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SUSTAINABLE SUPPLY CHAIN DESIGN FOR PERISHABLE PRODUCTS: A LITERATURE REVIEW

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ABSTRACT

Supply chain design (SCD) is highly addressed in the operational research. Moreover, sustainability plays a significant role in the supply chain performance. This paper gives a literature review on the subject of sustainable supply chain design (SSCD) for perishable products during 2014-2020. A summary table is developed to compare between the different research papers to provide a deeper understanding for the literature. The papers are compared according to different classifications such as: perishability, sustainability, objective functions, modelling approaches, software tools used and also the field of application. Finally, a list of potential issues for future research opportunities is recommended.

KEYWORDS: "Sustainable Supply Chain (SSC)", "Supply Chain Design (SCD)", "Perishable products", "Pharmaceutical", "Food".

1. Introduction

Supply chain design (SCD) is one of the most important decisions in supply chain management (SCM). It has a significant contribution in the supply chain performance. It is considered as the strategic planning for supply chain [1–3] . It addresses several decisions of the supply chain structure such as the number, the location and the capacities of the facilities and the allocation flows among them [3,4]. In other words, it helps in making the strategic and operational decisions. Strategic decisions may include the establishments of new facilities, finding the most optimal configuration for the supply chain structure, adopting of technology and assigning facilities to each other. While, operational decisions may include products' handling and shipment.

Sustainable supply chain design (SSCD) addresses the incorporation of the three pillars of sustainability including environmental, economic, and social aspects. The objective behind the SSCD is to achieve an equilibrium between the different goals of the supply chain. It is needed to minimize both environmental and social impacts and to also maximize economic performance. Organizations are now trying to reach an equilibrium between the triple bottom lines (TBLs) of sustainability [5,6]. At the end of the 1980s, the expression "sustainable development" was introduced to control the economic, social, and environmental issues [7]. Nowadays, sustainability has been highly put into consideration in different operations. However, there is a lack of mathematical models that merges between economic, environmental and social impacts of supply chains [5]. Perishability phenomenon is considered in food and healthcare industry where the products easily deteriorate during manufacturing, storage or distribution. Perishable products lose their value in a short time, from the moment they are produced. They start deteriorating from the moment they are produced on. Companies should manage those products subjected to perishability. Inventory management of perishable is complex because of customers' demand variability, distribution, lifetime [8,9]. Food, dairy products, pharmaceutical products and blood are main examples for perishable products [10]. The limitation of the shelf life, overproduction, and storage are the main features of perishable products [11]. They can be used only during their lifetime; after which those expired products must be got rid of and discarded [12].

Recently, there is a notable research direction towards the field of SSCD for perishable products. The objective of this paper is to present a comprehensive literature review on SSCD for perishable products in order to investigate previous studies in this field and clarify the most effective studies in addition to areas of research. Section 2 presents the review methodology. Section 3 presents the analysis of articles. Section 4 presents the SCND definition. Section 5 presents the analytical categorization of research articles. Section 6 presents the literature review findings. Section 7 covers the conclusion and finally the recommended research opportunities in the future are presented in Section 8.

2. Review Methodology

Due to the importance of the correlation between SSCD and perishable products, the need for studying and exploring this area is identified. The review methodology is illustrated in [Figure-1]. The current study followed a systematic review methodology as follows:

- Online search for research articles on reputable scientific databases such as Elsevier is conducted using the following sources: Research Gate, Science Direct, Emerald Insight, Springer, Scopus...etc.
- Following keywords: “Sustainable Supply Chain (SSC)”, “Perishable products”, “Supply Chain Design (SCD)”, “Pharmaceutical”, “Food”.
- Articles in English language are only considered.

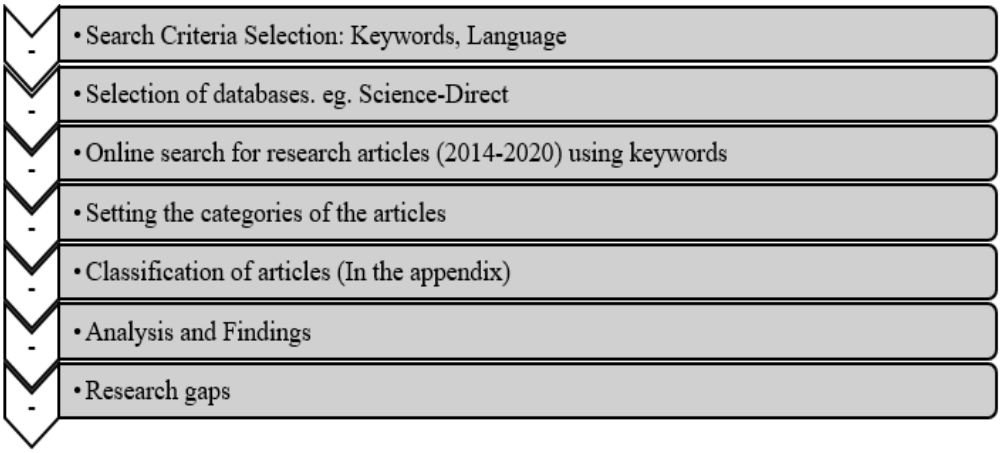

Fig. 1. Literature Review Methodology

3. Analysis of Articles

According to the selection criteria adopted in this study, and the keywords declared, articles from (2014) to (2020) were collected. The selected articles are categorized: sustainability, perishability phenomenon, objective functions either single, bi or multi objective, modeling approaches and characteristics either exact or heuristics/metaheuristics, software tools and applications. The articles are compared in Appendix A. Table 1 shows the reviewed papers that fulfilled the previously set key words.

Table: 1. Reviewed papers between 2014 and 2020.

Year	No.	paper
2020	3	[13–15]
2019	10	[5,16–24]
2018	13	[3,6,32–34,10,25–31]
2017	6	[2,35–39]
2016	3	[11,40,41]
2015	3	[42–44]
2014	3	[4,45,46]

4. Supply Chain Design

A supply chain design (SCD) changes raw material into final products and transports them to customers. It consists of several types of facilities and each facility has a certain task. It is called an echelon. The usual echelons of supply chain structures are composed of suppliers, distribution centers and customers and the typical materials flow are usually from suppliers to customers [1]. [Figure-2] illustrates an example for a supply chain structure [47]. Recently, the closed-loop supply chain design (CLSCD) has drawn a significant attention by researchers.

5. Analytical Categorization of Research Articles

The categories and dimensions of the analysis of this study is determined as follows :

- SSCD for perishable products
- Economic, environmental and social factors of SSCD
- Classification of models

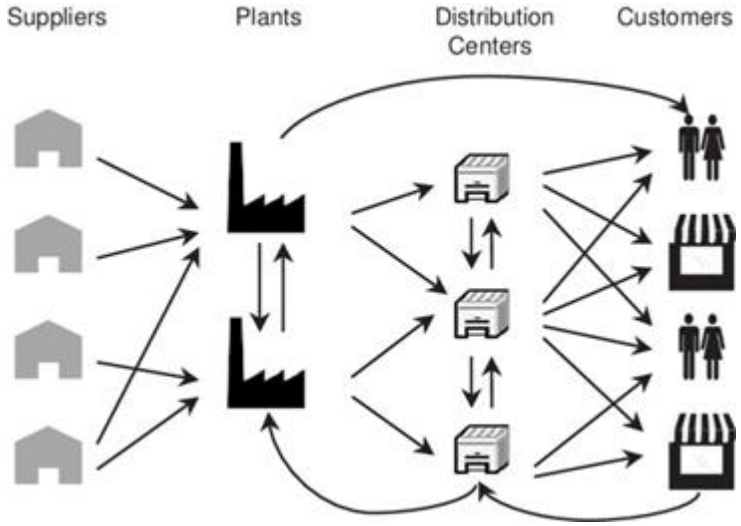

Fig. 2. Example of a supply chain structure [47]

5.1 SSCD for perishable products

Table 2 presents the research papers addressing the SSCD for perishable products. Jiang et al. [19] addressed the design of SSCN considering carbon foot print. They developed a bi-objective mathematical model to find optimized decisions of the partners' selection, technology and transportation mode, in addition to supplies of raw materials and recovery materials. They validated their proposed model on a real-world case of a beverage company in China. Rohmer et al. [21] presented a design model considering both cost and environmental objectives in the field of the global food system. Yakavenka et al. [22] developed a model of multi-objective functions for SSCD of perishable food. Their proposed model helps in selecting transportation mode, route selection, facilities locations and associated flows of goods. They applied their model in a case study of the distribution and exportation of fruit in Europe from the South-Eastern region to the North-Eastern region. Eskandari-Khanghahi et al. [3] developed model of multi-objective functions for blood supply chain; considering sustainability. Their proposed model helps in determining locations, assignments, inventory, and vehicles' routes simultaneously. Halim et al. [31] proposed a systematic framework for SSCD in order to select the suitable suppliers in the field of pharmaceutics. Patidar et al. [33] proposed a mathematical model for the sustainable supply chain structure of the Indian ago-food food supply chain the proposed model is to attain maximum efficiency

in the vehicle routing for the collection of products and products flow from farmers to the nearest food hub (market). Tavakkoli-Moghaddam et al. [10] developed a mathematical model for the reverse supply chain of perishable products. They implement the model on production company of ready-made foods of meat products. Musavi and Bozorgi-Amiri [38] developed a multi-objective model considering the freshness and quality of foods. Varsei and Polyakovskiy [39] developed a multi-objective model for the design of sustainable supply chain of wine. They implemented the model on a wine company located in Australia. Zahiri et al. [2] presented a multi-objective sustainable model for designing a pharmaceutical supply chain structure while considering both strategic decisions (e.g., location decisions) and tactical ones (i.e., structure allocation).

Table: 2. Reviewed papers on SSCD for perishable products

No.	Paper	Objective functions		Application
1	[19]	Bi	Eco-Env	beverage
2	[21]	Bi	Eco-Env	food
3	[22]	Multi	Eco-Env-Oth	fruit
4	[3]	Multi	Eco-Env-Soc	blood
5	[31]	Bi	Eco-Env	pharmaceutical
6	[33]	Single	Eco	agri-food
7	[10]	Multi	Eco-Env-Oth	meat
8	[38]	Multi	Eco-Env-Oth	food
9	[39]	Multi	Eco-Env-Soc	wine
10	[2]	Multi	Eco-Env-Soc-Oth	pharmaceutical
11	[41]	Single	Eco	deteriorating inventory
12	[46]	Bi	Eco-Env	food

Eco: Economic objective function Env: Environmental objective function
Soc: Social objective function Oth: Other objective functions

5.2 Economic, environmental, and social factors of SSCD

When addressing the objective functions used in the different research papers, it has been shown that some researchers depended on a single-objective function model, others depended on models with two or more objective functions. Some papers addressed the three pillars of sustainability in designing their supply chain structure. Their models aim to minimize the total cost, minimize the total amount of CO2 emission,

and maximize the social effect. Here are some main objective functions in the field of SCD:

5.2.1 Economic objective function

Traditional SCD aimed at minimizing cost, or in other words, maximizing profit. Some researchers developed models of a single objective function that depends only on the economic factor only [13,28,32,33,41]. Their models aim to minimize the total cost of the supply chain system, including the fixed establishment cost, the inventory holding cost, the transportation cost, and other sorts of different costs.

5.2.2 Economic and environmental objective functions

The increased attention to the environmental factors encourages some researchers to address the environmental factor along with the traditional economic factor. Some researchers developed bi-objective models with economic-environmental objective functions [16,21,30,31,45,46]. Their models aim to minimize the environmental impacts through minimizing CO2 emissions released from production or transportation processes.

5.2.3 Economic, environmental, and social objective functions

The social objective function aims to maximize the social influence, which includes the created number of job opportunities, the number of lost days due to damage to work, the number of unemployed workers at the manufacturers. Some researchers addressed the three pillars of sustainability i.e., economic, environmental, and social [2,3,15,39,40]. They developed multi-objective models with economic-environmental-social objective functions.

5.2.4 Other objective functions

Other objective functions other than the economic, environmental, and social objective functions have been considered. The model of Mohebalizadehgashti et al. [14] aims to maximize capacity utilization of facilities. An objective function in the model of Diabat [17] aims to minimize the expected products' delivery time from/to different facilities. Sabouhi et al. [27] seeks at maximizing the efficiency of the supplier under consideration. Tavakkoli-Moghaddam et al. [10] considered in their function product freshness, product quality. They try to maximize satisfaction in aid of the usage of technology. An objective function in [29] and [44] is to minimize the maximum unsatisfied

demand of products. Musavi and Bozorgi-Amiri's model [38] maximizes the total purchase probability of the all-customer zones. Rashidi et al. [11] attempts to minimize demand unresponsiveness. An important function in the field of blood supply chain has been addressed by Arvan [42]; their model minimizes the sum of times at which blood products remain in the network. Yakavenka et al. [22] considered the delivery time as an objective function; their proposed model attempts to minimize the sum of transportation times by the different transportation methods in the supply chain network.

Table: 3 Model Types

Model type description	Characteristics	
	Nonlinear terms	Discrete variables
Linear Programming (LP)	×	×
Nonlinear Programming (NLP)	✓	×
Mixed Integer Programming (MIP) or Mixed Integer Linear Programming (MILP)	×	✓
Mixed Integer Nonlinear Programming (MINLP)	✓	✓

5.3 Classification of models

The aim of this section is to review the model types for SSCD. There is a broad variety of model types. According to [48], they are classified to Linear programming (LP) and nonlinear programming (NLP). Table 3 illustrates the linear and nonlinear programming types and their characteristics. Multi-objective programming-based modelling approaches can be divided into multi-objective linear programming (MOLP), multi-objective integer linear programming (MOILP), multi-objective nonlinear programming (MONLP) and multi-objective nonlinear integer programming (MONLIP). The uncertainty in some models can be handled using fuzzy programming with Stochastic programming. Also, heuristics algorithms and metaheuristics are used to solve the mathematical programming models. Eskandarprour et al. [48] reviewed the methods used for multi-objective models as weighted sum of objectives method, epsilon-constraint method, metaheuristics, multi criteria decision analysis (MCDA) and other methods.

6. Findings

To achieve a comprehensive review of SSCD for perishable products, the findings of the selected articles are discussed in the following sections. These sections are:

- Scope of the SCD
- Field of applications
- Modelling approaches and characteristics
- Software tools

6.1 Scope of the SCD

According to the main keywords determined in [Figure-3], it is shown that 12 papers dealt specifically with the three main keywords "Sustainable", "Supply Chain Design" and "Perishable products". 18 papers dealt with SCD for perishable products, but not sustainable. 11 papers dealt with Sustainable SCD, but not perishable products. As shown in Table 4, it is observed that there has been limited study in the area of SSCD for perishable products (Only 12 articles).

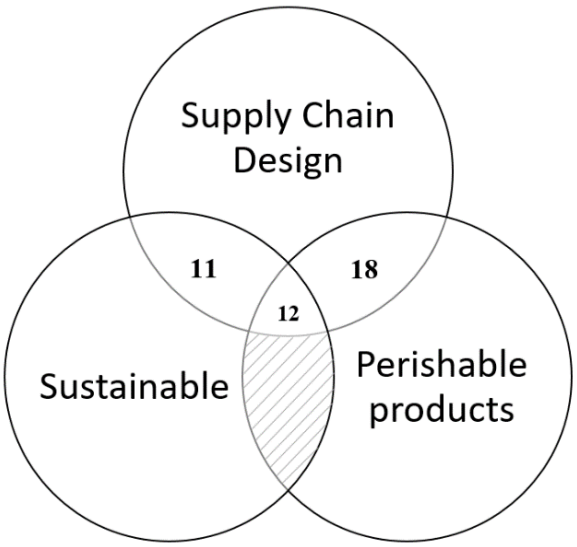

Fig. 3. Keywords and no. of articles

Table: 4 No. of reviewed articles of different scopes

(not sustainable) **SCD** for perishable products	18 articles
Sustainable SCD *(but not perishable)*	11 articles
Sustainable SCD for perishable products	12 articles

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6.2 Field of applications

According to research, it has been found that there are different applications. [Figure-4] illustrates the distribution of reviewed papers in respect of their application. 30 papers out of the reviewed papers addressed the perishable products. Models have been implemented on different applications such as food, beverages, pharmaceutical, blood…...etc.

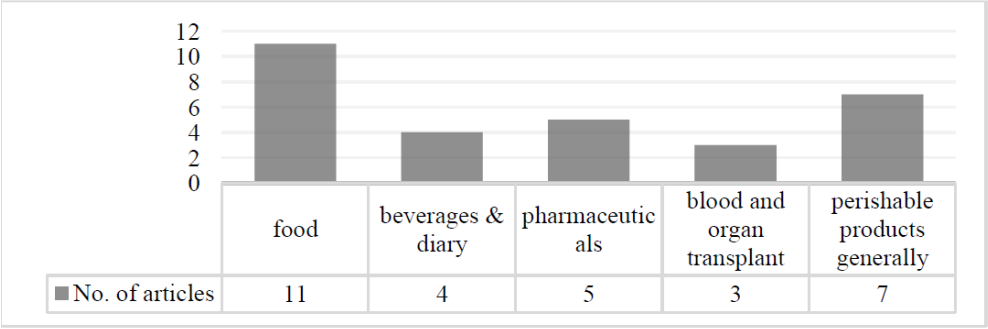


Fig. 4. Distribution of reviewed papers in respect of their application

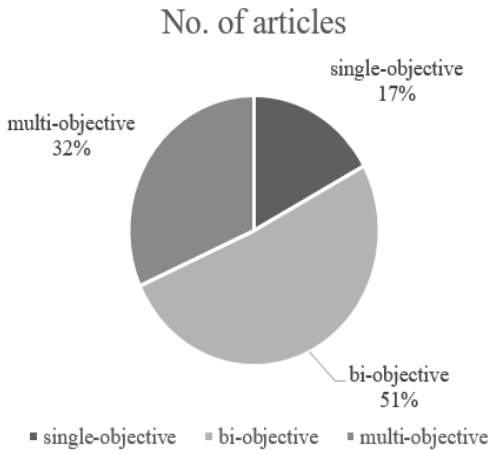
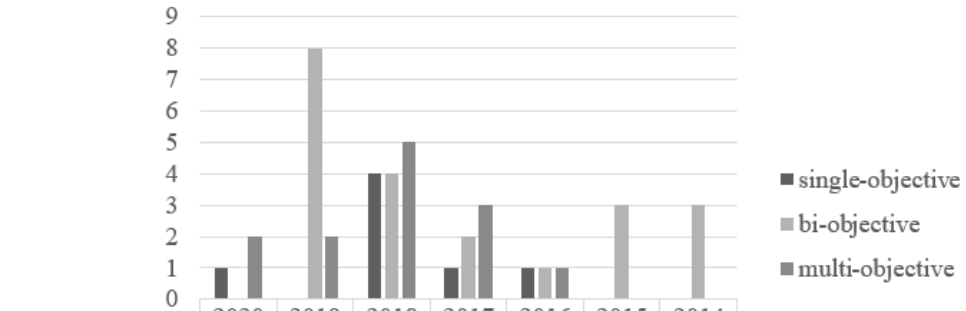


Fig. 5. Distribution of reviewed papers in respect of no. of objective functions

6.3 Modeling approaches and characteristics

Within the SCD, models can be divided into three model categories: single, bi and multi objective models. [Figure-5] demonstrates the distribution of reviewed papers in respect of no. of objective functions.

The review of selected articles showed that 17% dealt with single-objective models, while 51% dealt with bi-objective models, and 32% dealt with multi-objective ones. [Figure-6] shows the distribution of reviewed papers in respect of no. of objective functions across years.



	2020	2019	2018	2017	2016	2015	2014
single-objective	1	0	4	1	1	0	0
bi-objective	0	8	4	2	1	3	3
multi-objective	2	2	5	3	1	0	0

Fig. 6. Distribution of reviewed papers in respect of no. of objective functions across years

Regarding the model's solution approaches of the SSCD covered in literature, it has been found that they are either exact or heuristic. [Figure-7] illustrates the distribution of papers in respect of their solution approaches across years. Patidar et al. [33] used genetic algorithm (GA) along with particle swarm optimization (PSO) to solve the proposed mathematical model. Dai et al. [34] developed hybrid genetic algorithm (HGA) and hybrid harmony search (HHS), the quality of the solution of HHS is higher than that of HGA. Whereas, HGA is faster than HHS. Chalmardi and Camacho-Vallejo [16] and Eskandari-Khanghahi et al. [3] proposed an algorithm depending on the simulated annealing (SA) metaheuristic method. The performance of the SA algorithm and that of the harmony search (HS) algorithm are compared. Yavari and Geraeli [23] developed an efficient heuristic method (YAG method), to solve large-sized problems. Zahiri et al. [2] proposed a new meta-heuristic algorithm based on pareto solurions. Rashidi et al. [11] proposed Multi-Objective Imperialist Competitive Algorithm (MOICA) which is a meta-heuristic approach based on Pareto. They also applied two other algorithms based on genetic algorithm (GA), which are Non-dominated

Ranked Genetic Algorithm (NRGA) and Non-dominated Sorting Genetic Algorithm (NSGA-II). Results shows that MOICA exceeds both NRGA and NSGA-II in respect of the metrics of Mean Ideal Distance (MID), time and spacing. Validi et al. [46] considered three Genetic Algorithm (GA)-based optimizers; Multi-Objective GA-II (MOGA-II), Non-Dominated Sorting GA-II (NSGA- II) and 'Hybrid' combining Gas and sequential quadratic programming. It has been concluded that NSGA-II outperforms MOGA-II and 'Hybrid'. Also, Pourjavad and Mayorga [25] and Musavi and Bozorgi-Amiri [38] developed NSGA-II to solve their multi-objective mathematical model. In [38], the results of NSGA-II are compared to that of Non-dominated ranking genetic algorithm (NRGA). The provided results showed the NSGA I-algorithm had better performance than NRGA.

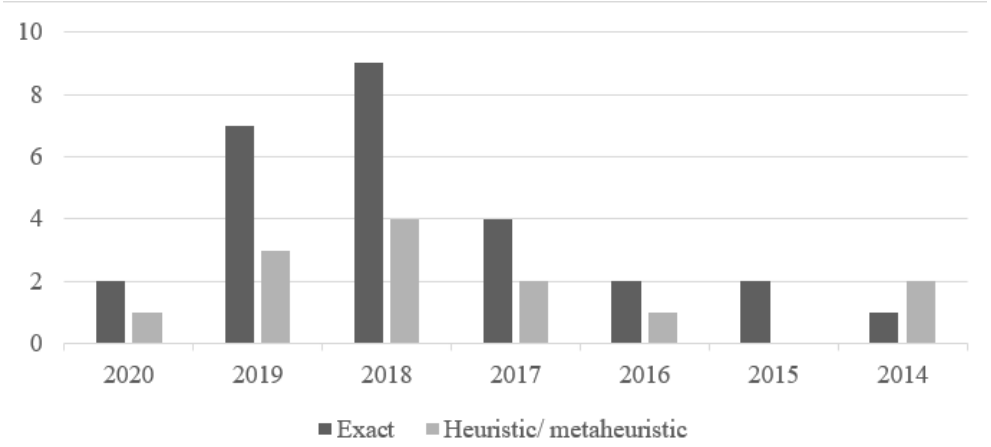


Fig. 7. Distribution of reviewed papers in respect of their solution approaches across years

Some researchers adopted multi-objective solution approaches in their model. Mohebalizadehgashti et al. [14], Babazadeh et al. [35] , Varsei and Polyakovskiy [39] and Daghigh et al. [40] developed a solution approach based on augmented-constraint method to solve their models. Diabat et al. [17] developed a solution approach based on Lagrangian relaxation and ε-constraint to efficiently solve their bi-objective proposed model. Rohmer et al. [21] and Arvan et al. [42] applied ε-constraint method for their model. Isaloo and Paydar [20] employed the weighted sum method for their model computation. Yakavenka et al. [22] and Isaloo and Paydar [20] utilized the method of goal programming in order to solve their models. [Figure-8] shows the mathematical models

adopted in the research papers. It reveals that mixed integer linear programming (MILP) is the most frequent used mathematical programming model type.

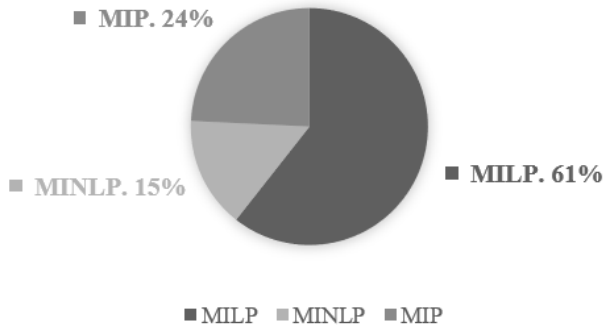


Fig. 8. Distribution of reviewed papers in respect of their mathematical model across years

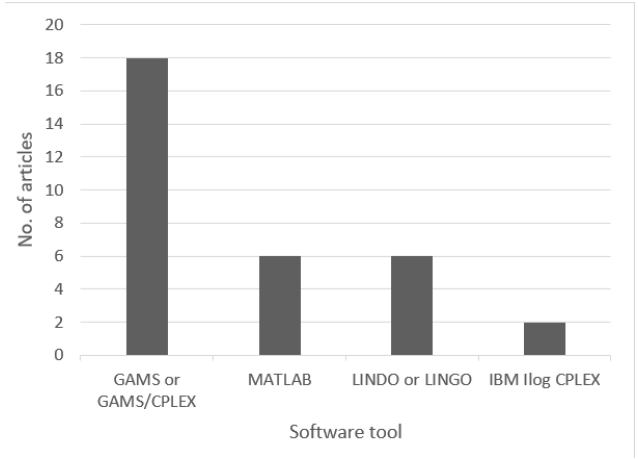


Fig. 9. Distribution of reviewed papers in respect of the software tools used

6.4 Software tools

Different software tools have been used in the solving the mathematical models of SSCD. [Figure-9] shows the distribution of papers in respect of the used software tool. It is found that GAMS software and CPLEX solver are the most used software and solver in solving the addressed models.

7. Conclusions

This paper presents a literature review on the studies in SSCD for perishable products. Perishability phenomenon is considered in a great proportion of products that are transferred daily from manufacturers to the customers. According to the search results, it was declared that studies on SSCD for these perishable products are rare. The summary table in Appendix A showed that some researchers addressed the economic factor only, and others addressed sustainability's three principals; economic, social and environmental. The results show that research has been increasingly growing in this topic. According to search results, researchers used mathematical programming (especially MILP) and commercial solver (especially GAMS/CPLEX).

8. Future Research Opportunities

Researches between 2018 and 2020 reveals the following research gaps as future research opportunities:

- Addressing the effect of varies transportation mode, transport network and real-time quality control using internet of things [13].
- Considering the inventory of products for perishable products. in retailers [14].
- Use of routing vehicle instead of direct allocation [17].
- The expansion of the model and taking other decisions, such as transportation mode and combining it with other issues as routing [23] .
- Addressing disruptions in facilities or flow of materials in the supply chain [23,31].
- Adopting heuristic and meta-heuristic solution approaches to handle large problems with very large datasets.
- Incorporate more objectives in the optimization including minimizing the supply chain.

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Appendix A: Summary table for reviewed papers

No.	Paper	Perishable	Sustainable	No. of objective functions	Economic	Environmental	Social	Others	Modeling approach	Exact or Metaheuristic	Solution approach	Software	Application
1st: Reviewed papers on SSCD for perishable products													
1	[19]	✓	✓	Bi	✓	✓	×	×	MILP	E	_	LINGO	Beverage
2	[21]	✓	✓	Bi	✓	✓	×	×	LP	E	ε-constraint	Xpress-IVE	food
3	[22]	✓	✓	Multi	✓	✓	×	✓	MILP	E	Goal Programming	Open Solver	fruit
4	[3]	✓	✓	Multi	✓	✓	✓	×	MILP	M	Simulated annealing	MATLAB - GAMS/ CPLEX	Blood
5	[31]	✓	✓	Bi	✓	✓	×	×	_	E	_	an Excel-based AHP and LLamasoft's Supply Chain Guru	pharma
6	[33]	✓	✓	Single	✓	×	×	×	MINLP	M	GA and Particle swarm	_	Agri-food
7	[10]	✓	✓	Multi	✓	✓	×	✓	_	E	_	_	ready-made foods of meat products
8	[38]	✓	✓	Multi	✓	✓	×	✓	MILP	M	NSGA-II	GAMS/ CPLEX	food
9	[39]	✓	✓	Multi	✓	✓	✓	×	MIP	E	Augmented ε-constraint method	IBM ILOG CPLEX	wine
10	[2]	✓	✓	Multi	✓	✓	✓	✓	MILP	M	a novel Pareto-based lower bound	GAMS	Pharma
11	[41]	✓	✓	Single	✓	×	×	×	__	E	piecewise nonlinear optimisation	_	deteriorating inventory
12	[46]	✓	✓	Bi	✓	✓	×	×	MIP	M	GA based algorithms	_	food

2nd: Reviewed papers on SCD for perishable products (perishable but not sustainable)													
1	[13]	✓	×	Single	✓	×	×	×	_	E	_	_	avocado
2	[14]	✓	×	Multi	✓	✓	×	✓	MILP	E	Augmented ε-constraint method	LINGO	meat
3	[17]	✓	×	Bi	✓	×	×	✓	MILP	E	Lagrangian relaxation and ε-constraint	GAMS	_
4	[23]	✓	×	Bi	✓	✓	×	×	MILP	M	Yavari and Geraeli method	GAMS/ CPLEX	–
5	[24]	✓	×	Bi	✓	✓	×	×	MINLP	E	LP-metrics method	_	dairy
6	[34]	✓	×	Single	✓	×	×	×	MINLP	M	Hybrid	MATLAB/ LINDO	–
7	[25]	✓	×	Multi	✓	✓	✓	×	MILP	M	NSGA-II	_	_
8	[27]	✓	×	Bi	✓	×	×	✓	_	E	Data envelopment analysis	GAMS	food
9	[32]	✓	×	Single	✓	×	×	×	MIP	E	_	LINGO	dairy
10	[28]	✓	×	Single	✓	×	×	×	MINLP	E	possibilistic programming	GAMS	pharma
11	[29]	✓	×	Bi	✓	×	×	✓	MILP	E	a novel robust optimization	GAMS	pharma
12	[37]	✓	×	Single	✓	×	×	×	MIP	H	GA	GAMS/ CPLEX	–
13	[36]	✓	×	Bi	✓	×	×	✓	MIP	E	_	Gurobi	orange and tangerine
14	[11]	✓	×	Bi	✓	×	×	✓	_	M	Imperialist Competitive Algorithm	MATLAB	_
15	[42]	✓	×	Bi	✓	×	×	✓	MILP	E	ε-constraint method	CPLEX	blood
16	[44]	✓	×	Bi	✓	×	×	✓	MILP	E	a robust possibilistic programming approach	GAMS/ CPLEX	pharma
17	[45]	✓	×	Bi	✓	✓	×	×	MIP	M	Hybrid	MATLAB	food
18	[4]	✓	×	Bi	✓	×	×	✓	MIP	E	Fuzzy programming	GAMS	organ transplant

3rd: Reviewed papers on SSCD (sustainable but not perishable)													
1	[15]	×	✓	Multi	✓	✓	✓	×	_	M	Hybrid GA	MATLAB	_
2	[16]	×	✓	Bi	✓	✓	×	×	MILP	M	SA	GAMS	_
3	[18]	×	✓	Bi	✓	✓	×	×	MILP	E	Large Neighborhood Search	IBM Ilog CPLEX	_
4	[5]	×	✓	Multi	✓	✓	✓	×	MIP	M	hybrid swarm intelligence	MATLAB	_
5	[20]	×	✓	Bi	✓	✓	×	×	MILP	E	Weighted sum method & Weighted goal programming	LINGO	plastic injection
6	[30]	×	✓	Bi	✓	✓	×	×	MILP	E	Distributed approximation approach	CPLEX	_
7	[26]	×	✓	Multi	✓	✓	✓	×	MILP	E	Hybrid robust possibilistic & Improved Augmented ε-Constraint	GAMS/ CPLEX	_
8	[6]	×	✓	Multi	✓	✓	✓	×	MILP	E	Fuzzy programming approach	LINGO	_
9	[35]	×	✓	Bi	✓	✓	×	×	MINLP	E	lexicographic and augmented ε-constraint methods	GAMS/ CPLEX	Biodiesel
10	[40]	×	✓	Multi	✓	✓	✓	×	MILP	E	Augmented ε-constraint method	GAMS	_
11	[43]	×	✓	Bi	✓	×	×	✓	MILP	E	robust optimization	CPLEX	_

Abbreviations:
GA: Genetic algorithm
SA: Simulated annealing
NSGA-II: Non-Dominated Sorting genetic algorithm-II

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تصميم شبكة الإمداد المستدامة للمنتجات القابلة للتلف: دراسة مرجعية

الملخص العربي:

يتم تناول تصميم شبكة سلسلة الإمداد بشكل كبير في البحوث التشغيلية، وعلاوةً على ذلك ، فإن دراسة الاستدامة تلعب دوراً هاماً في أداء سلسلة الإمداد ، الغرض من هذه الورقة البحثية هو وضع دراسة مرجعية للدراسات السابقة حول موضوع تصميم شبكة سلسلة الإمداد المستدامة للمنتجات القابلة للتلف خلال الفترة ٢٠١٤ -٢٠٢٠ ،تم إعداد جدول موجز للمقارنة بين الأوراق البحثية المختلفة لتوفير فهم أعمق للموضوع ،تمت مقارنة الأوراق البحثية وفقاً لتصنيفات مختلفة مثل: قابلية التلف ، والاستدامة ، والوظائف الموضوعية ، ونهج النمذجة ، وأدوات البرمجيات المستخدمة ، مجال التطبيق. وأخيرا، يوصى بوضع قائمة بفرص البحث المحتملة في المستقبل.