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## Article

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Journal of Industrial Engineering and Management (JIEM)

## Provided in Cooperation with:

The School of Industrial, Aerospace and Audiovisual Engineering of Terrassa (ESEIAAT), Universitat Politècnica de Catalunya (UPC)

*Suggested Citation:* Mirabelli, Giovanni; Solina, Vittorio (2022) : Optimization strategies for the integrated management of perishable supply chains: A literature review, Journal of Industrial Engineering and Management (JIEM), ISSN 2013-0953, OmniaScience, Barcelona, Vol. 15, Iss. 1, pp. 58-91,  
<https://doi.org/10.3926/jiem.3603>

This Version is available at:

<https://hdl.handle.net/10419/261787>

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## Optimization Strategies for the Integrated Management of Perishable Supply Chains: A Literature Review

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Received: May 2021

Accepted: October 2021

### Abstract:

**Purpose:** The main purpose of this article is to systematically review the papers published in the period 2005-2020 about the integration of production, inventory and distribution activities in perishable supply chains.

**Design/methodology/approach:** The proposed research methodology is based on several steps. First, database and keywords are selected, with the aim to search and collect the main papers, dealing with the integration of production, inventory, distribution activities in perishable supply chains. Then, a bibliometric analysis is carried out, to detect: the main publishing sources, the chronological distribution, the most used keywords, the featured authors, about the selected papers. A five-dimension classification framework is proposed to carry out a content analysis, where the papers of the literature review are classified and discussed, according to: supply chain structure, objective, perishability type, solution approach, approach validation.

**Findings:** Interest in the application of optimization models for integrated decision-making along perishable supply chains is strongly growing. Integrating multiple stages of the supply chain into a single framework is complex, especially when referring to perishable products. The vast majority of the problems addressed are then NP-Hard. Only a limited quantity of the selected papers aims to solve real-life case studies. There is a need for further research, which is capable of modeling and quantitatively improving existing supply chains. The potentials of Industry 4.0 are currently little explored.

**Originality/value:** Based on the analysis of the papers published, this article outlines the current state of the art on the optimization strategies for the integrated management of perishable supply chains, which are very complex to be managed. Research trends and gaps are discussed, future challenges are presented.

**Keywords:** literature review, perishable products, supply chain management, inventory management, production, distribution

### To cite this article:

Mirabelli, G., & Solina, V. (2022). Optimization strategies for the integrated management of perishable supply chains: A literature review. *Journal of Industrial Engineering and Management*, 15(1), 58-91.  
<https://doi.org/10.3926/jiem.3603>

## 1. Introduction

In its most traditional form, a supply chain (SC) is characterized by four main actors or stages: suppliers, manufacturers, distributors and customers (Kumar, Ganapathy, Gokhale & Tiwari, 2020). Variety and heterogeneity of stakeholders, who often have conflicting objectives, make the design and management of supply chains an extremely difficult task (Diabat, Abdallah & Le, 2016; Hammami, Frein & Bahli, 2017). According to Bank, Mazdeh and Heydary (2020), supply chain management (SCM) is the process that aims to efficiently integrate the different stages of the supply chain with the aim of delivering the right number of products at the right time to end users. SCM usually means making decisions at different levels: strategic, tactical, and operational, based on the temporal impact (Diabat & Theodorou 2015; Miller, 2002). Strategic decisions have a long-term impact, usually years, in fact they cannot be easily changed as they involve significant investments (e.g., location-allocation decisions). Tactical decisions, on the other hand, have mid-term effects (i.e., months) and most often concern inventory management. Finally, operational decisions usually have a daily or weekly impact and frequently concern scheduling and routing decisions (Hiassat, Diabat & Rahwan, 2017; Rafie-Majd, Pasandideh & Naderi, 2018).

Growing globalization is leading companies around the world to compete not only on price and product quality, but also on the reliability of deliveries. In fact, customers are really more demanding and expert (Guido, Mirabelli, Palermo & Solina, 2020). For these reasons, research in the area of SCM has undergone a dramatic increase in recent years, focusing on the integrated planning of production, storage and distribution activities (Viergutz & Knust, 2014). The integration between different levels of supply chain decisions usually leads to multiple benefits. The pioneering research work by Chandra and Fisher (1994) states that 3-20 % cost savings can be achieved through integrated planning of production and distribution activities. In the literature, there are many other pioneering experiments in integrated planning, with good results in terms of overall efficiency (Thomas & Griffin, 1996; Fumero & Vercellis, 1999). Supply chain integration increases flexibility with respect to customer requests, reduces waste, then promotes a more sustainable perspective (Dai, Gao & Giri, 2020). It should be emphasized that traditional and conventional approaches were based on the separate and sequential optimization of each SC stage. Optimizing independently the costs of each actor leads to an increase in SC total costs, due to the lack of coordination. On the contrary, coordinated SCs are characterized by lower overall costs and higher profits (Bank et al., 2020; Chan, Wang, Goswami, Singhania & Tiwari, 2020). Basically, the optimization of a certain local problem can significantly affect the solution quality of subsequent problems, to the detriment of the overall SC solution (Neves-Moreira, Almada-Lobo, Cordeau, Guimares & Jans, 2019). Integrated planning is extremely useful especially in make-to-order (MTO) environments, where finished products usually have to be delivered to the customers shortly after production, in order to guarantee a good service level. In this case, the lack of production-distribution alignment could lead to: (i) significant quality decay such as to make the product undesirable for the customer (e.g., production activities are scheduled too in advance with respect to distribution operations), (ii) failure to meet delivery deadlines (e.g., the completion of production activities occurs too late with respect to the availability of the means of transport for distribution) (Marandi & Zegordi, 2017; Armstrong, Gao & Lei, 2008; Stecke & Zhao, 2007).

SCM is even more challenging when dealing with perishable products (Castro & Jaimes, 2017; Castro, Cabrera & Jaimes, 2021; Solina & Mirabelli, 2021). According to Amorim, Meyr, Almeder and Almada-Lobo (2013), a good can be considered perishable if at least one of the following conditions takes place during a well-defined planning horizon: (1) its physical status deteriorates, (2) its value decreases according to an internal or external customer, (3) there is the risk of possible future reduced functionality, based on the opinion of some authority. These authors generically refer to raw materials, semi-finished products, or finished products. In the literature, there are two main types of perishable products. In the first case, we can speak of fixed-lifetime products because they are characterized by a well-defined expiry date, beyond which they must be discarded; traditional examples are dairy products and pharmaceuticals (i.e., when the shelf-life is printed on the product). This category also includes products that become obsolete after a relatively short time period, for example Christmas items, hi-tech goods, fashion apparel, calendars, yearbooks (Jadidi, Jaber & Zolfaghari, 2017; Coelho & Laporte, 2014). In the second case, instead, deterioration occurs over time in such a way that the product gradually loses its value during storage, until it becomes non-consumable. Fruits, vegetables, flowers, bread are only a few examples (Rong, Akkerman & Grunow, 2011). Basically, in the latter case, shelf-life is not predetermined and the inventory replenishment

decisions are extremely critical and challenging (Palak, Eksioglu & Geunes, 2018; Rohmer, Claassen & Laporte, 2019). Perishability affects multiple fields. In the health sector, kidney or heart transplants are strongly influenced by the perishable nature of the organ (Zahiri, Tavakkoli-Moghaddam & Pishvaei, 2014), in the pharmaceutical field, chemical composition of medicines determines the period of time within which they are still effective (Chung & Kwon, 2016), in hospitals a correct blood bank management is crucial for patient health (Najafi, Ahmadi & Zolfagharinia, 2017). However, the agri-food sector is probably the one in which the perishable nature of goods affects decision-making the most. The agri-food supply chains are often characterized by frequent customer orders of small quantities, tight time windows for deliveries, yield and demand uncertainty. Therefore, the related optimization models are often extremely complex to solve through exact methods, from the computational point of view, and heuristic quantitative approaches are necessary in order to determine good solutions in a reasonable time. In this context, real-time information sharing between the players in the chain becomes a key-factor to ensure an adequate service level while minimizing costs. The lack of coordination in the food supply chains mainly causes (i) unharvested fruits and/or vegetables upstream, while (ii) unsold products downstream. In both cases, bad operations management causes waste, which must be disposed of with consequent increase in costs and pollution, due to further transport.

The main purpose of this study is to systematically review the papers published in the 2005-2020 period about the integrated management of perishable supply chains (IMPSCs). Our review aims to answer the following research questions:

- RQ1. How much research has been conducted, in the last years, on the IMPSCs?
- RQ2. Which journals and authors have contributed most to the literature on the IMPSCs?
- RQ3. What aspects characterize perishable supply chains, when they are addressed according to an integrated perspective?
- RQ4. What are the most recurring objectives within the IMPSCs?
- RQ5. What are the most used approaches for solving problems within the IMPSCs and how are they validated?
- RQ6. How is the concept of perishability modeled and treated within the IMPSCs?
- RQ7. What are the research gaps and future challenges in the field of IMPSCs?

With the aim to find exhaustive answers to these questions, our paper critically reviews the existing issues in IMPSCs literature, which is discussed in the subsequent sections. In particular, an original five-dimension classification framework is proposed, in order to categorize all the reviewed papers.

### 1.1. Other Literature Reviews and our Contribution

In this section, we summarize the other literature reviews, in which supply chain integration is discussed, in order to make our contribution as clear as possible.

Bilgen and Ozkarahan (2004) provide a literature survey on supply chain management at the strategic, tactical and operational levels. In particular, they focus their attention on models concerning the problems of production and distribution. The goal is to provide a classification according to the solution approach used: optimization-based methodologies, meta-heuristic-based models, information-technology-driven models, hybrid models. Finally, the most significant research trends are revealed. Mula, Peidro, Diaz-Madronero and Vicens (2010) propose a literature review on mathematical programming models for supply chain production and transport planning. The 44 reviewed papers, covering a period of 20 years (i.e., 1989-2009), are classified and discussed on the basis of some criteria (see Table 1). A detailed review of tactical optimization models for integrated production and transport routing planning decisions is presented by Diaz-Madronero, Peidro and Mula (2015). The authors analyze 22 papers over 20 years (1994-2014) and propose a classification framework, based on the following criteria: production, inventory, and routing aspects, objective function, solution approach. Soto-Silva, Nadal-Roig, Gonzalez-Araya and Pla-Aragones (2016) propose an interesting survey about the application of operational research models to the fresh fruit supply chain. The selected papers are classified according to: decision level (i.e., strategic, tactical,

operational), modeling approach, purpose, applicability, novelty. The literature review by Moons, Ramaekers, Caris and Arda (2017) focuses on the integration of production scheduling and vehicle routing decisions at the operational level. The 33 selected papers are first divided into 3 main groups (i.e., single-machine environment, parallel-machine environment, other machine environments) and then classified according to production, inventory, and distribution features, objective, solution approaches.

In Table 1, we summarize the main features of the other literature reviews. In particular, we highlight the reference period and the number of papers reviewed. Furthermore, we show according to which dimensions the collected papers have been classified. As it can be seen, there is no other survey focused on the integration of supply chain activities, in which the papers are jointly classified on the basis of the five dimensions of our framework: supply chain structure, objective function, solution approach, approach validation, perishability type.

Basically, we propose a literature review, where papers dealing with perishable items are collected and classified. One of the main goals is to highlight the most used approaches to address perishability and limit food waste, in order to make supply chains more sustainable. Perishability significantly affects revenue, as goods subject to deterioration are usually sold in accordance with discount policies (Chen, Wu, Wang & Li, 2019), but also costs, as it is necessary to take into account additional requirements regarding production (e.g., restricted time constraints), storage (e.g., refrigerated inventories), and transportation activities (e.g., refrigerated vehicles) (Meneghetti & Monti, 2015; Meneghetti & Ceschia, 2020; Castro & Jaimes, 2017; Giallombardo, Mirabelli & Solina, 2021). Furthermore, the main consequences of decay are lost sales and disposal costs. According to Rohmer et al. (2019), in today's competitive markets, the quality and freshness of food products significantly influence customer satisfaction (Guido et al. 2020), therefore they are fundamental aspects for the survival of each business. Moreover, we review 54 articles, which is quite a significant number when compared to many past literature reviews. It should be noted that there are also other literature reviews on perishable (or in general agri-food) supply chains, but they are not focused on the integration of production, inventory, distribution activities (Siddh, Soni & Jain, 2015; Ganesh-Kumar, Murugaiyan & Madanmohan, 2017; Vrat, Gupta, Bhatnagar, Pathak & Fulzele, 2018).

The remainder of this paper is organized as follows. In Section 2, we give all the details on our research methodology. Section 3 presents a bibliometric analysis about the selected papers. Section 4 is a content analysis, where our classification framework is applied. In Section 5, we outline the main current research gaps, the possible future challenges. Section 6 shows some conclusions.

Reference	# Papers reviewed	Time horizon	SCS	OF	SOA	AV	PT
Bilgen & Ozkarahan (2004)	N.A.	N.A.	-	-	✓	-	-
Mula et al. (2010)	44	1989-2009	✓	✓	✓	✓	-
Diaz-Madronero et al. (2015)	22	1994-2014	✓	✓	✓	-	-
Soto-Silva et al. (2016)	44 (28+16)	1976-2015	-	-	✓	✓	-
Moons et al. (2017)	33	1996-2016	✓	✓	✓	-	-
Our paper	54	2005-2020	✓	✓	✓	✓	✓

AV: Approach Validation; OF: Objective Function; PT: Perishability Type; SOA: Solution Approach; SCS: Supply Chain Structure

Table 1. Comparison between our paper and the other literature reviews

## 2. Research Methodology

In this section, we describe the research methodology used to carry out our literature review. It is characterized by several steps in sequence, as shown in Figure 1.

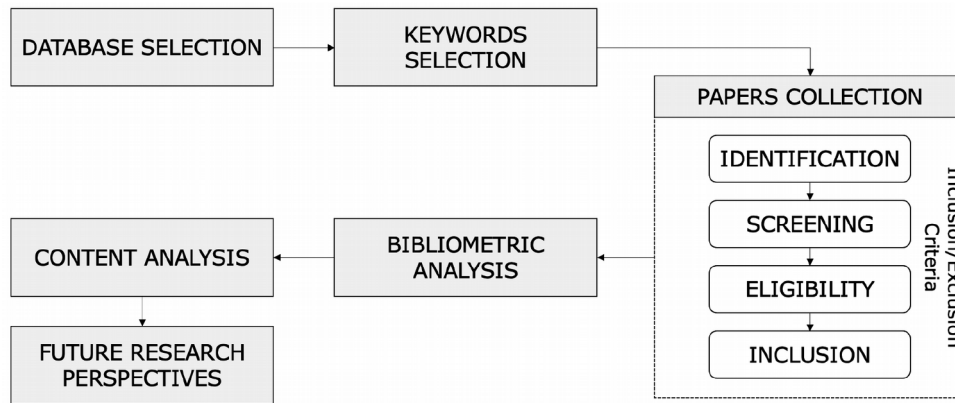


Figure 1. Research Methodology Scheme

First of all, it is necessary to select one or more databases within which to retrieve the records useful for conducting the survey. Several scientific databases exist. We have decided to query Scopus, which is currently one of the most recognized and comprehensive databases. It contains more than 20,000 peer reviewed journals related to different publishers (e.g., Elsevier, Taylor & Francis, IEEE) and is much more exhaustive than others (e.g., Web of Science, IEEE Explore). Scopus was queried at the end of 2020. The second step of the methodology concerns the keywords selection to carry out the database queries. The main purpose of our study is to collect research works, where quantitative approaches to integrate decisions related to production, storage and distribution activities, are proposed. Therefore, we have decided (i) to combine the keywords linked to these 3 areas (i.e., production, storage and distribution), and (ii) to consider in any case the distribution issues and the perishable nature of the products. Altogether, six queries were conducted, the results of which are shown in Table 2. We have used specific search criteria (see Table 3).

# Search	Keywords combination	Result
1	“Production distribution” AND “perishable”	109
2	“Production transportation” AND “perishable”	64
3	“Production routing” AND “perishable”	30
4	“Inventory routing” AND “perishable”	51
5	“Inventory transportation” AND “perishable”	68
6	“Inventory distribution” AND “perishable”	192
	Total (after removing duplicates)	366

Table 2. Database queries: results

Search criterion	Selection
Search field	Article title, Abstract, Keywords
Years	2005-2020
Subject areas	All
Document type	Journal Article
Language	English

Table 3. Search criteria



The result of this first search was a set of 366 documents, which were reduced to 88 after reading their title and abstract. Then, after reading the full-text, it was decided to include only 54 documents, as shown in Table 4. Basically, the following exclusion criteria were applied:

- Articles not based on quantitative approaches (intended mainly as optimization models).
- Articles not relevant to the topic.
- Articles, where there is no explicit integration between 2 or more activities (i.e., production, inventory, distribution) of the perishable supply chain.

Reference	Title	Journal
Zanoni & Zavanella (2007)	Single-vendor single-buyer with integrated transport-inventory system: Models and heuristics in the case of perishable goods	Computers and Industrial Engineering
Naso, Surico & Turchiano (2007)	Reactive scheduling of a distributed network for the supply of perishable products	IEEE Transactions on Automation Science and Engineering
Chen, Hsueh & Chang (2009)	Production scheduling and vehicle routing with time windows for perishable food products	Computers and Operations Research
Ahumada & Villalobos (2011a)	A tactical model for planning the production and distribution of fresh produce	Annals of Operations Research
Ahumada & Villalobos (2011b)	Operational model for planning the harvest and distribution of perishable agricultural products	International Journal of Production Economics
Ahumada, Villalobos & Mason (2012)	Tactical planning of the production and distribution of fresh agricultural products under uncertainty	Agricultural Systems
Amorim, Gunther & Almada-Lobo (2012)	Multi-objective integrated production and distribution planning of perishable products	International Journal of Production Economics
Farahani, Grunow & Gunther (2012)	Integrated production and distribution planning for perishable food products	Flexible Services and Manufacturing Journal
Amorim et al. (2013)	Managing perishability in production-distribution planning: A discussion and review	Flexible Services and Manufacturing Journal
AriaNezhad, Makuie & Khayatmoghadam (2013)	Developing and solving two-echelon inventory system for perishable items in a supply chain: case study (Mashhad Behrouz Company)	Journal of Industrial Engineering International
Le, Diabat, Richard & Yih (2013)	A column generation-based heuristic algorithm for an inventory routing problem with perishable goods	Optimization Letters
Coelho & Laporte (2014)	Optimal joint replenishment, delivery and inventory management policies for perishable products	Computers and Operations Research
Seyedhosseini & Ghoreyshi (2014a)	An integrated model for production and distribution planning of perishable products with inventory and routing considerations	Mathematical Problems in Engineering
Seyedhosseini & Ghoreyshi (2014b)	Integration of production and distribution decisions of perishable products considering feasible delivery routes	International Journal of Applied Management Science
Viergutz & Knust (2014)	Integrated production and distribution scheduling with lifespan constraints.	Annals of Operations Research

Reference	Title	Journal
Soysal, Bloemhof-Ruwaard, Haijema & van der Vorst (2015)	Modeling an Inventory Routing Problem for perishable products with environmental considerations and demand uncertainty	International Journal of Production Economics
Mirzaei & Sei (2015)	Considering lost sale in inventory routing problems for perishable goods	Computers and Industrial Engineering
Seyedhosseini & Ghoreyshi (2015)	An integrated production and distribution planning model for perishable products	International Journal of Operational Research
Belo-Filho, Amorim & Almada-Lobo (2015)	An adaptive large neighborhood search for the operational integrated production and distribution problem of perishable products	International Journal of Production Research
Wu, Shen & Zhu (2015)	A multi-period location model with transportation economies-of-scale and perishable inventory	International Journal of Production Economics
Bortolini, Faccio, Ferrari, Gamberi & Pilati (2016)	Fresh food sustainable distribution: Cost, delivery time and carbon footprint three-objective optimization	Journal of Food Engineering
Shaabani & Kamalabadi (2016)	An efficient population-based simulated annealing algorithm for the multi-product multi-retailer perishable inventory routing problem	Computers and Industrial Engineering
Li, Chu, Yang & Calvo (2016)	A Production Inventory Routing Planning for Perishable Food with Quality Consideration	IFAC-PapersOnLine
Diabat et al. (2016)	A hybrid tabu search based heuristic for the periodic distribution inventory problem with perishable goods	Annals of Operations Research
Vahdani, Niaki & Aslanzade (2017)	Production-inventory-routing coordination with capacity and time window constraints for perishable products: Heuristic and meta-heuristic algorithms	Journal of Cleaner Production
Rahimi, Baboli & Rekik (2017)	Multi-objective inventory routing problem: A stochastic model to consider profit, service level and green criteria	Transportation Research Part E: Logistics and Transportation Review
Devapriya, Ferrell & Geismar (2017)	Integrated production and distribution scheduling with a perishable product	European Journal of Operational Research
Marandi & Zegordi (2017)	Integrated production and distribution scheduling for perishable products	Scientia Iranica
Li, Chu & Chen (2017)	Coordinated Production Inventory Routing Planning for Perishable Food	IFAC-PapersOnLine
Azadeh, Elahi, Farahani & Nasirian (2017)	A genetic algorithm-Taguchi based approach to inventory routing problem of a single perishable product with transshipment	Computers and Industrial Engineering
Hiassat et al. (2017)	A genetic algorithm approach for location-inventory-routing problem with perishable products	Journal of Manufacturing Systems
Accorsi, Gallo & Manzini (2017)	A climate driven decision-support model for the distribution of perishable products	Journal of Cleaner Production
Lacomme, Moukrim, Quilliot & Vinot (2018)	Supply chain optimisation with both production and transportation integration: multiple vehicles for a single perishable product	International Journal of Production Research
Crama, Rezaei, Savelsbergh & Van Woensel (2018)	Stochastic inventory routing for perishable products	Transportation Science



Reference	Title	Journal
Rafie-Majd et al. (2018)	Modelling and solving the integrated inventory-location-routing problem in a multi-period and multi perishable product supply chain with uncertainty: Lagrangian relaxation algorithm	Computers and Chemical Engineering
Soysal, Bloemhof-Ruwaard, Haijema & van der Vorst (2018)	Modeling a green inventory routing problem for perishable products with horizontal collaboration	Computers and Operations Research
Hu, Toriello & Dessouki (2018)	Integrated inventory routing and freight consolidation for perishable goods	European Journal of Operational Research
Dolgui, Tiwari, Sinjana, Kumar & Son (2018)	Optimising integrated inventory policy for perishable items in a multi-stage supply chain	International Journal of Production Research
Neves-Moreira et al. (2019)	Solving a large multi-product production-routing problem with delivery time windows	Omega
Chao, Zhihui & Baozhen (2019)	Optimization of two-stage location-routing-inventory problem with time-windows in food distribution network	Annals of Operations Research
Qiu, Qiao & Pardalos (2019)	Optimal production, replenishment, delivery, routing and inventory management policies for products with perishable inventory	Omega
Ghasemkhani, Tavakkoli-Moghaddam, Shahnejat-Bushehri, Momen & Tavakkoli-Moghaddam (2019)	An integrated production inventory routing problem for multi perishable products with fuzzy demands and time windows	IFAC-PapersOnLine
Onggo, Panadero, Corlu & Juan (2019)	Agri-food supply chains with stochastic demands: A multi-period inventory routing problem with perishable products	Simulation Modelling Practice and Theory
Rohmer et al. (2019)	A two-echelon inventory routing problem for perishable products	Computers and Operations Research
Violi, Laganà & Paradiso (2020)	The inventory routing problem under uncertainty with perishable products: an application in the agri-food supply chain	Soft Computing
Li, Chu, Coté, Coelho & Chu (2020)	The multi-plant perishable food production routing with packaging consideration	International Journal of Production Economics
Wei, Guan, Liu, Gao & Zhang (2020)	Production, replenishment and inventory policies for perishable products in a two-echelon distribution network	Sustainability
Manouchehri, Nookabadi & Kadivar (2020)	Production routing in perishable and quality degradable supply chains	Heliyon
Sinha & Anand (2020)	Optimizing supply chain network for perishable products using improved bacteria foraging algorithm	Applied Soft Computing Journal
Chan et al. (2020)	Multi-objective particle swarm optimisation based integrated production inventory routing planning for efficient perishable food logistics operations	International Journal of Production Research
Liu & Liu (2020)	Integrated production and distribution problem of perishable products with a minimum total order weighted delivery time	Mathematics
Bank et al. (2020)	Applying meta-heuristic algorithms for an integrated production-distribution problem in a two level supply chain	Uncertain Supply Chain Management

Reference	Title	Journal
Biuki, Kazemi & Alinezhad (2020)	An integrated location-routing-inventory model for sustainable design of a perishable products supply chain network	Journal of Cleaner Production
Dai et al. (2020)	A hybrid heuristic algorithm for cyclic inventory-routing problem with perishable products in VMI supply chain	Expert Systems with Applications

Table 4. Selected papers

### 3. Bibliometric Analysis

In this section, we show the results of our bibliometric analysis, which was partly supported by the free software VOSviewer (1.6.13 version) (Van Eck & Waltman, 2009). We refer only to the 54 selected papers.

#### 3.1. Publishing Sources

In Table 5, the distribution of the 54 reviewed articles across the journals is shown. The top 9 journals have published around 60% of the articles (i.e., 32), and the International Journal of Production Economics is the most prolific, with 6 papers. It is followed by Annals of Operations Research, Computers & Industrial Engineering, Computers & Operations Research, International Journal of Production Research, all with 4 contributions. Considering that we have selected only documents, where optimization models are used to deal with perishable supply chains issues, this result is in line with our expectations because the most prolific journals concern the “Management Science and Operations Research” area.

Journal	# Articles	% Contribution
International Journal of Production Economics	6	11.11
Annals of Operations Research	4	7.41
Computers & Industrial Engineering	4	7.41
Computers & Operations Research	4	7.41
International Journal of Production Research	4	7.41
IFAC-PapersOnLine	3	5.56
Journal of Cleaner Production	3	5.56
European Journal of Operational Research	2	3.70
Omega	2	3.70
Others	22	40.74
Total	54	100.00

Table 5. Distribution of the 54 selected papers across the journals

#### 3.2. Chronological Distribution

With the aim to have an idea about the interest over the years in supply chain coordination strategies in the case of perishable products, in Figure 2 we show a graph relating to the temporal distribution of the selected papers with reference to the period 2005-2020. As it can easily be seen, interest in the topic of this literature review has grown considerably in recent years. This trend is quite expected for several reasons. In recent years, the development of global markets and higher customer expectations have forced the supply chain players to better coordinate and integrate their plans, in order to maintain high levels of performance and be competitive on the market. Today, in fact, companies compete not only on product price or quality, but also on the reliability and timeliness of deliveries. Therefore, academic interest in models capable of jointly optimizing the production, storage and distribution of perishable goods has significantly grown recently.

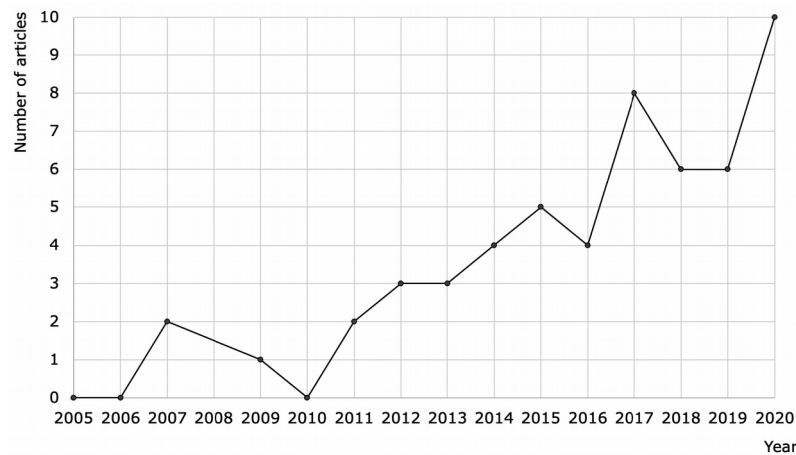


Figure 2. Distribution of the 54 selected papers over the years

### 3.3. Statistics on Keywords

It is also very interesting to highlight the keywords most frequently used by the authors, in order to identify the most recurring research areas. Since the VOSviewer software is unable neither to distinguish between singular and plural nor between words that have the same root and meaning, similar keywords have been merged. In Table 6, for each overall keyword, the list of keywords from which it derives, and the overall number of occurrences, are shown. A hyphen means that the related overall keyword has not changed from the original one.

Original keywords	Overall keyword	# Occurrences
Perishable good, Perishable goods, Perishable product, Perishable products	Perishable good(s)/product(s)	38
Inventory-routing, Inventory routing, Inventory routing problem	Inventory routing (problem)	13
Vehicle routing, Vehicle routing problem	Vehicle routing (problem)	7
-	Supply chain	6
-	Perishability	6
Genetic algorithm, Genetic algorithm(s)	Genetic algorithm(s)	6
-	Food quality	4
-	Production scheduling	4
Metaheuristic, Meta-heuristic, Meta-heuristic algorithm, Metaheuristics	Metaheuristic(s) (algorithm)	4
Production and distribution, Production and distribution planning	Production and distribution (planning)	4
Time window, Time windows	Time window(s)	4

Table 6. Statistics on keywords

Based on the keywords combination used to carry out the search (i.e., in each query, the word “perishable” is present), as expected, the perishability-related keywords are the most frequently used. However, from the above analysis, some important research trends emerge. First of all, it is possible to state that the distribution stage is often addressed and modelled through a vehicle routing problem (VRP). In its most traditional form, a VRP aims to find an optimal set of routes for a vehicle fleet to serve a certain number of customers, while minimizing the total traveling cost (Vidal, Laporte & Matl, 2020). In this context, it is important to underline that the high number of occurrences of the overall keywords “Inventory routing (problem)” and “Vehicle routing (problem)” was certainly influenced by a couple of combinations used to conduct the queries: “production routing” and “inventory routing”. The overall keyword “Time window(s)” suggests that the requirement to serving customers within

delivery time windows is also taken into account. Moreover, many papers deal with an inventory routing problem (IRP), which is an extension of the VRP, where inventory control and routing decisions are combined (Rafie-Majd et al., 2018). The occurrence of the overall keywords “Genetic algorithm(s)” and “Metaheuristic(s) (algorithm)” is not a surprise because when different supply chain stages are integrated into a single monolithic problem, non-exact approaches are often necessary to find good solutions in a reasonable time. In fact, the large set of decisions and factors to be jointly considered often result in computationally intractable problems (Neves-Moreira et al., 2019).

### 3.4. Featured Authors

In Table 7, the information about the top contributing authors and their relative institution and country, is shown.

Author	Institution	Country	# Articles
Almada-Lobo, B.	Universidade do Porto	Portugal	4
Amorim, P.	Universidade do Porto	Portugal	3
Chu, F.	Université Paris-Saclay, Fuzhou University	France, China	3
Li, Y.	Université Paris-Saclay, Academy of Military Science of the Chinese People's Liberation Army	France, China	3
Ghoreyshi, S.M.	Iran University of Science & Technology	Iran	3
Seyedhosseini, M.	Iran University of Science & Technology	Iran	3
Ahumada, O.	Universidad Autonoma de Occidente	Mexico	3
Diabat, A.	New York University Abu Dhabi, New York University	United Arab Emirates, United States	3

Table 7. Top contributing authors

Almada-Lobo B. is the most prolific author with 4 publications. He has co-authored three of them with Amorim P. (Amorim et al., 2012, 2013; Belo-Filho et al., 2015). Their research area has mainly focused on addressing the integrated production and distribution planning with perishable products, from an operational point of view. A quite similar topic has been treated by Ghoreyshi S.M. and Seyedhosseini M. in their co-authored papers (Seyedhosseini and Ghoreyshi, 2014a, 2014b, 2015). Chu F. and Li Y. has instead co-authored 3 articles, mainly focused on modelling and solving some interesting variants of the production-inventory-routing problem with perishable goods (Li et al., 2016, 2017, 2020). The peculiarity of the three Ahumada's papers concerns the study of agri-food supply chains (i.e., pepper and tomato), with a lot of attention to the harvesting stage and the possibility of multiple transportation modes (e.g., trucking, railroad, air) for what concerns the distribution stage (Ahumada & Villalobos, 2011a, 2011b; Ahumada et al., 2012). Diabat, A. has considered both the location-inventory-routing problem and the inventory-routing problem in his studies (Le et al., 2013; Diabat et al., 2016; Hiassat et al., 2017). In Table 8, we show the 10 countries, which have the highest number of documents, based on the origin of the authors. Iran and United States are the most prolific. Moreover, we can state that the challenge of integrating decision-making in perishable supply chains has been taken up to a quite similar extent in 3 continents, namely Europe, Asia, America. As mentioned, globalization has involved companies and supply chains all over the world, therefore it is not possible to identify a specific country for which these problems are much more acute than others.

With the aim to better understand the influence of the various authors on the topic of this paper, in Figure 3 we provide a citation network analysis regarding the authors of the 54 selected papers, performed through VOSviewer.

Almada-Lobo B. and Ahumada O. are the most cited authors, but the first one, as it can be easily seen from Figure 3, is much more connected with the other selected papers. Diabat A., Laporte G. and Coelho L.C. are the three authors with the highest “Total link strength”, which means their papers are very influential for what concerns the topic addressed in this manuscript.

Country	# Articles
Iran	14
United States	14
China	10
France	7
Canada	6
Netherlands	5
Italy	5
India	4
Portugal	4
Germany	4

Table 8. Top 10 countries, based on the origin of the authors

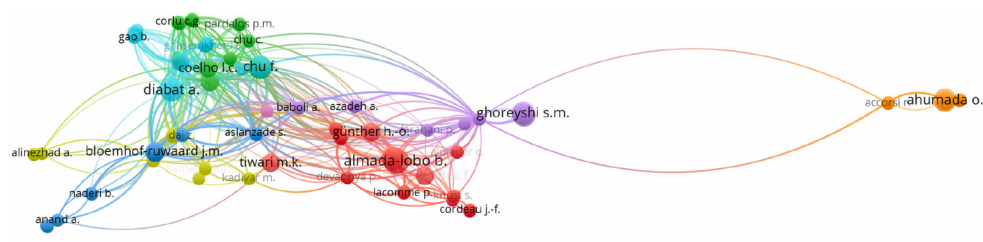


Figure 3. Citation network analysis

#### 4. Content Analysis

In this section, the content of the 54 selected papers is widely discussed. A five-dimension classification framework, as shown in Figure 4, is proposed. Such a framework was built inductively. Basically, by reading and studying the selected articles, the authors identified 5 macro-areas to better classify them and derive the main research trends and possible future challenges as regards optimization strategies for the integrated management of perishable supply chains: supply chain structure, objective, perishability type, solution approach and approach validation.

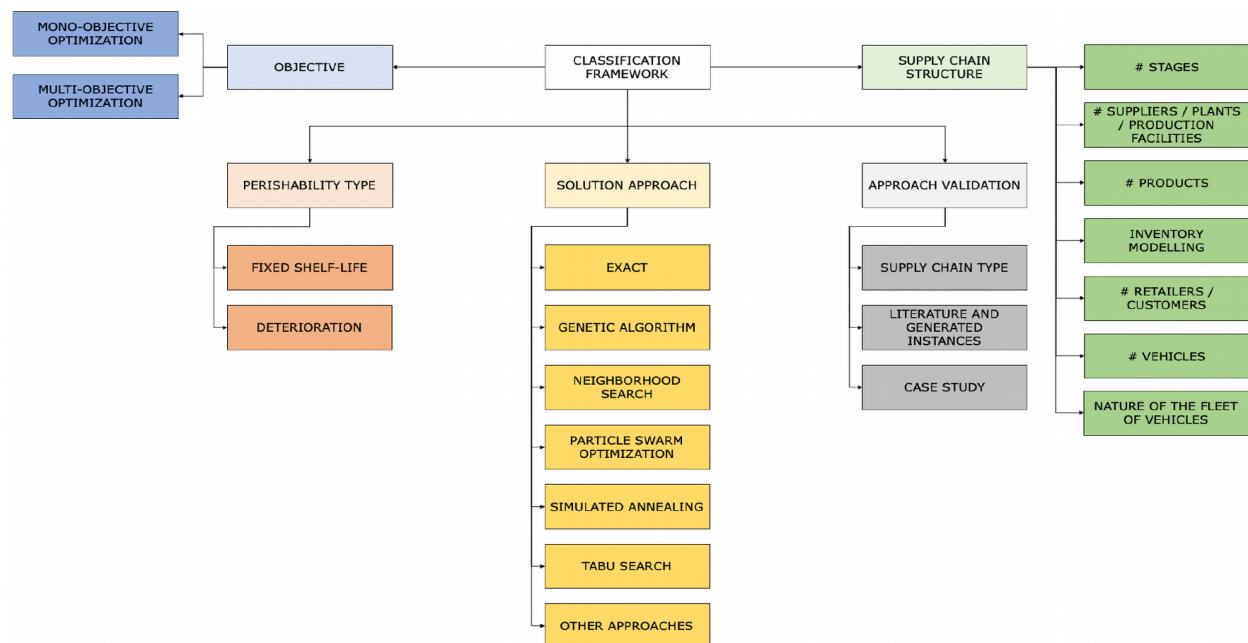


Figure 4. Classification framework

#### 4.1. Supply Chain Structure

In this subsection, we report some statistics on the supply chain structure of the 54 selected papers. First, with the aim to give an idea about the complexity of each addressed problem, we define a very critical indicator, which is the number of modeled supply chain stages. As shown in Figure 5, 72 % of the papers concern a two-level structure. The remaining papers address a more complex supply chain structure. Wu et al. (2015) tackle a problem characterized by three main levels: a single supplier, a set of potential facility locations, a set of retailers. One of the main contributions is the modeling of the facilities as cross-docking points. Similarly, Dolgui et al. (2018) address a supply chain, made up of multiple plants, multiple cross-docks, multiple markets. Cross-docking is a logistics concept, which aims to coordinate as much as possible the arrival of goods and their next shipment in order to minimize storage times and optimize distribution to end customers. This approach favors economies of transportation and, above all, enables hub-and-spoke networks which replace the more traditional point-to-point structures (Stephan & Boysen, 2011). A similar concept is used by Hu et al. (2018), who consider a set of growers, a consolidation center, and a set of retailers/wholesalers. Basically, the perishable product is transferred from local growers to a consolidation center via short-haul routing, while long-haul routing is necessary for the shipment from the consolidation center to geographically dispersed nodes. Vahdani et al. (2017) formulate and solve a mathematical programming model for simultaneous scheduling of production and delivery of perishable products to customers. The production system is divided into two stages, each of them having several production sites. The last level includes, instead, a set of retailers, that place the different orders. Rafie-Majd et al. (2018) consider a three-echelon supply chain, characterized by a supplier, a set of distribution centers, a certain number of retailers, within an integrated inventory-location-routing problem. This structure is very similar to that by Chao et al. (2019), where instead the suppliers/manufacturers are multiple. Rohmer et al. (2019) consider an intermediate depot between a single supplier and multiple customers. Violi et al. (2020) take into account a real agriculture supply chain in Italy, where a single perishable product is moved from a set production plants to a set of retailers, through a supplier located in the middle. Only two papers consider a four-echelon supply chain. Bortolini et al. (2016) place two intermodal hubs between multiple producers and multiple retailers. Biuki et al. (2020) take into account suppliers, manufacturers, distribution centers, and customers. Lastly, the three papers written by Omar-Ahumada and Rene Villalobos (Ahumada and Vilallobos, 2011a, 2011b; Ahumada et al., 2012), with the aim to replicate as much as possible the behavior of the fresh agricultural supply chains, model explicitly the following stages: harvesting, packing, warehousing, distribution centers, customers.

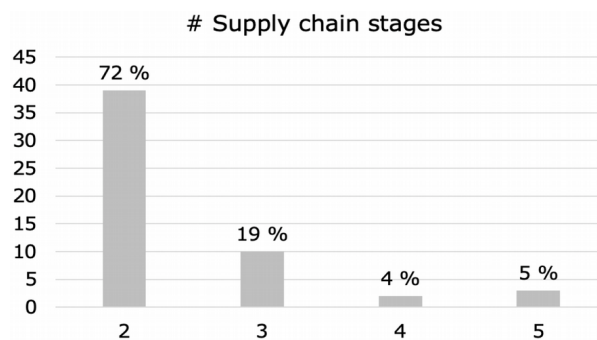


Figure 5. Statistics on supply chain structure: # Supply chain stages

Then, we have defined some parameters related to the 3 main areas of this literature review:

- Production area: # suppliers/plants/production facilities, # products.
- Inventory Area: inventory modelling at suppliers/plants/production facilities, inventory modelling at retailers/customers.
- Distribution area: # retailers/customers, # vehicles, nature of the fleet of vehicles.

We specify that when we talk about # suppliers/plants/production facilities and # retailers/customers, we are referring respectively to the first and last level of each modelled supply chain. In Figures 6-11, the main statistics about the supply chain structure of the analyzed papers are summarized.



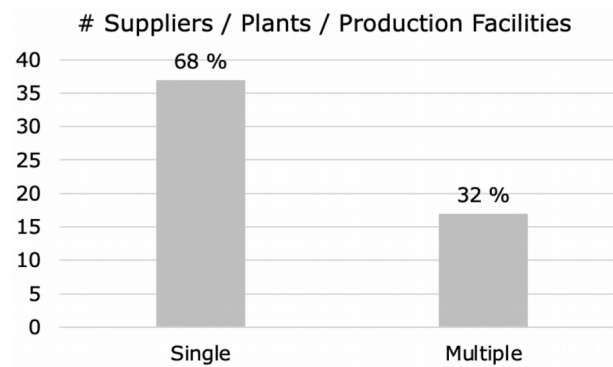


Figure 6. Statistics on supply chain structure: # suppliers/plants/production facilities

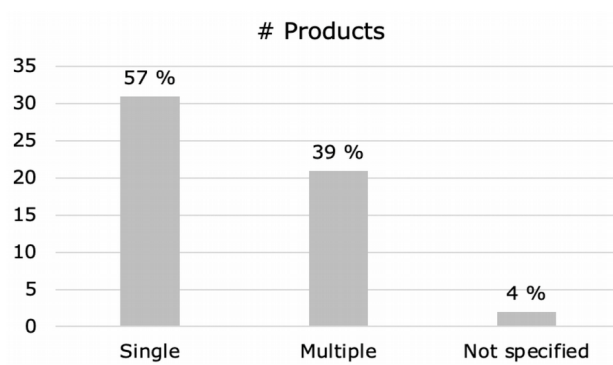


Figure 7. Statistics on supply chain structure: # Products

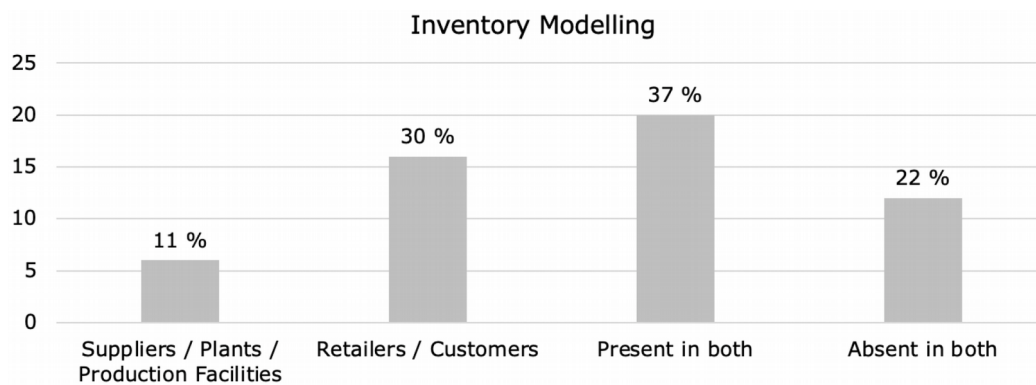


Figure 8. Statistics on supply chain structure: Inventory Modelling

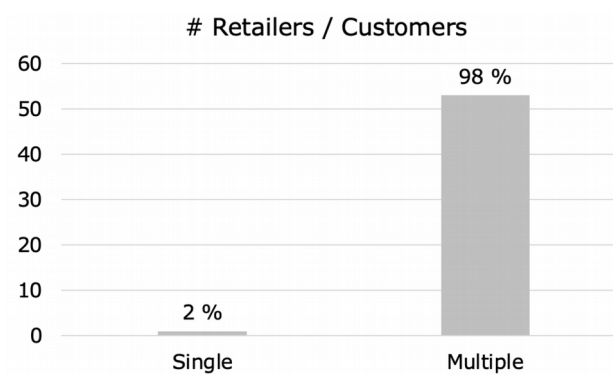


Figure 9. Statistics on supply chain structure: # retailers / customers

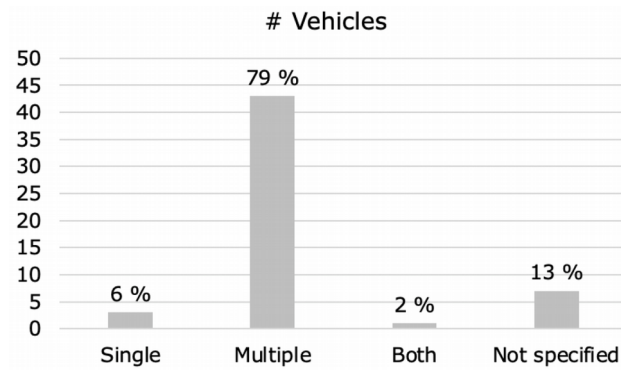


Figure 10. Statistics on supply chain structure: # vehicles

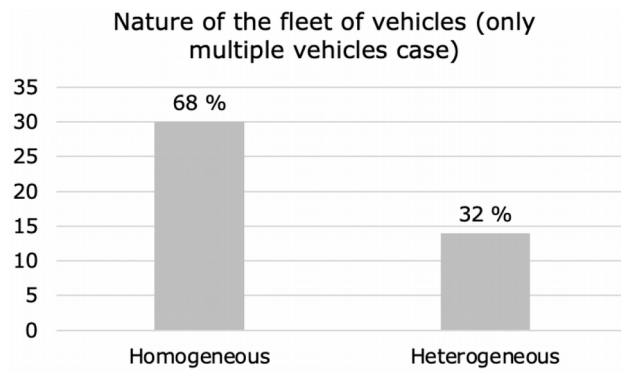


Figure 11. Statistics on supply chain structure: nature of the fleet of vehicles (only multiple vehicles case)

The suppliers / plants / production facilities are in most cases (i.e., 68 %) single, as well as the number of products (i.e., 57 %). It should be noted that 2 papers speak of jobs rather than products (Marandi & Zegordi, 2017; Bank et al., 2020). The retailers/customers are always multiple, except for the research work by Zanoni and Zavanella (2007), where a single-vendor-to-single-buyer model is addressed. Inventory is modeled at least upstream or downstream in most papers. Instead, it is completely absent in 22 % of cases, especially when authors model production-distribution problems, in which it is not necessary to store finished products before their distribution. The vehicles are multiple and homogeneous in the vast majority of cases. It should be noted that Lacomme et al. (2018) refer to both a single vehicle case (i.e., literature instances) and a multiple vehicle case (i.e., new instances). The number of vehicles is not explicitly specified in some papers, because the possibility of multiple transportation modes is taken into account (e.g., trucking, railroad, air) (Ahumada & Villalobos, 2011a, 2011b; Ahumada et al., 2012; AriaNezhad et al., 2013; Bortolini et al., 2016) or third-party logistics service providers (3PL) are considered for what concerns the distribution phase (Amorim et al., 2012).

#### 4.2. Objective

In Tables 9-11, the 54 selected papers are classified according to their objective. For what concerns the mono-objective minimization, we refer to production cost (PC), inventory cost (IC), distribution cost (DC). The term “other” indicates cost items, which do not explicitly belong to one of the aforementioned categories.

Reference	PC	IC	DC	Other
Zanoni & Zavanella (2007)	-	✓	✓	-
Naso et al. (2007)	✓	-	✓	Truck loading and unloading waiting times
Farahani et al. (2012)	✓	-	✓	-

Reference	PC	IC	DC	Other
Amorim et al. (2013)	✓	-	✓	-
AriaNezhad et al. (2013)	✓	✓	✓	Cost of delayed or earlier delivery; cost of perished goods
Le et al. (2013)	-	✓	✓	-
Seyedhosseini & Ghoreyshi (2014a)	✓	✓	✓	-
Seyedhosseini & Ghoreyshi (2014b)	✓	✓	✓	-
Soysal et al. (2015)	-	✓	✓	Cost of waste
Mirzaei & Seifi (2015)	-	✓	✓	Cost of lost sale
Seyedhosseini and Ghoreyshi (2015)	✓	✓	✓	-
Belo-Filho et al. (2015)	✓	-	✓	-
Wu et al. (2015)	-	✓	✓	Cost of facilities set-up
Shaabani & Kamalabadi (2016)	✓	✓	✓	-
Diabat et al. (2016)	-	-	✓	-
Devapriya et al. (2017)	-	-	✓	-
Marandi & Zagordi (2017)	-	-	✓	Tardy cost
Azadeh et al. (2017)	-	✓	✓	Cost of spoilage; cost of transshipment
Hiassat et al. (2017)	-	✓	✓	Cost of warehouses opening
Accorsi et al. (2017)	-	✓	✓	Disposal cost
Lacomme et al. (2018)	-	-	-	Makespan (i.e., arrival time of the last vehicle at the depot)
Rafie-Majd et al. (2018)	-	✓	✓	Cost of opening the distribution centers; cost of waste; cost of order
Soysal et al. (2018)	-	✓	✓	Cost of waste
Hu et al. (2018)	-	✓	✓	-
Dolgui et al. (2018)	✓	✓	✓	Cost of ordering; cost of handling; cost of deteriorated units (i.e., lost sales)
Neves-Moreira et al. (2019)	-	✓	✓	-
Chao et al. (2019)	-	✓	✓	Vehicle maintenance cost; ordering cost; time window violation penalty cost; cargo damage cost of perishable food; energy cost (referred to vehicle)
Qiu et al. (2019)	✓	✓	✓	-
Onggo et al. (2019)	-	✓	✓	Stock-out cost; deterioration cost
Rohmer et al. (2019)	-	✓	✓	-
Violi et al. (2020)	-	✓	✓	Cost of loss products; risk measure
Wei et al. (2020)	✓	✓	✓	-
Manouchehri et al. (2020)	✓	✓	✓	-
Sinha & Anand (2020)	✓	✓	✓	Ordering costs; deterioration cost
Liu & Liu (2020)	-	-	-	Total weighted delivery time of the orders
Bank et al. (2020)	-	-	-	Makespan
Dai et al. (2020)	✓	✓	✓	Ordering cost; shortage cost of retailers

Table 9. Mono-objective minimization

Reference	Profit	Satisfied demand
Chen et al. (2009)	✓	-
Ahumada & Villalobos (2011a)	✓	-
Ahumada & Villalobos (2011b)	✓	-
Ahumada et al. (2012)	✓	-
Coelho & Laporte (2014)	✓	-
Viergutz & Knust (2014)	-	✓
Li et al. (2016)	✓	-
Vahdani et al. (2017)	✓	-
Li et al. (2017)	✓	-
Crama et al. (2018)	✓	-
Ghasemkhani et al. (2019)	✓	-
Li et al. (2020)	✓	-

Table 10. Mono-objective maximization

Reference	# Objectives	List of objectives
Amorim et al. (2012)	2	Minimization of total costs (i.e., production costs, transportation costs, spoilage costs); Maximization of the freshness of the products delivered to the distribution centers (i.e., customers' willingness to pay)
Bortolini et al. (2016)	3	Minimization of operating cost; Minimization of carbon footprint; Minimization of delivery time
Rahimi et al. (2017)	3	Maximization of profit; maximization of service level (i.e., minimization of rate of delays, minimization of the number of backordered products, minimization of backorder frequency rate); minimization of greenhouse gas emissions
Chan et al. (2020)	4	Minimization of production, inventory, and routing costs; maximization of the average food quality; minimization of CO2 emissions; minimization of weighted delivery lead time
Biuki et al. (2020)	3	Minimization of cost of the network; maximization of environmental efficiency of the logistics chain network; maximization of social sustainability

Table 11. Multi-objective optimization

It can be easily noted that the vast majority of the papers are mono-objective and aim to minimize the costs. In some cases, production, inventory, and distribution/transportation costs are jointly minimized (AriaNezhad et al., 2013; Seyedhosseini & Ghoreyshi, 2014a, 2014b; Seyedhosseini & Ghoreyshi, 2015; Shaabani & Kamalabadi, 2016; Dolgui et al., 2018; Qiu et al., 2019; Wei et al., 2020; Manoucheri et al., 2020; Sinha & Anand, 2020; Dai et al., 2020). When dealing with perishable supply chains, it is common to find cost items associated with the perishable nature of goods: cost of perished goods (AriaNezhad et al., 2013; Chao et al., 2019), cost of waste (Soysal et al., 2015; Rafie-Majd et al., 2018; Soysal et al., 2018), cost of spoilage (Azadeh et al., 2017), disposal cost (Accorsi et al., 2017), cost of deteriorated units (i.e., lost sales) (Mirzaei & Seifi, 2015; Dolgui et al., 2018; Sinha & Anand, 2020; Violi et al., 2020). Two papers minimize the makespan (Lacomme et al., 2018; Bank et al., 2020). The cost of ordering has been written in the third column of Table 9, only when explicitly considered; in fact, in many cases, it is implicitly included into the inventory costs. Only one paper introduces a risk measure within the objective function (Violi et al., 2020). They give a mean-risk structure to the objective, that is written as a convex combination of two terms: the expected value of the overall costs and a risk measure, that is the conditional value at risk (CVaR) (Rockafellar & Uryasev, 2000). Except for one case (Viergutz & Knust, 2014), the maximization of the objective function is always about profit. In only five papers, the multi-objective optimization is addressed. In this case, some

sustainability-oriented objectives are considered, such as carbon foot print minimization (Bortolini et al., 2016; Rahimi et al., 2017; Chan et al., 2020), environmental efficiency of the logistics chain network and social sustainability maximization (Biuki et al., 2020).

### 4.3. Perishability Type

Supply chain management in the case of perishable items is quite complicated and time-critical (Biuki et al., 2020; Alkaabneh, Diabat & Gao, 2020). The main aim of this part is to provide a picture of the ways in which the different authors have addressed perishability. In the literature, the most recognized classification of perishability concerns two types of items: (i) fixed-lifetime and (ii) age-dependent. Fixed-lifetime goods have a well-defined expiration date, beyond which they perish (e.g., dairy products, pharmaceuticals). Age-dependent goods, instead, are subject to deterioration, then they lose value over time (e.g., agricultural products); although they have an expiration date, it is not predetermined (Coelho & Laporte, 2014; Palak et al., 2018). The 54 selected papers are classified according to such a taxonomy. Figure 12 shows how perishability issues are dealt in the literature. Fixed shelf-life and deterioration are almost equally popular as a way of dealing with perishable conditions. Some papers use even both assumptions, while others deal with perishability implicitly, without therefore specifying whether the good has a well-defined expiration date or loses its quality over time.

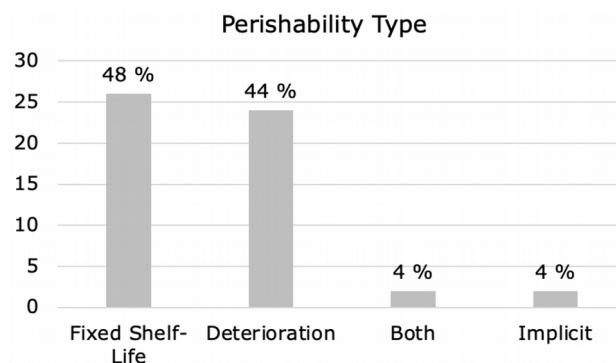


Figure 12. Perishability type

#### 4.3.1. Fixed Shelf-Life

28 papers deal with products with fixed shelf-life. Some of them introduce interesting and challenging features. Given a two-echelon supply chain (i.e., single producer and multiple customers), AriaNezhad et al. (2013) consider in the objective function the cost from perishing the goods in the original factory warehouse. Bortolini et al. (2016) use a particular function, aimed at estimating the market purchase probability (Osvald & Stirn, 2008); basically, they take into account explicitly the loss of product quality over time. Coelho and Laporte (2014) define a discrete set for the product age, and they study the impact of item age on revenue and inventory holding costs. They claim that their approach can also be used in the case of products subject to deterioration. Amorim et al. (2012) formulate two different models to consider respectively the cases of fixed and loose shelf-life. In this latter case, the authors link the shelf-life to the knowledge of predictive microbiology, then to the stocking temperature. The use of a multi-objective framework allows to take into account, in both cases, the freshness of the product, therefore the customers' willingness to pay. S.M. Seyedhosseini and S.M. Ghoreyshi claim that, although their optimization models were designed for perishable products with fixed lifetime, they can be extended to deteriorating goods that decrease their value throughout the lifetime. In this case, the quality loss of goods should be included in the inventory costs (Seyedhosseini & Ghoreyshi, 2014b; Seyedhosseini & Ghoreyshi, 2015). In some papers, reaching the expiration date is penalized in the objective function through the waste cost (Soysal et al., 2015; Soysal et al., 2018; Rafie-Majd et al., 2018). With the aim to limit the amount of unsold products, Rahimi et al. (2017) introduce a step-wise nonlinear holding cost. They take into consideration that non-fresh products need extra-inspections before they are carried to the next period. The proposed holding cost function replicates the price discounts for non-fresh products, and guarantees a trade-off between economic, service level and environmental criteria. Li et al.

(2020) take into consideration different shelf-lives, depending on the packaging. Their article is mainly based on the following assumption: the same item can have a different shelf-life depending on the packaging used. Basically, innovative food packaging can significantly lengthen the expiration date of products, lowering the decay rate (Rizzo & Muratore, 2009; Li, Yu, & Wu, 2017). The authors investigate the tradeoff between packaging costs and shelf-life benefits. One of the main contributions of Biuki et al. (2020) is instead to consider both the shelf-life of raw materials and finished products, within the proposed Mixed-Integer Programming (MIP) model.

#### 4.3.2. Deterioration

In 25 papers, the shelf-life is not fixed and known a priori, but the aspects related to deterioration and loss of quality are emphasized.

A set of research works traces explicitly the food quality throughout the supply chain, by using a quality level index (Li et al., 2016; Li et al., 2017; Ghasemkhani et al., 2019; Chan et al., 2020). They stress the assumption that food quality significantly affects selling price and customer demand.

Most papers propose a fixed decay rate, which implies a linear deterioration of the product quality (Chen, 2009; Ahumada & Villalobos, 2011a; Ahumada et al., 2012; Farahani et al., 2012; Rohmer et al., 2019; Violi et al., 2020; Dai et al., 2020). It must be noted that Chao et al. (2019) take into account both the deterioration due to the transport time and that due to a break during the transportation process (e.g., turning on/off frequently the door of a truck).

Ahumada and Villalobos (2011b) focus their attention on the loss of value of agri-products, once harvested. They use a post-harvest color function (Hertog, Lammertyn, Desmet, Scheerlinck & Nicolai, 2004), assuming to store the products at a constant temperature. Basically, in the objective function of the proposed optimization model, an expected cost is used, derived from rejected or discounted shipments, which depend on the color of the product when it reaches the customer. Deterioration is addressed by Mirzaei and Seifi (2015), by considering lost sale as a linear or exponential function of the inventory age. A couple of papers assume exponential deterioration rate (Azadeh et al., 2017; Dolgui et al., 2018). This assumption takes into account the growth of micro-organisms within the product, which in many cases follows an exponential behavior. Although Accorsi et al. (2017) consider a set of shelf-life values in their model, they explicitly take into account the quality decay of perishable products. In particular, they refer to kinetic models, based on the Arrhenius equation and the accelerated aging factor (Lee, Yam & Piergiovanni, 2008; Tsironi, Dermesonlouoglou, Giannaglou, Gogou, Katsaros & Taoukis, 2017). Common thermodynamic models are instead considered to replicate the heat transfer mechanism in refrigerated storage rooms and vehicles. In some models, the deterioration rate is time-dependent (Wu et al., 2015; Vahdani et al., 2017; Qiu et al., 2019; Wei et al., 2020; Sinha & Anand, 2020). Onggo et al. (2019) consider the case of inventory of products with different ages. They address product perishability, by considering multiple degradation speed levels. Manoucheri et al. (2020) use the Gompertz equation (Gil, Miller, Brandao & Silva, 2011), with the aim to estimate microbial growth.

Lastly, a couple of papers address only implicitly perishability (Marandi & Zegordi, 2017; Liu & Liu, 2020).

#### 4.4. Solution Approach

In this section, we group the 54 selected papers, according to the approach used, to solve the addressed problem.

##### 4.4.1. Exact Approaches

In many research works, the proposed solution approach is the main contribution. The models that integrate the planning of production, storage and distribution activities are generally very complex from a computational point of view, therefore they require heuristic approaches (i.e., not exact), to find a good solution in reasonable time. For this reason, in a few papers the solution is determined solely through an optimal approach by using a software (e.g., CPLEX, LINGO, MATLAB) (Soysal et al., 2015; Accorsi et al., 2017; Soysal et al., 2018; Ghasemkhani et al., 2019). Some authors do not use heuristic approaches, but impose an optimality gap, with the aim to limit the computational time (Ahumada & Villalobos, 2011a, 2011b; Amorim et al., 2013). The branch-and-cut is adopted within different papers (Coelho & Laporte, 2014; Shaabani & Kamalabadi, 2016; Qiu et al., 2019; Li et al., 2020;



Wei et al., 2020), while Viergutz and Knust (2014) use the branch-and-bound algorithm. In many other cases, the optimal or sub-optimal solutions are determined, only with the aim to demonstrate the efficiency, in terms of computational time, of the proposed novel algorithm, through a specific comparison. Figure 13 summarizes some statistics about number of papers, using exact approaches among those selected in this comprehensive literature review.

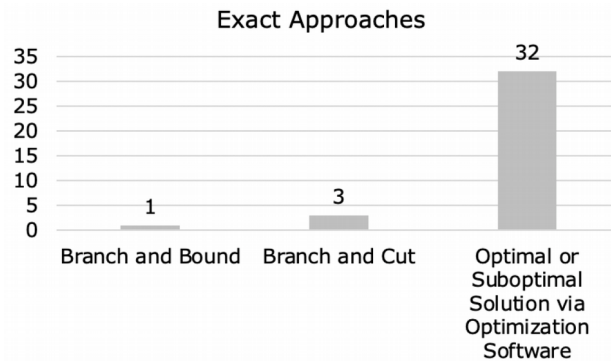


Figure 13. Statistics on the use of Exact Approaches

#### 4.4.2. Genetic Algorithms

Genetic algorithms aim to mimic biological evolutionary processes and have been successfully used for solving many optimization problems (Godinho-Filho, Barco & Tavares Neto, 2012; Lee, 2018).

Naso et al. (2007), with the aim to solve the problem of coordinating the production and distribution planning within a network of independent supply centers, propose a hybrid metaheuristic approach, where genetic algorithms and constructive heuristics are integrated. Amorim et al. (2012) formulate models for the integrated production and distribution planning, where perishable goods have fixed or loose shelf-life. For the second case, a hybrid genetic heuristic is proposed. A genetic algorithm, coded in MATLAB, is designed by AriaNezhad et al. (2013), for a two-echelon model, aimed to control the inventory of perishable goods. Rahimi et al. (2017) use the NSGA-II for a multi-objective inventory-routing problem. Devapriya et al. (2017) use a genetic algorithm and two memetic algorithms for an integrated production-distribution scheduling problem. Azadeh et al. (2017) integrate a genetic algorithm and the Taguchi approach to solve an inventory routing problem with transshipment. Dolgui et al. (2018) propose a non-revisiting genetic algorithm (NrGA), which represents a novel version of traditional genetic algorithms.

#### 4.4.3. Neighborhood Search

Some meta-heuristics exploit the concept of solution neighborhood: variable neighborhood search (VNS) and large neighborhood search (LNS) are among the most used approaches in this context. VNS is based on two main steps: a descent phase to find a local optimum and a perturbation to “escape” from the corresponding valley (Hansen, Mladenovic, Brimberg & Moreno Perez, 2010). About LNS, instead, an initial solution is gradually improved through some phases of destruction and reparation (Pisinger & Ropke, 2010).

Farahani et al. (2012) design a novel approach, that integrates short-term production and distribution planning, within an iterative scheme. The distribution problem is solved through an LNS algorithm. Belo-Filho et al. (2015) develop an adaptive LNS for solving the operational integrated production and distribution problem with perishable products. The adaptiveness of the approach is related to the destroy and repair operators, that are chosen adaptively. The authors demonstrate that the adaptive LNS outperforms exact approaches and the fix-and-optimize method. An adaptive LNS metaheuristic is also developed by Rohmer et al. (2019) for tackling an inventory-routing problem. An LNS-based heuristic is used by Vahdani et al. (2017) for a production-inventory-routing problem. Such an approach appears quite promising, when compared with LINGO and a water cycle algorithm (Eskandar, Sadollah, Bahreininejad & Hamdi, 2012). The hybrid search algorithm proposed by Manouchehri et al. (2020) combines VNS and SA with good results for a production

routing problem. Li et al. (2020) use an improved LNS, which outperforms a genetic algorithm, in solving an integrated production and distribution problem with a minimum total order weighted delivery time.

#### 4.4.4. Particle Swarm Optimization

Particle Swarm Optimization (PSO) replicates some social behaviors of natural organisms (Banks, Vincent & Anyakoha, 2007).

Seyedhosseini and Ghoreyshi (2014a) study an integrated model for production and distribution planning of perishable products. While the production submodel is solved by LINGO, a PSO-based heuristic is proposed with good results for the distribution part. Marandi and Zagordi (2017) design and apply an improved PSO to deal with a production-distribution scheduling problem. The contribution mainly lies in the use of additional operators (i.e., 1-exchanged and 2-opt), with the aim to prevent the premature convergence of the algorithm. Chan et al. (2020) propose a modified multi-objective particle swarm optimization algorithm with multiple social structures. With the aim to efficiently solve an integrated location-routing-inventory problem, Biuki et al. (2020) propose two hybrid metaheuristics as parallel and series combinations of GA and PSO. The computational experience shows that the parallel approach is better than the series one.

#### 4.4.5. Simulated Annealing

Simulated Annealing (SA) is a technique that has gained a lot of popularity in recent years in solving optimization problems. It is based on an analogy with the behavior of physical systems during the cooling process (Suman & Kumar, 2010).

Mirzaei and Seifi (2015) combine SA and Tabu Search (TS) for an inventory routing problem. Shaabani and Kamalabadi (2016) present a population-based simulated annealing algorithm (PBSA) for a multi-product multi-retailer perishable inventory routing problem. The PBSA is compared with SA and GA, to show its superiority in terms of efficiency. Bank et al. (2020) propose a low-level co-evolutionary hybrid algorithm to solve an integrated production-distribution problem. The approach combines SA and GA, because the features of GA are applied in the local search process of SA.

#### 4.4.6. Tabu Search

For what is known, Tabu Search was proposed by Glover (1986) and is nowadays one of the most used heuristic methods for combinatorial optimization.

Viergutz and Knust (2014) propose model extensions with reference to the research work by Armstrong et al. (2008), which addresses an integrated production-distribution scheduling problem. They solve some of them by a tabu search approach. Diabat et al. (2016) design a hybrid tabu search, which outperforms a column generation approach in solving a periodic distribution inventory problem.

#### 4.4.7. Other Approaches

In the previous subsections, the most used approaches to solve the problems addressed within this literature review have been highlighted. However, other important algorithms have been recently adopted: local search (Viergutz & Knust, 2014; Vahdani et al., 2017; Hu et al., 2018; Onggo et al., 2019), lagrangian relaxation (Shaabani & Kamalabadi, 2016; Rafie-Majd et al., 2018), matheuristic algorithms (Crama et al., 2018; Neves-Moreira et al., 2019; Li et al., 2020), Ant Colony Optimization (ACO) (Chao et al., 2019), rolling horizon (Neves-Moreira et al., 2019; Violi et al., 2020), BFA (Sinha & Anand, 2020), simulation (Soysal et al., 2015; Onggo et al., 2019), column-generation based algorithms (Le et al., 2013; Wu et al., 2015; Diabat et al., 2016).

### 4.5. Approach Validation

Each proposed solution approach needs to be properly validated. In this subsection, the selected papers are classified according to the nature of the instances through which the goodness of each algorithm has been demonstrated, see Table 12. Some authors use instances already known in the literature. Others, introducing completely new problems, are forced to randomly generate new data. While, in some cases, real data are used,

derived from specific case studies. Furthermore, the supply chain type is reported; obviously, it is specific, only when referring to a case study (real or hypothetical).

Reference	Supply Chain Type	Literature Instances	Generation of Instances	Case Study
Zanoni & Zavanella (2007)	Generic	-	✓	-
Naso et al. (2007)	Ready-mixed concrete	-	✓	✓
Chen et al. (2009)	Generic	✓	✓	-
Ahumada & Villalobos (2011a)	Pepper, Tomato	-	-	✓
Ahumada & Villalobos (2011b)	Pepper, Tomato	-	-	✓
Ahumada et al. (2012)	Pepper, Tomato	-	-	✓
Amorim et al. (2012)	Generic	-	✓	-
Farahani et al. (2012)	Catering	✓	✓	✓
Amorim et al. (2013)	Generic	-	✓	-
AriaNezhad et al. (2013)	Conserved wax bean and jam	-	-	✓
Le et al. (2013)	Generic	-	✓	-
Coelho & Laporte (2014)	Generic	-	✓	-
Seyedhosseini & Ghoreyshi (2014a)	Generic	-	✓	-
Seyedhosseini & Ghoreyshi (2014b)	Generic	-	✓	-
Viergutz & Knust (2014)	Generic	-	✓	-
Soysal et al. (2015)	Fresh tomato	-	-	✓
Mirzaei & Seifi (2015)	Generic	✓	✓	-
Seyedhosseini & Ghoreyshi (2015)	Generic	-	✓	-
Belo-Filho et al. (2015)	Generic	-	✓	-
Wu et al. (2015)	Generic	-	✓	-
Bortolini et al. (2016)	Fruit and vegetables	-	-	✓
Shaabani & Kamalabadi (2016)	Generic	✓	✓	-
Li et al. (2016)	Generic	-	✓	-
Diabat et al. (2016)	Generic	-	✓	-
Vahdani et al. (2017)	Generic	✓	✓	-
Rahimi et al. (2017)	Generic	-	✓	-
Devapriya et al. (2017)	Generic	-	✓	-
Marandi & Zegordi (2017)	Generic	-	✓	-
Li et al. (2017)	Generic	✓	✓	-
Azadeh et al. (2017)	Dairy	-	-	✓
Hiassat et al. (2017)	Generic	-	✓	-
Accorsi et al. (2017)	Cherry	-	-	✓
Lacomme et al. (2018)	Generic	✓	✓	-
Crama et al. (2018)	Generic	✓	✓	-
Rafie-Majd et al. (2018)	Generic	-	✓	-
Soysal et al. (2018)	Fig, cherry	-	-	✓

Reference	Supply Chain Type	Literature Instances	Generation of Instances	Case Study
Hu et al. (2018)	Cut flower	-	-	✓
Dolgui et al. (2018)	Generic	✓	✓	-
Neves-Moreira et al. (2019)	Meat	✓	-	✓
Chao et al. (2019)	Fresh seafood	✓	✓	✓
Qiu et al. (2019)	Fresh meat	✓	✓	✓
Ghasemkhani et al. (2019)	Generic	✓	✓	-
Onggo et al. (2019)	Generic	✓	-	-
Rohmer et al. (2019)	Generic	-	✓	-
Violi et al. (2020)	Tangerine	-	-	✓
Li et al. (2020)	Generic	-	✓	-
Wei et al. (2020)	Generic	✓	✓	-
Manoucheri et al. (2020)	Chicken	-	✓	✓
Sinha & Anand (2020)	Generic (glass industry)	-	✓	✓
Chan et al. (2020)	Meat	-	✓	✓
Liu and Liu (2020)	Generic	✓	✓	-
Bank et al. (2020)	Generic	-	✓	-
Biuki et al. (2020)	Generic	-	✓	-
Dai et al. (2020)	Generic	-	✓	-

Table 12. Approach validation

19 out of the 54 selected papers demonstrate the goodness of the proposed solution approach via case study.

Only a couple of papers refer to non-food products. Naso et al. (2007) focus on the production of ready-mixed concrete for construction engineering and refer to a supply network in Northern Europe. The instances replicate the typical workdays of the different nodes of the network. The authors claim that the perishability features of ready-mixed concrete have many similarities with agri-food products. Sinha and Anand (2020) refer, instead, to an Iranian glass industry, whose main information is reported in (Hajiaghaei-Keshteli and Fathollahi Fard, 2019).

10 papers are about fruit and/or vegetables. The three articles by Omar Ahumada and J. Rene Villalobos (Ahumada & Villalobos, 2011a, 2011b; Ahumada et al., 2012) refer to a hypothetical producer of peppers and tomatoes, based in Mexico. Farahani et al. (2012) develop a main set of instances, based on the real setting of a catering company in Denmark. Additional test sets are included, in order to validate the solution approach under different problem sizes. Some parameters are randomly generated, while others are derived from the Solomon instances (Solomon, 1987). AriaNezhad et al. (2013) consider a manufacturing company of conserved wax bean and jam. Soysal et al. (2015) apply their model to a real supply chain located in Turkey, where a distribution center provides fresh tomatoes to 11 supermarkets. Several Key Performance Indicators (KPIs) are introduced to highlight the benefits, coming from the proposed mathematical approach: average vehicle load, number of vehicles used, total emissions, total driving time, total fuel cost, total inventory cost, total waste cost, total cost. Bortolini et al. (2016) address the distribution of six types of fruits and vegetables (i.e., potatoes, apples, pears, Brussels sprouts, oranges, tomatoes) cultivated by a set of Italian producers to supply a set of European retailers. They consider and compare three different transportation modes (i.e., truck, train, airplane). The proposed expert system, called Food Distribution Planner, can effectively manage product perishability and limit CO<sub>2</sub> emissions. Accorsi et al. (2017) consider an Italian supply chain of fresh cherries, characterized by 4 production plants aimed at processing raw cherries and packaging, and 3 warehouses. The application of the proposed Mixed-Integer Linear Programming (MILP) model can significantly impact on economic and environmental aspects of the considered cold chain. Soysal et al. (2018) prove

the benefits of horizontal collaboration between two real suppliers, which produce figs and cherries, respectively. The data used by Violi et al. (2020) come from an Italian supply chain, where a medium agri-food company supplies tangerines to a set of retailers.

4 papers refer to meat products. A very challenging case study is addressed by Neves-Moreira et al. (2019): 175 multiple meat products are manufactured by a meat processing center and delivered to 185 meat stores, by using 35 heterogeneous vehicles. The proposed integrated approach can guarantee a cost saving of 21.73 %, compared to the company's solution. Qiu et al. (2019) consider a Chinese chain, where a food company provides fresh meat products to some stores. The proposed approach ensures a decrease of 12 % in the total cost. Manouchehri et al. (2020) refer to a company in Iran, that supplies packed chicken to a set of customers, by refrigerated vehicles. The developed optimization model returns the production lot size, inventory levels and optimal routes for each vehicle. The Chinese supply chain considered by Chan et al. (2020) is made by a company, which provides a single fresh meat product to 40 retail stores. 3 homogeneous vehicles are used for the distribution phase, under a planning horizon of one week. The model designed by the authors provides a 15.51 % cost reduction.

Three papers concern respectively dairy products (Azadeh et al., 2017), cut flowers (Hu et al., 2018), fresh seafood (Chao et al., 2019). All the remaining papers randomly generate new data, or refer to some well-known literature instances, as specified in Table 12.

## 5. Discussion: Research Trends and Future Challenges

In this review paper, a framework for classifying scientific articles, which address the coordination of activities in perishable supply chains, via optimization strategies, has been proposed. This framework contains five dimensions: objective, perishability type, solution approach, approach validation, supply chain structure. Some important research trends can be detected:

- Most of the publishing journals belong to the areas “management science and operations research”, “industrial and manufacturing engineering”.
- Interest in the application of optimization models for integrated decision-making along perishable supply chains is strongly growing. More than 50 % of the articles published in the last 15 years refer to the period 2016-2020.
- A careful analysis of the selected documents shows a strong interest in the following main problems, as shown in Table 13: the integrated production-distribution problem, the inventory-routing problem, the production-routing and the production-inventory-routing problem, the location-inventory-routing problem.

Reference	Integrated production-distribution problem	Inventory-routing problem	Production-routing OR Production-inventory-routing problem	Location-inventory-routing problem
Ahumada & Villalobos (2011a)	✓	-	-	-
Ahumada & Villalobos (2011b)	✓	-	-	-
Ahumada et al. (2012)	✓	-	-	-
Amorim et al. (2012)	✓	-	-	-
Farahani et al. (2012)	✓	-	-	-
Amorim et al. (2013)	✓	-	-	-
Le et al. (2013)	-	✓	-	-
Seyedhosseini & Ghoreyshi (2014a)	✓	-	-	-

Reference	Integrated production-distribution problem	Inventory-routing problem	Production-routing OR Production-inventory-routing problem	Location-inventory-routing problem
Seyedhosseini & Ghoreyshi (2014b)	✓	-	-	-
Viergutz & Knust (2014)	✓	-	-	-
Seyedhosseini & Ghoreyshi (2015)	✓	-	-	-
Belo-Filho et al. (2015)	✓	-	-	-
Mirzaei & Seifi (2015)	-	✓	-	-
Soysal et al. (2015)	-	✓	-	-
Li et al. (2016)	-	-	✓	-
Shaabani & Kamalabadi (2016)	-	✓	-	-
Rahimi et al. (2017)	-	✓	-	-
Azadeh et al. (2017)	-	✓	-	-
Devapriya et al. (2017)	✓	-	-	-
Marandi & Zegordi (2017)	✓	-	-	-
Vahdani et al. (2017)	-	-	✓	-
Li et al. (2017)	-	-	✓	-
Hiassat et al., 2017	-	-	-	✓
Lacomme et al. (2018)	✓	-	-	-
Soysal et al. (2018)	-	✓	-	-
Hu et al. (2018)	-	✓	-	-
Rafie-Majd et al., 2018	-	-	-	✓
Onggo et al. (2019)	-	✓	-	-
Dai et al. (2019)	-	✓	-	-
Rohmer et al. (2019)	-	✓	-	-
Ghasemkhani et al. (2019)	-	-	✓	-
Neves-Moreira et al. (2019)	-	-	✓	-
Chao et al. (2019)	-	-	-	✓
Liu & Liu (2020)	✓	-	-	-
Bank et al. (2020)	✓	-	-	-
Violi et al. (2020)	-	✓	-	-
Dai et al., 2020	-	✓	-	-
Manoucheri et al. (2020)	-	-	✓	-
Li et al. (2020)	-	-	✓	-
Biuki et al., 2020	-	-	-	✓

Table 13. Most recurrent problems

- Integrating multiple stages of the supply chain into a single framework is complex, especially when referring to perishable products. The vast majority of the problems addressed are then NP-Hard, therefore



non-exact approaches are needed to find a sub-optimal solution in reasonable time. Currently, evolutionary algorithms (e.g., genetic algorithms) are among the most preferred by researchers.

- A very high percentage of the reviewed research works deal with two-level supply chains, i.e., supplier(s)-to-customer(s). When the supply chain is 3-tier, a cross-docking or consolidation node is often placed halfway.

As a consequence, there are some significant challenges that need to be addressed in the next future:

- In more recent years, the research branch concerning electric vehicles is spreading significantly (Macrina, Di Puglia Pugliese, Guerriero & Laporte, 2019; Zhen, Xu, Ma & Xiao, 2020). Erdogan and Miller-Hooks (2012) defined the green vehicle routing problem, where the fleet is composed of alternative fuel vehicles, which have a very positive environmental impact. Currently, this topic is very little explored within the perishable supply chains. Furthermore, only a few of the reviewed research works use CO2 emissions as a supply chain KPI.
- As for the distribution phase, very few papers evaluate the possibility of using transportation modes different to truck (e.g., train or airplane) and even intermodal ones. This research line deserves to be further investigated because it could make perishable supply chain more efficient and guarantee a higher service level to the end customer.
- Only one of the reviewed papers (Soysal et al., 2018) deals with horizontal collaboration as regards the distribution of goods with limited shelf-life. This topic deserves to be better developed in the coming years because it is very sustainability-oriented. Sharing vehicles for shipping means limiting CO2 emissions and then protecting environment (Pan, Trentesaux, Ballot & Huang, 2019; Giallombardo et al., 2021).
- Recently, a new set of hybrid optimization strategies named matheuristics has emerged. They combine mathematical programming algorithms and metaheuristics in a cooperative way (Jourdan, Basseur & Talbi, 2009; Ball, 2011). Matheuristic strategies have been attracting the interest of many scholars and have already been successfully applied to solve some combinatorial optimization problems. Some examples are: vehicle routing (Fikar & Hirsch, 2015), patient admission scheduling problem with operating rooms (Guido, Solina, Mirabelli & Conforti, 2018), flow shop (Della-Croce, Grosso & Salassa, 2014), workforce planning (Valeva, Hewitt & Thomas, 2017), cloud manufacturing scheduling (Vahedi-Nouri, Tavakkoli-Moghaddam, Hanzalek, Arbabi & Rohaninejad, 2020). There is a clear shortage of matheuristic strategies applied to integrated planning problems in perishable supply chains, although they are very promising and, in most cases, efficient (Archetti, Boland & Speranza, 2017; Avci & Yildiz, 2019).
- The potential of Industry 4.0 (Ivanov, Tang, Dolgui, Battini & Das, 2021) is little explored. Blockchain is an emerging technology, which has a significant impact on efficiency and sustainability of supply chains (Saber, Kouhizadeh, Sarkis & Shen, 2019; Mirabelli & Solina, 2020; Saurabh & Dey, 2020; Astarita, Giofrè, Mirabelli & Solina, 2020). It would be very interesting to understand how improving the quality of information exchange between the various nodes of the chain can impact on the coordination of activities. Basically, blockchain could better guarantee the demand-supply matching, which would result in the reduction of perished products (i.e., waste). Moreover, many of the documents examined deal with production planning, but the features of smart manufacturing appear very little exploited until now.
- There is a significant need to give impetus to the development of multi-objective models, in order to pursue not only economic, but also environmental and social sustainability.
- Only one of the reviewed papers explores the relationship between product shelf-life and packaging used (Li et al., 2020). More research is needed addressing this emerging topic. More expensive packaging is usually also more sustainable and extends the product lifetime. In this context, it would be very useful to have more investigations on the impact that different packaging can have on the economic and environmental sustainability of the perishable supply chains.

- Only 35% of the selected papers aim to solve real-life case studies. The reasons behind this low number could be linked to poor collaboration between academia and industry. There is a need for further research, which is capable of modeling and quantitatively improving existing supply chains. In fact, it is very important to have useful approaches available to practitioners and entrepreneurs, in order to create a stronger link between academia and industry.

## 6. Conclusions

The analysis of the collected documents shows that there is a growing interest in the topic of integrated management of perishable supply chains. At the moment, most of the papers concern 2-level supply chains and the proposed optimization models are mainly validated theoretically. Regarding the concept of perishability, there is a balance regarding the number of papers concerning fixed shelf-life products and subject-to-deterioration goods. Currently, the main gap in the literature concerns the limited number of case studies, probably due to a poor academia-industry connection; furthermore, the potential of Industry 4.0 still seems little explored.

The main limitation of this research consists in having used a limited number of keywords for the collection of documents, and in having excluded all those papers not focused on the adoption of optimization models, as a means of managing supply chain in an integrated manner.

As this literature review collects the main scientific articles published between 2005 and 2020, related to the integrated management of production, storage and distribution activities in perishable supply chains, it can be a starting point for all scholars and practitioners who want to study and deepen such a topic in the coming years.

## Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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