**Perishability modeling**	**Risk modeling**	**RM strategy (interpretation)**		**Remarks**
	Supply-side	Demand-side			Resilient	Robust	
[61]	• Yield (biological and environmental) • Harvest failure (biological and environmental)	Demand size	Newsvendor model	Two-stage SP		✓	• Balancing customer service that retailer is willing to accept under production investment • Providing robust model with service level constraint
[63]	• Yield • Quality		Quality loss cost: trade-off cost vs. time for optimal assignment of perishables to storage	SP		✓	• Considering quality components in the objective function composed of product sale, waste fruit sale, out-of-spec product sales, purchasing cost, fruit cooling cost, cold maintenance cost, and labor cost
[65]	• Yield uncertainty (because of weather, disease, etc.) • Yield-dependent cost uncertainty	• Demand size • Yield-dependent price uncertainty	Newsvendor model	Two-stage SP	✓		• Providing concave objective function for the amount of farm space leased in stage 1 problem • Deciding on optimal amounts of olive oil to be produced from internally grown olives and from olives that have been purchased from spot market, after realization of the yield's price in the stage 2 problem • Dividing time-stages as time-to-grow and time-to-sell after growing
[64]	• Length of harvest season • Crop size under climatic variations		Newsvendor model	SP (Newsvendor model with risk cost penalties to find optimum harvest rate)		✓	• Assuming long lead-time for purchasing harvest equipment
[66]	• Harvest yield	• Demand size	Newsvendor model	Two-stage SP		✓	• Mitigation planning by considering two possible supply locations in two sequential growing seasons, when demand is available at the end of the second season
[67]	• Harvest yield	• Demand size	Newsvendor model	Two-stage SP		✓	• Mitigation planning by considering two possible supply locations in two sequential growing seasons, when demand is available at the end of the second season • Considering demand correlation between varieties of products

4.2. Findings

In the past couple of decades, the scope of agribusiness research has been expanded from farm planning to include more stages and connections, i.e., a supply chain (see [137, 49]). However, Table 1 shows the number of quantitative studies is still limited in the subject of Agriculture Supply Chain (ASC) under uncertainty, i.e., we only found 42 quantitative studies on ASCRM that have been published to date. These papers have been described with further details in Table 2a (for long-life agricultural products) and Table 2b (for perishable agricultural products). Interestingly, the number of papers are about the same in Tables 2a and 2b (i.e., 22 papers in Table 2a and 20 papers in Table 2b). Initially, we expected fewer perishable models in the literature due to the additional complexity and because perishability is only a small proportion of the general SCRM literature. The similar number of studies in long-life and perishable agricultural products highlights the importance of perishability to the ASCRM literature.

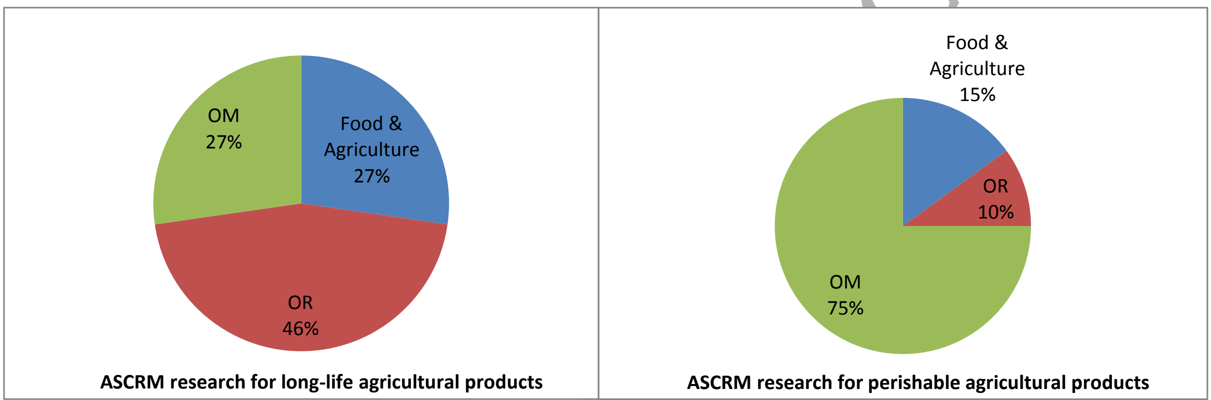


Figure 4: Contributing journal areas to the development of ASCRM research for long-life and perishable agricultural products

When we classified the reviewed papers with respect to the scope of the journal they were published in, we found different trends for contributions of the journals in the development of ASCRM that related to long-life compared with perishable agricultural products. This comparison is provided in Figure 4 by considering the three journal scopes of: Food and Agriculture, OR, and OM. As depicted in Figure 4, OM journals have the main contribution in research development in the context of quantitative risk management for perishable agricultural products. However, OR journals have the highest contribution in the literature with respect to the long-life agricultural products. In contrast to our expectation, agricultural and food-based journals do not provide a large contribution in terms of volume of papers, especially for perishable agricultural products. This is perhaps because of the technical expertise involved in mathematically modeling risk.

Further, from a detailed content-wise classification standpoint, we reviewed the papers by focusing on different aspects of agricultural scope, risk type, RM strategies, and their modeling approach toward risks, as provided in Tables 2a and 2b. Figure 5 counts the number of papers published under each of these topics.

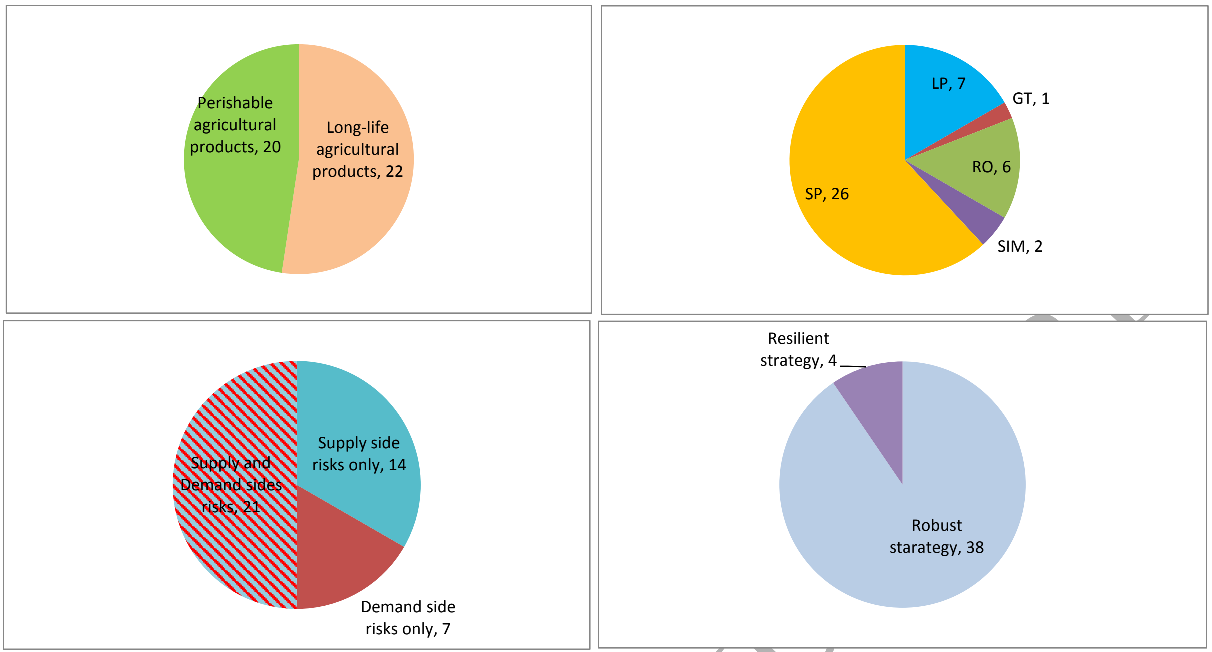


Figure 5: Content-wise counting of the papers in ASCRM research

From Figure 5 and as noted above, perishable and long-life product problems attract similar levels of attention; supply-side risks are slightly more attractive for researchers compared with demand-side risks or both supply- and demand-side risks; SP is the most common approach toward risk modeling; and resilient strategies have been discussed far less than robust strategies. Note that there is no study published thus far in this context that considers both resilient and robust strategies simultaneously.

As discussed in the previous section, there are specific supply chain characteristics that affect supply chains in agriculture; these are perishability, supply spikes, long supply lead-time of products, and biological-based supply processes affected by environmental factors. Although these characteristics are specific to ASCs as described in the current study, they are also treated in other fields with levels of similarity. Discovering such common points could extend the research domain into other areas and vice versa. For instance, perishability is also a considerable concern in electronics or gasoline supply chains [46]; moreover, supply spikes also affect energy (e.g., solar energy) or water-related supply chains to some degree [138]. However, in gasoline supply chains, perishability is usually described using a decaying process as gasoline has no fixed shelf-life, but in ASCs, we commonly assign a maximum shelf-life for agricultural products [139].

A long lead-time is considered another key characteristic of ASCs but is still an area of concern in supply chains of other sectors, such as semi-conductors and petroleum [140]. However, the long supply lead-time in ASCs (e.g., related to the cultivation process) is basically biologically-based and can be affected by further uncertain challenges, e.g., related to soil or weather situations. The specific ASC characteristics described in this section influence the focus of the ASCRM studies as described in the following subsections. More findings with respect to the aspects of agricultural scope, risk type, RM strategy, and risk modeling are described in Subsections 4.2.1 to 4.2.4, respectively.

4.2.1. Product Type

Product type is a key criterion in the classification of the papers by differentiating between perishable and long-life products. In fact, perishability provides a life-time limitation which is considerably important in modeling. Therefore, perishability is considered as a first-order classification criterion in our review and has been used to section the papers into Tables 2a and 2b.

Table 2a summarizes different models on SCRM for long-life agricultural products. The models mainly consider multiple-period settings because there is no limitation on freshness of products over time. The ASC models that are applied to long-life agricultural product problems are mainly studied in the context of supply chain handling, investment, or capacity extension under uncertainty for agricultural products such as seeds or palm bunches (see [31, 32] and [36]).

In Table 2b, we can divide the studies into newsvendor and non-newsvendor models for perishable agricultural products. Non-newsvendor models are models under multi-period settings with different approaches towards perishability. Table 2b shows that the number of papers is similar in both groups (i.e., 10 in each group among the years). Given the additional modeling complexity in multi-period models, this shows the particular importance of these models to researchers. Furthermore, the second group of studies is quite recent (all published after 2010, except one in 2005), which perhaps implies an increasing trend. Such a trend may also occur in the general SCRM literature, where newsvendor models are still very widely used.

The newsvendor studies in Table 2a consider a basic approach in dealing with perishable and short life-cycle products (through a single-period inventory management model, see [49], [65], [51], and [35]). In fact, most of these papers studied the ASC problems under a long single-period (equivalent with the time the products can stay fresh) for perishable agricultural products. For instance, in [51]'s case of olive oil production, to prevent the acidic taste in olive oil or perishing after long-term storage, a long, fixed shelf-life of two years has been incorporated into the model.

Although newsvendor models have been used commonly to handle perishability as described, there are some aspects that might be neglected after viewing a single-period model when looking at disruption. In fact, as [141] states, single-period models underestimate the time-correlation of disruption risks. In saying that, single-period models in agriculture could be justified in some cases (e.g., highly perishable products that can be used for just one period or a period that is very long, such as an entire selling season). However, as most agricultural products under current sophisticated agribusiness systems are stored for multiple periods, there is a need to plan accordingly for modeling in a multi-horizon setting, e.g., by analyzing the best trade-off between cost and quality under disruptions. Taking this into consideration, the correlating impact of disruptions could be captured among different time periods.

In the non-newsvendor group of the reviewed papers in Table 2b, perishability is considered with some basic measures that evaluate the freshness (e.g., remaining fixed shelf-life) while discussing multiple period settings. Such considerations make modeling of RM strategies more challenging, and perhaps, for this reason, both the number of studies and the scope of the studies are limited. For instance, consideration of a variable shelf-life has just been found in one study ([37]). In addition, as shown in Table 2b and noted above, most of the studies that are classified in this category have recently been published (see [37], [44], and [38]). In these papers, various considerations toward perishability have been made. For instance, in [44]'s study, the estimated fruit color has been treated as a measure of firmness/freshness when considering a fixed shelf-life. In [38]'s study, the delay in receiving returning transportation items (RTIs) has been considered as a critical factor in the ripening process. In fact, under consideration of delay in receiving RTIs, bigger lot-sizes should be considered, which in turn affect the ripening process by generating heat in non-central areas and ultimately accelerating deterioration.

Figure 6 depicts the comparative number of papers in the context of ASCRM for each category of long-life products, perishable products under newsvendor settings, and perishable products under non-newsvendor settings over the years.

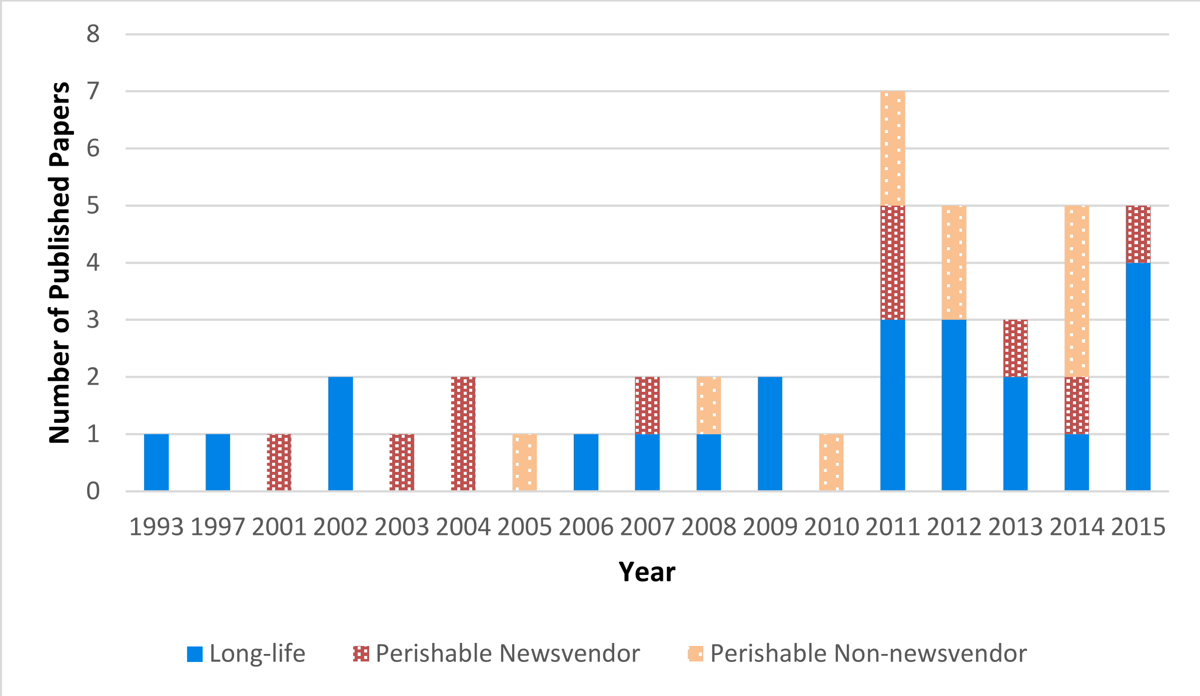


Figure 6: Publishing trends in the area of ASCRM for long-life products and perishable products under newsvendor or non-newsvendor models

We end this subsection by noting that, although perishability is a key attribute in ASCs, it is also a concern in some other supply chains. For instance, as described in [46], perishability and life-time issues are considerable in both agricultural and high-tech supply chains; perishability is related to a biological process in agriculture, while it is competition-based within high-tech industries. Thus, the time-based perishability function should be defined differently. In addition, possible approaches against perishability may also differ, e.g., disassembly is used as a common approach under quality defects in the high-tech industry, but is not applicable in ASCs, as defective products cannot be reused. Saying this, there are some similar considerations in the two industries, e.g., the value of depreciation of products over time, or FIFO (first in first out) warehousing.

4.2.2. Risk Types

As discussed in Section 3, and from the aspect of risk-type, the reviewed papers are divided into two main groups of studies, namely supply-side and demand-side risks. Under supply-side risks, the seasonality of supply and weather-related biological process of supply makes the decision making challenging in ASCs. It is worthwhile to note that the weather-related and seasonal supply also impacts other supply chains such as water or solar-energy supply chains. However, as briefly mentioned in the beginning of the section, in those supply chains there are no additional concerns about the biological process of supply. Under demand-side risks, although commonly presented in most supply chain problems (as variability in market price or capacity), it is noticeable that most markets for agricultural products are less standardized (e.g., compared with electricity markets). This may require approaches with non-standardized instruments [34], thus RM is more challenging in ASC problems with these demand uncertainties.

The second column in Tables 2a and 2b summarizes different risks under the two categories of supply and demand risks for the papers reviewed. From this part of the table, we can see that the main focus of the studies is on supply-side risks (or in some cases demand-side risks) that stem from weather conditions, although in different ways. For instance, an uncertain length of a harvest season and crop size is considered in [64]; uncertainty in yield and crop quality is considered in [63]; yield, cost, and price uncertainties are considered in [44]; yield and yield dependent trading cost and selling prices are considered in [51]; and yield, crop quality (under different production rate), and open market supply cost variabilities are considered in [42]. In a few other cases, supply-side risks have been studied in other contexts such as: unreliable sourcing [35], supply-side transportation [37], or risk of delay in receiving a returning transportation item (RTI) [38]. Quality-related supply risk is discussed from a different angle in [31, 32] when addressed as random or opportunistic misrepresentation by the farmer during the testing stage of a grain production supply chain.

In comparison to supply-side risks in general, demand-side risks have received less attention among studies related to both long-life and perishable products. In particular, there are 8 versus 5 studies in long-life products (where 9 papers considered both) and 6 versus 2 in perishables (where 12 papers considered both). The main demand side risks considered in these studies first relate to the demand size and then to market price uncertainty. These uncertainties are mostly studied separately, except in some cases such as [40, 44, 43, 65] that consider both of these uncertainties simultaneously. By differentiating between types of risks from the standpoint of probability and intensity (i.e., high probability and low intensity in business-as-usual uncertainty versus low probability and high intensity in disruption risks), we notice that the focus of most of the studies in the field of ASCRM is on operational (= business as usual) uncertainty rather than rare disruption scenarios. Particularly, among the reviewed papers in Tables 2a and 2b in just three papers ([61, 35, 37]), has supply disruption been discussed in a preliminary way. In addition, demand-side disruption (e.g., a market brand failure) has thus far been completely ignored in ASC problems under uncertainty. Under connectivity of supply-side and demand-side risks in many supply chains, this simplified assumption may not be realistic.

Overall, in ASCRM problems studied thus far, the uncertainty has been addressed as either disruptions, i.e., LPHC events, or business-as-usual uncertainty, i.e., HPLC events (mainly as business-as-usual uncertainties). A non-agricultural SC paper that considers both types is [74], which considers both a complete shortage that results in no supply (i.e., a disruption) and a possible delay in supply (i.e., an operational uncertainty).

In regards with the type of risk, supply-side risks are the main focus of ASC models, especially when they relate to environmental/meteorological impacts. However, compared with the vast literature of supply disruption in manufacturing supply chains (see [1]), applications of supply disruption are fairly limited in ASCs. Demand disruption has not been studied at all for ASCs (although business-as-usual uncertainty has); even for manufacturing supply chains it has been studied in a very limited scope, where [142] and [143] are among the few studies that consider demand disruption in non-agricultural supply chains in a preliminary way (i.e., through some coordination strategies under harsh demand uncertainties in the operations stage of production).

4.2.3. Risk Management Strategies

As mentioned earlier, in this review, we categorize RM strategies as providing robustness or resilience. In Tables 2a and 2b the papers are categorized by focusing on the type of RM strategy utilized (whether they are robust and/or resilient). Most of the papers reviewed in the context of ASC did not specifically refer to the terms robustness and resilience and only considered a subset of the associated elements (diversification-related strategies have been mainly used under this category). Diversification is traditionally considered as the main response to risk in agriculture and is normally achieved by adding new resources or diversifying the resource locations [25]. Diversification can also be obtained through using multiple suppliers, which increases robustness and mitigates risk. The latter definition has been utilized in most of the reviewed papers in Tables 2a and 2b. For instance, in [49], a beef supply chain model was studied under business-as-usual risks which aimed at sustaining performance under both supply-side and demand-side uncertainties through supply diversification (using both contract and open-market sources); hence, implying robustness.

In general, supplier diversification or the dual sourcing strategy has a long history in supply chain problems under uncertainty. Many analytical studies support the advantages of using this strategy compared with single-sourcing, given particular uncertainties that relate to supply price, delivery lead-times, yield, as well as a risk-averse buyer (see [144, 145, 146]). Supplier diversification is also effective for ASCRM, e.g., see [49]. However, because of the plausible correlation between the supply sources in one agricultural region, supplier diversification may need to extend across different regions, especially under supply-side uncertainties. The concept of diversification across different regions is also applicable in oil supply chains, as long as the regions have a comparable quality of crude oil [147].

Except for supplier diversification, other robust strategies discussed in Section 3.3 have relatively fewer applications in the ASC problems reviewed here. We believe there are some reasons for this tendency. For instance, use of inventory-based strategies may not be very effective due to concern about product perishability and freshness.

In total, resilient strategies have been studied far less than robust strategies (1 compared with 21 in Table 2a, and 3 compared with 17 in Table 2b). In addition, the resilient strategy that was considered in those studies was provided in a fairly preliminary way (key resilience attributes of agility and recovery capacity have not been addressed). For instance, in [37], rescheduling plans for sales under a transportation disruption could be interpreted as resilience in a limited scope.

Product substitution is one of the commonly used resilient RM strategies in the context of SCRM. In a supply chain model with N different products and N corresponding demand classes (i.e., when products are graded into N classes according to some quality), by considering product substitution, we can use a product class to satisfy demand for the same product class as well as for certain other product classes. Product substitution provides flexibility for decision making under risk when the decision maker can allocate the product to different demand classes only after realization of demand or supply uncertainty. Thus, product substitution is mainly referred to as a reactive RM strategy [148]. Occasionally, product substitution is also referred to as a mitigation strategy that supports diversification in some ways, e.g., in sourcing decisions when diversifying by products rather than suppliers (see [85]). Generally speaking, product substitution is a reactive strategy and has a wide application in SCRM problems.

Product substitution can be offered under different structures. One of the popular structures in product substitution is known as downward substitution, when unmet demand of a low quality product is replaced by an alternative high-quality product (downbinning) or a conversion of that high-quality product (downconversion [148]). In manufacturing supply chains under co-production systems when multiple products are produced simultaneously, there are often random quantities of vertically differentiated products that provide the potential for product substitution [149]. As a specific example, in semiconductor manufacturing, demand for a low-speed device is often filled with a reconfigured high-speed device when the low-speed device is unavailable [140]. For ASC problems, in comparison with manufacturing (especially semiconductor) supply chains, it is plausible that higher quality agricultural products are substituted for a conversion of lower quality products, e.g., use high-quality fruit for fruit juice (a strategy referred to as "downconversion" in [149]).

Product substitution can also play an important role in planning under demand uncertainty. Such product substitution is often offered through a demand-switching RM strategy as discussed in [86]. In this situation, the firm motivates the customers to buy an alternative product when their preferred product is not available. According to [150, 151], when demand correlation increases, the expected value of substitution is increased. We believe this is also a sensible conclusion under the scope of ASC problems, although we are not aware of any research that studies this.

Thus far in this subsection, we discussed different examples of robust and resilient RM strategies used in supply chain problems with a particular focus on ASCs. However, a key question still remains as to how these strategies or concepts are quantified. Measuring the resilience concept is a crucial question as studies considering resilient strategies are limited so far (particularly in the context of ASCRM). First, we summarize a number of methods for measuring robustness found in the literature that are consistent with the conceptual definition of robustness provided in the current review.

1. Comparing the expected value of the performance under uncertain scenarios with the expected value in the base case. There are several means of doing this.

(a) One can consider the difference between these two quantities (base performance and performance under disruption). Although this approach has been initially used in some supply chain models to evaluate robustness (in [152]), there was no specific study in the context of ASC that used it.

(b) Rather than a difference, we could also consider the ratio of change in the performance, i.e., the ratio of the difference between the two performances to the base performance, e.g., see [28] in the category of studies for long-life agricultural products.

(c) Alternatively, we can identify the ratio of change in the performance to the base performance over the ratio of change in the associated uncertain parameter to the corresponding base case parameter, e.g., see [32, 52] in the category of studies for long-life agricultural products and [42, 49, 44] in the category of studies for perishable agricultural products.

2. Combining the expected performance and risk measures, such as with a weighted average or a ratio between the risk measure and the expected performance, or including the risk measure through a model constraint. In particular, see [41, 45, 56, 53, 60, 70] in the category of studies for long-life agricultural products and [36, 39, 46, 51, 43, 55, 64, 61] in the category of studies for perishable agricultural products. In [61], the risk measure has been addressed using a constraint that indicates the desired degree of robustness by ensuring that the deviation of the solution from optimality under each uncertain scenario does not exceed some positive value p (this approach is called p-robustness). However, in the rest of the papers, the risk measure is combined into the objective function. For instance, in [153], the robustness measure is combined into the objective function and presented as a weighted combination of the expected performance and the worst-case performance (i.e., conditional value-at-risk of the performance).

3. Considering network structure related metrics, such as network connectivity or accessibility, e.g., in [62] the robust network structure design aims at providing the shortest path from each node to the rest of the nodes in the supply chain network. Although this is the only study in the context of ASCRM that used a network-based approach to address robustness, this approach has been applied widely in other supply chains, such as manufacturing supply chains. For instance, [97] defines a robustness measure using network connectivity methods, i.e., as a probability of the availability of a minimum of one walk between source and sink. This is considered similarly in other works, such as [154], but under different performance measures. Article [155] defines metrics in the way that measures the total number of nodes and arcs such that their removal does not separate the source and sink (i.e., there is still a minimum of one walk remaining between them). In [155], the described metric was evaluated for different network structures (i.e., block-diagonal, scale-free/power-law, centralized, and diagonal) through a simulation approach.

In the rest of the papers summarized in Tables 2a and 2b, there were no specific discussions regarding robustness measures; indeed, even the term "robust" has not been used in most of the studies and was instead implied by the authors according to the realized concepts. In these studies, the uncertainty has been considered in a risk-neutral manner (i.e., through consideration of expected value of the performance measure), or in some cases, by discussing particular mitigation strategies (see [30, 57, 69]).

In contrast with robustness in the literature considered (see §2), there is no research in the context of ASCRM, nor indeed SCRM, that thoroughly addresses resilience metrics. Therefore, in this review, a number of suggestions can be provided for future studies.

In accordance with the conceptual definition of resilience from Section 3.3, the time to recovery is appropriate as a quantitative resilience measure (see [3, 81]). In other words, resilience can be quantified by the time that a supply chain network requires to return to normal operation after disruption. In addition to time to recovery, we suggest two other recovery-based metrics for resilience that measure supply chain performance during the recovery period. We suggest the following metrics for measuring resilience:

1. Time to recovery (i.e., time between the beginning of a disruption until the disrupted supply chain has recovered);

2. Lost profit during the recovery period; and

3. Recovery level (i.e., the performance level that the supply chain recovers to after disruption).

The resilience metrics suggested here are important for supply chain problems that contain uncertainty, however they are particularly critical for ASC problems. Agricultural products are generally highly sensitive to both the time to recovery and the recovery process due to their perishability and limited shelf-life. Thus, the choice of resilience metric(s), as suggested here, will influence the recovery process and consequently affect both the probability of survival and the quality of surviving products in ASCs after facing disruption. From a modeling standpoint, it is crucial that the resilience metric accounts for the time until a disrupted supply chain returns to normal operation, particularly as a proportion of the fresh product's lifetime, i.e., if the time to recovery is longer than a product's lifetime, then recovery will not save those products. Hence, when deciding on a resilient strategy, there is a trade-off between the cost of the strategy and lost profit, where the strategy is only appropriate if recovery can occur within the fresh product's lifetime.

Nevertheless, even though the recovery measures suggested here are core resilience concepts, none of the literature referenced in our review precisely addresses these measures of recovery. According to [95], the time component of resilience has not been well studied by researchers in the context of supply chain management so far. Without consideration of time, the suggested resilience metrics cannot be fully addressed, so there is a dearth of previous work that addresses these quantitative resilience metrics. However, some studies imply the resilience concept through time-related performance measures or post-disruption risk management strategies. In the following studies, the improvement in a time-related performance measure or the application of some reactive RM strategies can improve one of the suggested resilience metrics, even though the metric itself has not been clearly addressed.

First, [111] defines the resilience measure as a supply chain lead-time ratio, which is a ratio between the promised (expected) and the actual lead-time of the delivery of a component to an automaker. The lead-time ratio is defined over the supply chain nodes for the period under analysis. To overcome the disruption caused by a delay in receiving the components and in determining a lead-time ratio close to one, they suggest using an alternative transportation route as a flexible (resilient) approach. In their study, by targeting the lead-time ratio close to one under transportation disruption, the recovery lead-time under disruption will be reduced. Hence, their proposed measure for resilience may imply a short time to recovery to some extent.

Similarly, [112] discusses resilience in the context of a two-stage reconfigurable network design by selecting a delivery lead-time as the performance measure under disruption scenarios defined by node/arc failures. The underlying concept is that a higher level of arc/node availability results in a shorter delivery time, therefore, less inventory is needed throughout the supply chain network, which means less overall cost. Thus, their definition may imply less recovery time because of the associated shorter response time to a disruption, but this implication was not discussed. In a similar manner, consideration of response time as the performance measure in [156] results in some level of resilience as shorter response times can enable faster recovery.

Alternatively, some studies consider reactive RM strategies that affect the resilience measures, especially those related to lost profit during the recovery and the recovery level after recovery. For instance, [34] considers a backup supply strategy with an optional contingent contract as a resilient strategy for an ASC with long-life agricultural products. The backup strategy has been discussed for ASC problems with perishable agricultural products, e.g., see [35, 65]. In [37] a rerouting strategy has been used as a reactive RM strategy by allowing the possibility of switching between demand markets. As described in these studies, use of RM can assist in improving the performance measures (i.e., total cost or profit) during and after recovery. As another example, the recovery process could be sped up by the use of emergency facilities that are protected and can hold emergency inventory (e.g., by constructing flood walls to prevent flooding for facilities that are capable of supplying parts in the face of disruption events) [157, 158]. To select the best subsets of supply facilities to be protected, [157] considers a trade-off between the cost of a suppliers' protection and the losses caused by supply disruptions (this concept is referred to as a "protection index"). Articles [157] and [158] highlight the importance of using more emergency sources but fewer suppliers in total. In other words, in these studies, rather than diversification of suppliers (by selecting more suppliers), investment is mainly focused on emergency sources.

To sum up, in this section, we summarized a number of metrics to describe the concepts of robustness and resilience in ASCRM problems. Although robustness metrics are discussed to some extent, we have not found any literature that fully addresses resilience metrics. This is a crucial lack of research under the context of ASCRM because of the higher level of inherent uncertainty in ASCs (e.g., related to the climate, the economic environment, and the social environment) and the perishability of agricultural products. In fact, the inherent uncertainty in ASCs promotes the use of reactive solutions (resilient strategies) rather than proactive solutions (robust strategies), which require less prediction about risks [89]. In addition, perishability of products can be controlled by the use of a resilience measure, such as minimizing the time to recovery. In saying this, resilience measures have been partially discussed in some quantitative studies. e.g., when a time-based performance measure is used or when a reactive RM strategy is applied. In such studies, the improvement of resilience measures is a beneficial outcome rather than the focus of the research.

4.2.4. Risk Modeling Approaches

Thus far, different mathematical modeling approaches toward risk have been applied in the context of ASCs. As described earlier in Section 3.4, these are: minimization of the total, absolute deviation (MOTAD), game theory (GT), linear programming (LP)-based approaches (mixed-integer linear programming – MILP, multi-objective optimization – MOO, goal programming – GP), stochastic programming (SP)/stochastic dynamic programming (SDP), fuzzy optimization, simulation (SIM), and robust optimization (RO). We should note that MOTAD has only been used in agricultural risk modeling studies in farm levels and not in ASCs. In addition, as mentioned above, although the properties of RM models are different in ASC problems compared with other types of supply chain models, the core mathematical approaches toward risk modeling are similar.

Among risk modeling approaches in the context of ASC, SP is by far the most popular approach, especially for recently published papers. Although MOTAD was the most common approach in classical agricultural risk modeling, especially in crop and farm planning (see [116], [113], and [117]), according to our review, it is no longer attractive in the context of ASCRM (see the risk modeling columns in Tables 2a and 2b). Other than SP, LP-based approaches have also received considerable attention in the literature followed by RO approaches (see Figure 5) but we expect that RO will attract more attention under higher levels of unexpected uncertainty, as discussed in Section 3.4.

In SP, particularly, two-stage models have been considered for many of the recent problems in ASCs that partition the decisions before and after realization of uncertainty (i.e., stages 1 and 2). Perhaps this is because, in reality, for most ASC problems, decisions are partitioned by uncertain parameters, e.g., transportation decisions before and after realization of yield. For instance, [30] studied a palm bunch supply chain under harvest uncertainty through a two-stage SP model that decides on input processing and output production capacities in stage 1, and also input processing levels within the assigned capacity in stage 2. In another example, [65] developed a two-stage SP model to determine growing and sales policies in an olive oil supply chain under uncertainty; here the stage 1 problem concerns the amount of farm space leased, and the stage 2 problem decides on the optimal amount of olive oil to be produced from internally grown olives and from olives that have been purchased from the spot market after realizing price uncertainty in the open market.

Although we did not find many studies that used SIM models in the context of ASCRM, when considering the higher levels of complexity in the real structure of ASCs, the implementation of simulation-based approaches should be both sensible and effective. For instance, agent-based simulation models can be applied when one side of the supply chain faces incomplete information [159]. In [31, 32], for a Canadian grain supply chain, such interaction is defined between a farmer and a grain handler where the handler aims to design proper testing strategies to minimize the risk of misrepresentation of variety (i.e., a part of the quality assurance process) by an individual farmer. As the grain handler has just limited information about the farmer's misrepresentation risk, this problem is classified as an agent-based model with incomplete information about the supplier. Although this is a well-known problem in supply chain management (see [160] and [161]), it has rarely been used in ASCs, perhaps because of the additional complexities in ASC models as discussed in Subsection 4.2.1.

Further, use of other types of SIM-based models such as system dynamics could extend the approach toward uncertainty in ASC problems; e.g., [95] used a hybrid LP system dynamics model to capture the time-related characteristic of resilience measures and provided a re-planning model under disruption in an automotive supply chain problem. Finally, GT models could also be applied further in ASC problems to improve the design of efficient coordination policies between the two sides of the ASC network, e.g., under behavioral risk as discussed in [31, 32].

In summary, among the applied methods for risk modeling in ASC problems, two-stage stochastic models received considerable attention because they matched the decision-making process with many real-life agricultural supply chain problems. Besides the LP-based approaches, RO has been used to some extent, which can be applied when less information is available about uncertain scenarios. By considering more rare high impact disruptive scenarios and complexities in the problems, RO and SIM may well receive higher attention in the future.

4.2.5. Summary

In this section, we aimed to map and evaluate the literature in the context of agribusiness supply chain risk management in order to suggest the potential research paths and boundaries of knowledge for future research. In summary, and according to our findings, the following areas are suggested for future research in Agribusiness Supply Chain Risk Management (ASCRM):

• To consider perishability under variable shelf-life time measures

• To consider other supply-side risks beyond weather changeability

• To incorporate demand-side disruptions

• To model supply chain resilience in ASCs through measures such as time to recovery (TTR) in the objective function

• To compare the effectiveness of a robust versus a resilient supply chain design and establish when the supply chain design should focus on robustness and when it should focus on resilience.

5. Conclusions

Although quantitative modeling approaches have been applied to agricultural problems for a long time, adoption of these methods for improving planning decisions in agribusiness supply chains under uncertainty is still limited. In the current study, quantitative models for risk management in ASCs were reviewed, with a particular focus on categorizing SCRM strategies as robust or resilient.

According to our review, limitations in quantitative ASC studies are recognizable from both the number of publications and the scope of existing studies. Thus, the literature on Agribusiness Supply Chain Risk Management (ASCRM) is likely to extend over the next few years. In particular, we have identified the following directions to be explored in future research in the field of ASCRM according to both the academic research gap and the needs of industries:

1. Perishability modeling. In this topic, the consideration of perishability in fresh products under variable shelf-life is a significant omission that needs to be incorporated in models related to disruption management in the context of ASCs. For instance, the price of technology to keep the products fresh for a longer time can be traded off with the additional profit generated by selling the produce when it is fresh. This consideration needs to be combined with the adoption of risk management strategies.

2. Multi-period planning. This is another area that lacks sufficient attention in the current ASCRM literature, even though, it is particularly important in the context of agribusiness because of time-dependent characteristics of agricultural products (relating to their freshness). Multi-period ASC planning under disruption is needed to handle quality management for agricultural products over time and concurrently consider time-correlation of disruption risks.

3. Rare high-impact disruption and the combination of them with operational uncertainty. Currently, most ASCRM models only considered robustness under business as usual risks; hence, the impact of low probability of high-impact disruption is rarely addressed. In addition, in many real-world ASC problems, both types of uncertainties (operational and disruption) can be viewed together, which requires incorporating them simultaneously in the corresponding model.

4. Robust and resilient strategies (especially resilient). One of the key missing areas in quantitative ASC studies relates to mitigation and contingency planning approaches. These methods are especially significant for ASCs given their additional inherent vulnerability. While robust models have recently been studied to some extent for ASCs, resilient strategies (i.e., contingency plans that reduce time-to-recovery) are highly neglected under rare disruptions.

5. Demand-side disruptions. No study can be found in ASC modeling that addressed demand-side disruptions (harsh rare demand-side uncertainty). Demand-side disruption is not only significant itself in ASCs (e.g., massive changes in open market prices and demand due to a harsh seasonal harvest), but could also stem from supply-side disruptions (i.e., according to the correlation between these uncertainties).

6. Highly integrated information-driven supply chains. Due to the complexity of agribusiness systems and the high level of uncertainty in their information (e.g., because of using predictive analytics on key parameters), highly integrated information-driven supply chain management systems should be considered. Such systems are key to incorporating diversity of uncertainty information in a complex adaptive ASC, which is especially important from industry stand-point.

7. Approaches that are endorsed by high-level management. Finally, to ensure practicability of the

proposed research methods, a further research consideration is to ensure that solutions/output from new risk management approaches can be applied in practice, hence, providing cost-efficient approaches toward risk, which are especially important from an industrial standpoint.

In this review, we not only summarized key research findings in ASCRM problems, but also provided a comparison with other supply chain problems, consequently, links the findings when there were attributes in common. Furthermore, we proposed a number of research gaps in the context of ASCRM to be explored that should increase the practicability of models for real-world agricultural supply chain problems. Although adding the proposed elements could extend the research to better model real-world problems in the agribusiness industry, researchers need to investigate if the additional complexity affects the solvability of the problems. Further, the benefits from the modeling-based solutions may also be limited by the quality of data, the willingness of the enterprise ownership to use this method, the culture of risk management, and the understanding of OR in the concerned company. Hence, these limitations may also need to be considered when exploring extension of the research in the proposed areas. We hope that the above gaps represent motivating opportunities for future research and promise to provide benefits to the ASC sector with further exploration.

Acknowledgments

The authors thank the editors and anonymous reviewers for their valuable comments on this paper. The first author acknowledges both the Research Assistant funding received from Waikato University's strategic investment fund for her work, which was awarded to the last author by the University of Waikato in New Zealand, and that received from the Department of Engineering Science, University of Auckland. The research of the third author was supported in part by Te Pūnaha Matatini Center of Research Excellence.

References

References

[1] B. Fahimnia, C. S. Tang, H. Davarzani, and J. Sarkis, "Quantitative models for managing supply chain risks: A review," *European Journal of Operational Research*, vol. 247, no. 1, pp. 1–15, 2015.

[2] S. Chopra and M. S. Sodhi, "Managing risk to avoid supply-chain breakdown," *MIT Sloan management review*, vol. 46, no. 1, p. 53, 2004.

[3] M. S. Sodhi and C. S. Tang, "Managing supply chain disruptions via time-based risk management," in *Managing supply chain risk and vulnerability*, pp. 29–40, Springer, 2009.

[4] Y. Sheffi, "The resilient enterprise: overcoming vulnerability for competitive advantage," *MIT Press Books*, vol. 1, 2005.

[5] I. Heckmann, T. Comes, and S. Nickel, "A critical review on supply chain risk–definition, measure and modeling," *Omega*, vol. 52, pp. 119–132, 2015.

[6] N. Chandrasekaran and G. Raghuram, *Agribusiness Supply Chain Management.* CRC Press, 2014.

[7] T. J. Lowe and P. V. Preckel, "Decision technologies for agribusiness problems: A brief review of selected literature and a call for research," *Manufacturing & Service Operations Management*, vol. 6, no. 3, pp. 201–208, 2004.

[8] J. J. Glen, "Mathematical models in farm planning: A survey," *Operations Research*, vol. 35, no. 5, pp. 641–666, 1987.

[9] I. Tatsiopoulos and A. Tolis, "Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods," *Biomass and Bioenergy*, vol. 24, no. 3, pp. 199–214, 2003.

[10] A. Dooley, W. Parker, and H. Blair, "Modelling of transport costs and logistics for on-farm milk segregation in new zealand dairying," *Computers and electronics in agriculture*, vol. 48, no. 2, pp. 75–91, 2005.

[11] M. Lucas and D. Chhajed, "Applications of location analysis in agriculture: a survey," *Journal of the Operational Research Society*, vol. 55, no. 6, pp. 561–578, 2004.

[12] A. Gupta, R. Harboe, and M. Tabucanon, "Fuzzy multiple-criteria decision making for crop area planning in narmada river basin," *Agricultural Systems*, vol. 63, no. 1, pp. 1–18, 2000.

[13] C. S. Tang, "Perspectives in supply chain risk management," *International Journal of Production Economics*, vol. 103, no. 2, pp. 451–488, 2006.

[14] W. Klibi, A. Martel, and A. Guitouni, "The design of robust value-creating supply chain networks: a critical review," *European Journal of Operational Research*, vol. 203, no. 2, pp. 283–293, 2010.

[15] O. Tang and S. N. Musa, "Identifying risk issues and research advancements in supply chain risk management," *International journal of production economics*, vol. 133, no. 1, pp. 25–34, 2011.

[16] K. Scholten, P. Sharkey Scott, and B. Fynes, "Mitigation processes–antecedents for building supply chain resilience," *Supply Chain Management: An International Journal*, vol. 19, no. 2, pp. 211–228, 2014.

[17] L. V. Snyder, Z. Atan, P. Peng, Y. Rong, A. J. Schmitt, and B. Sinsoysal, "Or/ms models for supply chain disruptions: A review," *IIE Transactions*, vol. 48, no. 2, pp. 89–109, 2016.

[18] O. Ahumada and J. R. Villalobos, "Application of planning models in the agri-food supply chain: A review," *European Journal of Operational Research*, vol. 196, no. 1, pp. 1–20, 2009.

[19] W. Zhang and W. E. Wilhelm, "OR/MS decision support models for the specialty crops industry: a literature review," *Annals of Operations Research*, vol. 190, no. 1, pp. 131–148, 2011.

[20] A. Weintraub and C. Romero, "Operations research models and the management of agricultural and forestry resources: a review and comparison," *Interfaces*, vol. 36, no. 5, pp. 446–457, 2006.

[21] A. Higgins, C. Miller, A. Archer, T. Ton, C. Fletcher, and R. McAllister, "Challenges of operations research practice in agricultural value chains," *Journal of the Operational Research Society*, vol. 61, no. 6, pp. 964–973, 2010.

[22] M. Shukla and S. Jharkharia, "Agri-fresh produce supply chain management: a state-of-the-art literature review," *International Journal of Operations & Production Management*, vol. 33, no. 2, pp. 114–158, 2013.

[23] W. E. Soto-Silva, E. Nadal-Roig, M. C. González-Araya, and L. M. Pla-Aragones, "Operational research models applied to the fresh fruit supply chain," *European Journal of Operational Research*, vol. 251, no. 2, pp. 345–355, 2016.

[24] V. Borodin, J. Bourtembourg, F. Hnaien, and N. Labadie, "Handling uncertainty in agricultural supply chain

management: a state of the art," *European Journal of Operational Research*, vol. 254, no. 2, pp. 348–359, 2016.

[25] G. Backus, V. Eidman, and A. Dijkhuizen, "Farm decision making under risk and uncertainty," *Netherlands Journal of Agricultural Science*, vol. 45, no. 2, pp. 307–328, 1997.

[26] J. B. Hardaker, S. Pandey, L. H. Patten, *et al.*, "Farm planning under uncertainty: a review of alternative programming models," *Review of Marketing and Agricultural Economics*, vol. 59, no. 01, 1991.

[27] J. B. Hardaker, *Coping with risk in agriculture.* CA, 2004.

[28] J. M. van Berlo, "A decision support tool for the vegetable processing industry; an integrative approach of market, industry and agriculture," *Agricultural Systems*, vol. 43, no. 1, pp. 91–109, 1993.

[29] R. H. Sees, "Guide to supply chain management: How getting it right boosts corporate performance (the economist) by david jacoby (review)," *Transportation Journal*, vol. 52, no. 4, pp. 522–524, 2013.

[30] O. Boyabatlı, "Supply management in multiproduct firms with fixed proportions technology," *Management Science*, vol. 61, no. 12, pp. 3013–3031, 2015.

[31] H. Ge, J. Nolan, and R. Gray, "Identifying strategies to mitigate handling risks in the canadian grain supply chain," *Canadian Journal of Agricultural Economics/Revue Canadienne D'Agroeconomie*, vol. 63, no. 1, pp. 101–128, 2015.

[32] H. Ge, R. Gray, and J. Nolan, "Agricultural supply chain optimization and complexity: A comparison of analytic vs simulated solutions and policies," *International Journal of Production Economics*, vol. 159, pp. 208–220, 2015.

[33] X.-Y. Ren, Q.-Q. Feng, S. Wang, and X. Wen, "Profit distribution of agricultural supply chain based on shapley value," *Advance Journal of Food Science and Technology*, vol. 7, no. 7, pp. 479–483, 2015.

[34] S. Wiedenmann and J. Geldermann, "Supply planning for processors of agricultural raw materials," *European Journal of Operational Research*, vol. 242, no. 2, pp. 606–619, 2015.

[35] S. Asian and X. Nie, "Coordination in supply chains with uncertain demand and disruption risks: Existence, analysis, and insights," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 44, no. 9, pp. 1139–1154, 2014.

[36] O. Boyabatli, Q. J. D. Nguyen, and T. Wang, *Capacity management in agricultural commodity processing and application in the palm industry.* Research Collection Lee Kong Chian School Of Business, 2015.

[37] X. Cai and X. Zhou, "Optimal policies for perishable products when transportation to export market is disrupted," *Production and Operations Management*, vol. 23, no. 5, pp. 907–923, 2014.

[38] T. Kim, C. H. Glock, and Y. Kwon, "A closed-loop supply chain for deteriorating products under stochastic container return times," *Omega*, vol. 43, pp. 30–40, 2014.

[39] J. R. Munhoz and R. Morabito, "Optimization approaches to support decision making in the production planning of a citrus company: a brazilian case study," *Computers and Electronics in Agriculture*, vol. 107, pp. 45–57, 2014.

[40] I. Awudu and J. Zhang, "Stochastic production planning for a biofuel supply chain under demand and price uncertainties," *Applied Energy*, vol. 103, pp. 189–196, 2013.

[41] A. Baghalian, S. Rezapour, and R. Z. Farahani, "Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case," *European Journal of Operational Research*, vol. 227, no. 1, pp. 199–215, 2013.

[42] O. Boyabatli and K. E. Wee, *Farm-yield management when production rate is yield dependent.* Research Collection Lee Kong Chian School Of Business, 2013.

[43] O. Ahumada, J. R. Villalobos, and A. N. Mason, "Tactical planning of the production and distribution of fresh

agricultural products under uncertainty," *Agricultural Systems*, vol. 112, pp. 17–26, 2012.

[44] O. Ahumada and J. R. Villalobos, "A tactical model for planning the production and distribution of fresh produce," *Annals of Operations Research*, vol. 190, no. 1, pp. 339–358, 2011.

[45] B. H. Gebreslassie, Y. Yao, and F. You, "Design under uncertainty of hydrocarbon biorefinery supply chains: multiobjective stochastic programming models, decomposition algorithm, and a comparison between cvar and downside risk," *AICHE Journal*, vol. 58, no. 7, pp. 2155–2179, 2012.

[46] A. Hasani, S. H. Zegordi, and E. Nikbakhsh, "Robust closed-loop supply chain network design for perishable goods in agile manufacturing under uncertainty," *International Journal of Production Research*, vol. 50, no. 16, pp. 4649–4669, 2012.

[47] T. Paksoy, N. Y. Pehlivan, and E. Özceylan, "Application of fuzzy optimization to a supply chain network design: a case study of an edible vegetable oils manufacturer," *Applied Mathematical Modelling*, vol. 36, no. 6, pp. 2762–2776, 2012.

[48] B. Tan and N. Çömden, "Agricultural planning of annual plants under demand, maturation, harvest, and yield risk," *European Journal of Operational Research*, vol. 220, no. 2, pp. 539–549, 2012.

[49] O. Boyabatli, P. Kleindorfer, and S. Koontz, "Procurement risk management in beef supply chains," 2011.

[50] Z. Guan and A. B. Philpott, "A multistage stochastic programming model for the new zealand dairy industry," *International Journal of Production Economics*, vol. 134, no. 2, pp. 289–299, 2011.

[51] B. Kazaz and S. Webster, "The impact of yield-dependent trading costs on pricing and production planning under supply uncertainty," *Manufacturing & Service Operations Management*, vol. 13, no. 3, pp. 404–417, 2011.

[52] J. Kim, M. J. Realff, and J. H. Lee, "Optimal design and global sensitivity analysis of biomass supply chain networks for biofuels under uncertainty," *Computers & Chemical Engineering*, vol. 35, no. 9, pp. 1738–1751, 2011.

[53] S. Mirzapour Al-E-Hashem, H. Malekly, and M. Aryanezhad, "A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty," *International Journal of Production Economics*, vol. 134, no. 1, pp. 28–42, 2011.

[54] D. Shen, K. K. Lai, S. C. Leung, and L. Liang, "Modelling and analysis of inventory replenishment for perishable agricultural products with buyer–seller collaboration," *International Journal of Systems Science*, vol. 42, no. 7, pp. 1207–1217, 2011.

[55] C. Bohle, S. Maturana, and J. Vera, "A robust optimization approach to wine grape harvesting scheduling," *European Journal of Operational Research*, vol. 200, no. 1, pp. 245–252, 2010.

[56] W. Jang and C. M. Klein, "Supply chain models for small agricultural enterprises," *Annals of Operations Research*, vol. 190, no. 1, pp. 359–374, 2011.

[57] S. Cholette, "Mitigating demand uncertainty across a winery's sales channels through postponement," *International Journal of Production Research*, vol. 47, no. 13, pp. 3587–3609, 2009.

[58] S. Burer, P. C. Jones, and T. J. Lowe, "Coordinating the supply chain in the agricultural seed industry," *European Journal of Operational Research*, vol. 185, no. 1, pp. 354–377, 2008.

[59] E. J. Lodree and B. M. Uzochukwu, "Production planning for a deteriorating item with stochastic demand and consumer choice," *International Journal of Production Economics*, vol. 116, no. 2, pp. 219–232, 2008.

[60] S. C. Leung, S. O. Tsang, W. L. Ng, and Y. Wu, "A robust optimization model for multi-site production planning problem in an uncertain environment," *European Journal of Operational Research*, vol. 181, no. 1, pp. 224–238, 2007.

[61] J. M. Merrill, *Managing risk in premium fruit and vegetable supply chains.* PhD thesis, Massachusetts Institute of Technology, 2007.

[62] F. G. Ortmann, *Modelling the South African fresh fruit export supply chain.* PhD thesis, Stellenbosch: University of Stellenbosch, 2005.

[63] A. Blanco, G. Masini, N. Petracci, and J. Bandoni, "Operations management of a packaging plant in the fruit industry," *Journal of Food Engineering*, vol. 70, no. 3, pp. 299–307, 2005.

[64] S. J. Allen and E. W. Schuster, "Controlling the risk for an agricultural harvest," *Manufacturing & Service Operations Management*, vol. 6, no. 3, pp. 225–236, 2004.

[65] B. Kazaz, "Production planning under yield and demand uncertainty with yield-dependent cost and price," *Manufacturing & Service Operations Management*, vol. 6, no. 3, pp. 209–224, 2004.

[66] P. C. Jones, G. Kegler, T. J. Lowe, and R. D. Traub, "Managing the seed-corn supply chain at syngenta," *Interfaces*, vol. 33, no. 1, pp. 80–90, 2003.

[67] P. C. Jones, T. J. Lowe, R. D. Traub, and G. Kegler, "Matching supply and demand: The value of a second chance in producing hybrid seed corn," *Manufacturing & Service Operations Management*, vol. 3, no. 2, pp. 122–137, 2001.

[68] J. V. Caixeta-Filho, J. M. van Swaay-Neto, and A. d. P. Wagemaker, "Optimization of the production planning and trade of lily flowers at jan de wit company," *Interfaces*, vol. 32, no. 1, pp. 35–46, 2002.

[69] F. H. Wouda, P. van Beek, J. G. van der Vorst, and H. Tacke, "An application of mixed-integer linear programming models on the redesign of the supply network of nutricia dairy & drinks group in hungary," *OR Spectrum*, vol. 24, no. 4, pp. 449–465, 2002.

[70] W. Miller, L. Leung, T. Azhar, and S. Sargent, "Fuzzy production planning model for fresh tomato packing," *International Journal of Production Economics*, vol. 53, no. 3, pp. 227–238, 1997.

[71] U. Jüttner, H. Peck, and M. Christopher, "Supply chain risk management: outlining an agenda for future research," *International Journal of Logistics: Research and Applications*, vol. 6, no. 4, pp. 197–210, 2003.

[72] S. M. Wagner and C. Bode, "Dominant risks and risk management practices in supply chains," in *Supply Chain Risk*, pp. 271–290, Springer, 2009.

[73] P. R. Kleindorfer and G. H. Saad, "Managing disruption risks in supply chains," *Production and Operations Management*, vol. 14, no. 1, pp. 53–68, 2005.

[74] T. Sawik, "Selection of a dynamic supply portfolio in make-to-order environment withrisks," *Computers & Operations Research*, vol. 38, no. 4, pp. 782–796, 2011.

[75] C. Tang and B. Tomlin, "The power of flexibility for mitigating supply chain risks," *International Journal of Production Economics*, vol. 116, no. 1, pp. 12–27, 2008.

[76] M. Christopher and H. Peck, "Building the resilient supply chain," *The International Journal of Logistics Management*, vol. 15, no. 2, pp. 1–14, 2004.

[77] A. J. Schmitt and L. V. Snyder, "Infinite-horizon models for inventory control under yield uncertainty and disruptions," *Computers & Operations Research*, vol. 39, no. 4, pp. 850–862, 2012.

[78] H. Peck, "Resilience in the food chain: A study of business continuity management in the food and drink industry," *Final Report to the Dep. for Environment, Food and Rural Affairs, Dep. of Defence Management & Security Analysis, Cranfield University, Shrivenham*, pp. 1–193, 2006.

[79] W. H. O. F. S. Dept, *Terrorist threats to food: guidance for establishing and strengthening prevention and response*

systems. World Health Organization, 2002.

[80] K. R. Everett, R. K. Taylor, M. K. Romberg, J. Rees-George, R. A. Fullerton, J. L. Vanneste, and M. A. Manning, "First report of pseudomonas syringae pv. actinidiae causing kiwifruit bacterial canker in new zealand," *Australasian Plant Disease Notes*, vol. 6, no. 1, pp. 67–71, 2011.

[81] D. Simchi-Levi, W. Schmidt, and Y. Wei, "From superstorms to factory fires managing unpredictable supply-chain disruptions," *Harvard Business Review*, vol. 92, no. 1-2, pp. 96–+, 2014.

[82] S. Smith *et al.*, "" farming"-it's declining in the us," *Choices*, vol. 7, no. 1, 1992.

[83] J. Vlajic, E. Hendrix, and J. van der Vorst, *Food supply chain network robustness: a literature review and research agenda*. Wageningen University, 2008.

[84] M. of Primary Industries (MPI), "Situation and Outlook for Primary Industries (SOPI)." `https://www.mpi.govt.nz/about-mpi/corporate-publications/`, 2013.

[85] B. Tomlin, "On the value of mitigation and contingency strategies for managing supply chain disruption risks," *Management Science*, vol. 52, no. 5, pp. 639–657, 2006.

[86] B. Tomlin, "Disruption-management strategies for short life-cycle products," *Naval Research Logistics (NRL)*, vol. 56, no. 4, pp. 318–347, 2009.

[87] T. Sawik, "Integrated supply, production and distribution scheduling under disruption risks," *Omega*, vol. 62, pp. 131–144, 2016.

[88] D. Leonard, "'the only lifeline was the wal-mart'," *Fortune*, vol. 152, no. 7, pp. 74–+, 2005.

[89] S. Dani and A. Deep, "Fragile food supply chains: reacting to risks," *International Journal of Logistics: Research and Applications*, vol. 13, no. 5, pp. 395–410, 2010.

[90] A. Norrman and U. Jansson, "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident," *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 5, pp. 434–456, 2004.

[91] G. A. Zsidisin, "Managerial perceptions of supply risk," *Journal of Supply Chain Management*, vol. 39, no. 4, pp. 14–26, 2003.

[92] M. Nishat Faisal, D. Banwet, and R. Shankar, "Mapping supply chains on risk and customer sensitivity dimensions," *Industrial Management & Data Systems*, vol. 106, no. 6, pp. 878–895, 2006.

[93] B. Gaudenzi and A. Borghesi, "Managing risks in the supply chain using the ahp method," *The International Journal of Logistics Management*, vol. 17, no. 1, pp. 114–136, 2006.

[94] S. Agiwal, H. Mohtadi, *et al.*, "Risk mitigating strategies in the food supply chain," in *American Agricultural Economics Assocation (Annual Meeting)*, 2008.

[95] D. Ivanov, A. Pavlov, A. Dolgui, D. Pavlov, and B. Sokolov, "Disruption-driven supply chain (re)-planning and performance impact assessment with consideration of pro-active and recovery policies," *Transportation Research Part E: Logistics and Transportation Review*, vol. 90, pp. 7–24, 2016.

[96] T. Sawik, "A portfolio approach to supply chain disruption management," *International Journal of Production Research*, pp. 1–22, 2016.

[97] M. Dong and F. F. Chen, "Quantitative robustness index design for supply chain networks," in *Trends in Supply Chain Design and Management*, pp. 369–391, Springer, 2007.

[98] K. A. Foster, "A case study approachto understanding regional resilience," *Institute of Urban & Regional Development*, 2007.

[99] D. Waters, *Supply chain risk management: vulnerability and resilience in logistics*. Kogan Page Publishers, 2011.

[100] S. R. Yadav, N. Mishra, V. Kumar, and M. Tiwari, "A framework for designing robust supply chains considering product development issues," *International Journal of Production Research*, vol. 49, no. 20, pp. 6065–6088, 2011.

[101] J. V. Vlajic, J. G. Van der Vorst, and R. Haijema, "A framework for designing robust food supply chains," *International Journal of Production Economics*, vol. 137, no. 1, pp. 176–189, 2012.

[102] V. Gabrel, C. Murat, and A. Thiele, "Recent advances in robust optimization: An overview," *European Journal of Operational Research*, vol. 235, no. 3, pp. 471–483, 2014.

[103] M. Goetschalckx and B. Fleischmann, "Strategic network planning," in *Supply Chain Management and Advanced Planning*, pp. 117–137, Springer, 2005.

[104] Y. Mo and T. P. Harrison, "A conceptual framework for robust supply chain design under demand uncertainty," in *Supply Chain Optimization*, pp. 243–263, Springer, 2005.

[105] J. M. Mulvey, R. J. Vanderbei, and S. A. Zenios, "Robust optimization of large-scale systems," *Operations Research*, vol. 43, no. 2, pp. 264–281, 1995.

[106] L. V. Snyder, *Supply chain robustness and reliability: Models and algorithms*. PhD thesis, Northwestern University, 2003.

[107] T. J. Pettit, *Supply chain resilience: development of a conceptual framework, an assessment tool and an implementation process*. PhD thesis, The Ohio State University, 2008.

[108] J. Fiksel, "Sustainability and resilience: toward a systems approach," *Sustainability: Science, Practice, & Policy*, vol. 2, no. 2, 2006.

[109] W. Klibi and A. Martel, "Modeling approaches for the design of resilient supply networks under disruptions," *International Journal of Production Economics*, vol. 135, no. 2, pp. 882–898, 2012.

[110] M. Christopher and H. Peck, "The five principles of supply chain resilience," *Logistics Europe*, vol. 12, no. 1, pp. 16–21, 2004.

[111] H. Carvalho, A. P. Barroso, V. H. Machado, S. Azevedo, and V. Cruz-Machado, "Supply chain redesign for resilience using simulation," *Computers & Industrial Engineering*, vol. 62, no. 1, pp. 329–341, 2012.

[112] Y. Kristianto, A. Gunasekaran, P. Helo, and Y. Hao, "A model of resilient supply chain network design: A two-stage programming with fuzzy shortest path," *Expert Systems with Applications*, vol. 41, no. 1, pp. 39–49, 2014.

[113] J. T. Scott and C. B. Baker, "A practical way to select an optimum farm plan under risk," *American Journal of Agricultural Economics*, vol. 54, no. 4 Part 1, pp. 657–660, 1972.

[114] H. Markowitz, "Portfolio selection," *The Journal of Finance*, vol. 7, no. 1, pp. 77–91, 1952.

[115] R. J. Freund, "The introduction of risk into a programming model," *Econometrica: Journal of the Econometric Society*, pp. 253–263, 1956.

[116] P. B. Hazell, "A linear alternative to quadratic and semivariance programming for farm planning under uncertainty," *American Journal of Agricultural Economics*, vol. 53, no. 1, pp. 53–62, 1971.

[117] T. O. Randhir and J. G. Lee, "Effect of water quality standards on farm income, risk, and nps pollution1," 2000.

[118] J. R. Anderson, J. L. Dillon, and J. Hardaker, *Agricultural Decision Analysis*. Information Systems Division, National Agricultural Library, 1977.

[119] G. B. Dantzig, *Linear programming and extensions*. Princeton University Press, 1998.

[120] G. W. Evans, "An overview of techniques for solving multiobjective mathematical programs," *Management Sci-*

ence, vol. 30, no. 11, pp. 1268–1282, 1984.

[121] D. Barnett, B. Blake, and B. A. McCarl, "Goal programming via multidimensional scaling applied to senegalese subsistence farms," *American Journal of Agricultural Economics*, vol. 64, no. 4, pp. 720–727, 1982.

[122] A. N. Rae, "An empirical application and evaluation of discrete stochastic programming in farm management," *American Journal of Agricultural Economics*, vol. 53, no. 4, pp. 625–638, 1971.

[123] A. M. Featherstone, P. V. Preckel, T. G. Baker, *et al.*, "Modeling farm financial decisions in a dynamic and stochastic environment.," *Agricultural Finance Review*, vol. 50, pp. 80–99, 1990.

[124] C. R. Taylor *et al.*, *Applications of dynamic programming to agricultural decision problems.* Westview Press, Inc., 1993.

[125] O. R. Burt, "Optimal replacement under risk," *Journal of Farm Economics*, vol. 47, no. 2, pp. 324–346, 1965.

[126] D. Yaron and A. Dinar, "Optimal allocation of farm irrigation water during peak seasons," *American Journal of Agricultural Economics*, vol. 64, no. 4, pp. 681–689, 1982.

[127] A. Stoecker, A. Seidmann, and G. Lloyd, "A linear dynamic programming approach to irrigation system management with depleting groundwater," *Management Science*, vol. 31, no. 4, pp. 422–434, 1985.

[128] J. Danielson and C. Taylor, *Optimal Crop Rotation to control Cephalosporium Stripe in Winter Wheat.* Boulder, CO: Westview Press, 1993.

[129] P. Anderson, "Perspective: Complexity theory and organization science," *Organization Science*, vol. 10, no. 3, pp. 216–232, 1999.

[130] N. Schieritz, "Integrating system dynamics and agent-based modeling," in *Proceedings of the XX International Conference of the System Dynamics society*, 2002.

[131] D. T. Robinson, D. G. Brown, D. C. Parker, P. Schreinemachers, M. A. Janssen, M. Huigen, H. Wittmer, N. Gotts, P. Promburom, E. Irwin, *et al.*, "Comparison of empirical methods for building agent-based models in land use science," *Journal of Land Use Science*, vol. 2, no. 1, pp. 31–55, 2007.

[132] S. A. Saseendran, K. G. Hubbard, K. K. Singh, N. Mendiratta, L. S. Rathore, and S. V. Singh, "Optimum transplanting dates for rice in kerala, india, determined using both ceres v3. 0 and climprob," *Agronomy Journal*, vol. 90, no. 2, pp. 185–190, 1998.

[133] M. Delfieh, M. Meskarbashi, B. Andarzian, and R. Farhoudi, "Simulating the effects of planting date and nitrogen fertilizer on yield and phenological stages of maize cultivar sc-604 under climatic conditions of south-western iran using ceres-maize model," *Research on Crops*, vol. 12, no. 2, pp. 326–335, 2011.

[134] A. Ben-Tal and A. Nemirovski, "Robust convex optimization," *Mathematics of Operations Research*, vol. 23, no. 4, pp. 769–805, 1998.

[135] D. Bertsimas and M. Sim, "The price of robustness," *Operations Research*, vol. 52, no. 1, pp. 35–53, 2004.

[136] A. Ben-Tal, B. Golany, A. Nemirovski, and J.-P. Vial, "Retailer-supplier flexible commitments contracts: a robust optimization approach," *Manufacturing & Service Operations Management*, vol. 7, no. 3, pp. 248–271, 2005.

[137] A. Higgins, P. Thorburn, A. Archer, and E. Jakku, "Opportunities for value chain research in sugar industries," *Agricultural Systems*, vol. 94, no. 3, pp. 611–621, 2007.

[138] M. Dawande, S. Gavirneni, M. Mehrotra, and V. Mookerjee, "Efficient distribution of water between head-reach and tail-end farms in developing countries," *Manufacturing & Service Operations Management*, vol. 15, no. 2, pp. 221–238, 2013.

[139] S. Goyal and B. C. Giri, "Recent trends in modeling of deteriorating inventory," *European Journal of Operational*

Research, vol. 134, no. 1, pp. 1–16, 2001.

[140] J. D. Johnson, *Managing variability in the semiconductor supply chain.* PhD thesis, Massachusetts Institute of Technology, 2005.

[141] A. J. Schmitt and M. Singh, "A quantitative analysis of disruption risk in a multi-echelon supply chain," *International Journal of Production Economics*, vol. 139, no. 1, pp. 22–32, 2012.

[142] X. Qi, J. F. Bard, and G. Yu, "Supply chain coordination with demand disruptions," *Omega*, vol. 32, no. 4, pp. 301–312, 2004.

[143] J. Li, X. Liu, J. Wu, and F. Yang, "Coordination of supply chain with a dominant retailer under demand disruptions," *Mathematical Problems in Engineering*, vol. 2014, 2014.

[144] I. Horowitz, "On two-source factor purchasing," *Decision Sciences*, vol. 17, no. 2, pp. 274–279, 1986.

[145] P. Kelle and E. Silver, "Decreasing expected shortages through order splitting," *Engineering Costs and Production Economics*, vol. 19, no. 1-3, pp. 351–357, 1990.

[146] R. V. Ramasesh, J. K. Ord, J. C. Hayya, and A. Pan, "Sole versus dual sourcing in stochastic lead-time (s, q) inventory models," *Management Science*, vol. 37, no. 4, pp. 428–443, 1991.

[147] S. G. Gülen, "Regionalization in the world crude oil market," *The Energy Journal*, pp. 109–126, 1997.

[148] A. Hsu and Y. Bassok, "Random yield and random demand in a production system with downward substitution," *Operations Research*, vol. 47, no. 2, pp. 277–290, 1999.

[149] B. Tomlin and Y. Wang, "Pricing and operational recourse in coproduction systems," *Management Science*, vol. 54, no. 3, pp. 522–537, 2008.

[150] M. Goyal and S. Netessine, "Volume flexibility, product flexibility, or both: The role of demand correlation and product substitution," *Manufacturing & service operations management*, vol. 13, no. 2, pp. 180–193, 2011.

[151] M. Ganesh, S. Raghunathan, and C. Rajendran, "The value of information sharing in a multi-product supply chain with product substitution," *Lie Transactions*, vol. 40, no. 12, pp. 1124–1140, 2008.

[152] Q. Qiang, A. Nagurney, and J. Dong, "Modeling of supply chain risk under disruptions with performance measurement and robustness analysis," in *Managing Supply Chain Risk and Vulnerability*, pp. 91–111, Springer, 2009.

[153] T. Sawik, "On the robust decision-making in a supply chain under disruption risks," *International Journal of Production Research*, vol. 52, no. 22, pp. 6760–6781, 2014.

[154] K. Zhao, A. Kumar, T. P. Harrison, and J. Yen, "Analyzing the resilience of complex supply network topologies against random and targeted disruptions," *IEEE Systems Journal*, vol. 5, no. 1, pp. 28–39, 2011.

[155] Y. Kim, Y.-S. Chen, and K. Linderman, "Supply network disruption and resilience: A network structural perspective," *Journal of Operations Management*, vol. 33, pp. 43–59, 2015.

[156] A. E. Nejad, I. Niroomand, and O. Kuzgunkaya, "Responsive contingency planning in supply risk management by considering congestion effects," *Omega*, vol. 48, pp. 19–35, 2014.

[157] T. Sawik, "Selection of resilient supply portfolio under disruption risks," *Omega*, vol. 41, no. 2, pp. 259–269, 2013.

[158] L. V. Snyder, M. P. Scaparra, M. S. Daskin, and R. L. Church, "Planning for disruptions in supply chain networks," in *Models, Methods, and Applications for Innovative Decision Making*, pp. 234–257, INFORMS, 2006.

[159] G. N. Gilbert, *Agent-based models.* No. 153, SAGE, 2008.

[160] H. V. D. Parunak, R. Savit, R. L. Riolo, and S. J. Clark, *DASCh: Dynamic analysis of supply chains.* DASCh Final Report, Part 0, Executive Summary, 1997.

[161] W. S. Lim, "Producer-supplier contracts with incomplete information," *Management Science*, vol. 47, no. 5,

pp. 709–715, 2001.