Closed-Loop Supply Chain Networks

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1 Introduction

Supply Chains describe a network of different participants. The starting point for a supply chain is usually the production of goods. Then, other participants will process the goods until the finished product is sold to the end customer. Therefore, a network usually contains producers, suppliers, distribution centers, and customers. The main objective of efficient supply chain management is optimizing costs and revenue along the supply chain.[1]

A basic supply chain network could be depicted, as the following plot indicates:

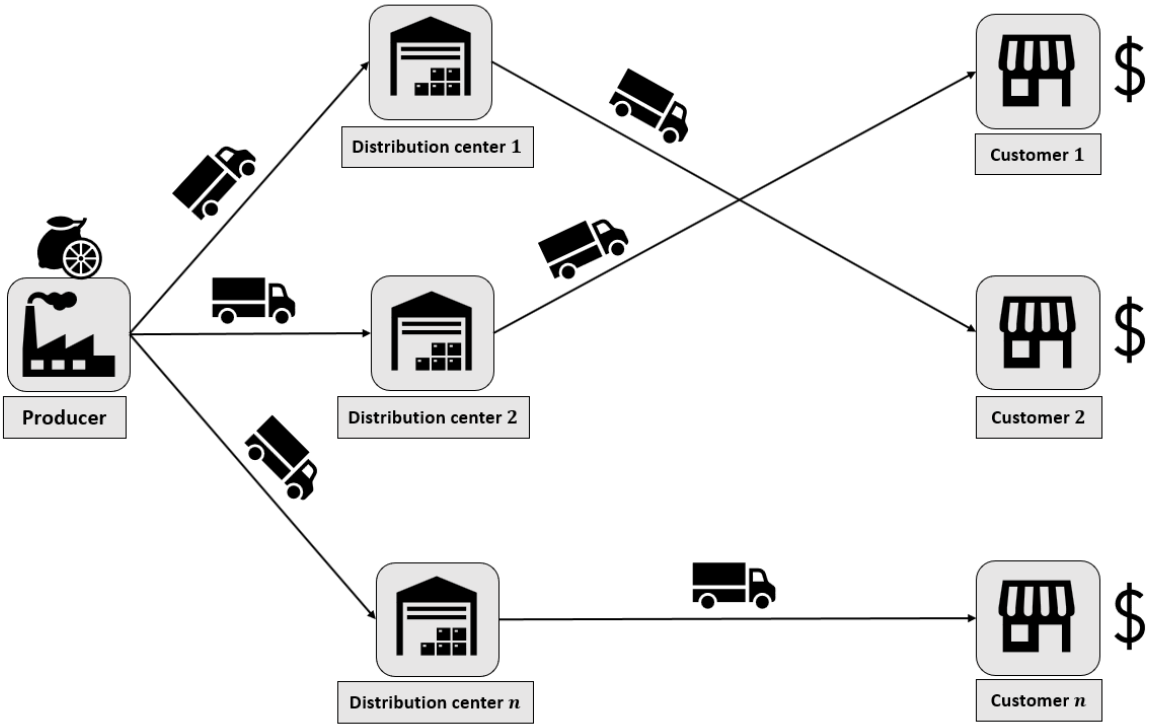

Figure 1: A supply chain network

As one can see, genuine life supply chains tend to have a network shape instead of a chain. The reason for that is the existence of various participants in business applications. Therefore, the term supply chain network is more accurate.[2] In our case, we have a company that produces citrus fruits on farms. After the fruits have been harvested, they will be delivered to distribution centers.

[1] See Günther/Tempelmeier (2020), p.19 for more information

[2] The terms „supply chain“ and „supply chain network” will be used as synonyms.

Distribution centers are essential for the efficient supply chain management. Their main functions are the reception and storage of goods and order preparation and shipment. They act as an intermediary in the logistical process and are relevant participants in cost optimization and delivery time reduction. As we are dealing with agricultural supply chains, various factors are relevant. One aspect, which is especially relevant in today's climate, is sustainability management. According to Cheraghalipour/Farsad (2018), its main objective is minimizing environmental, economic, and social sustainability risks. While companies generally are primarily monetarily oriented, the relevance of environmental factors increases at a high rate. One ecological aspect, which has gained a lot of pertinence in the last years, is emissions reduction. To incorporate these environmental and socio-economic issues into the supply chain network, various companies have considered and evaluated the importance of reverse logistics.

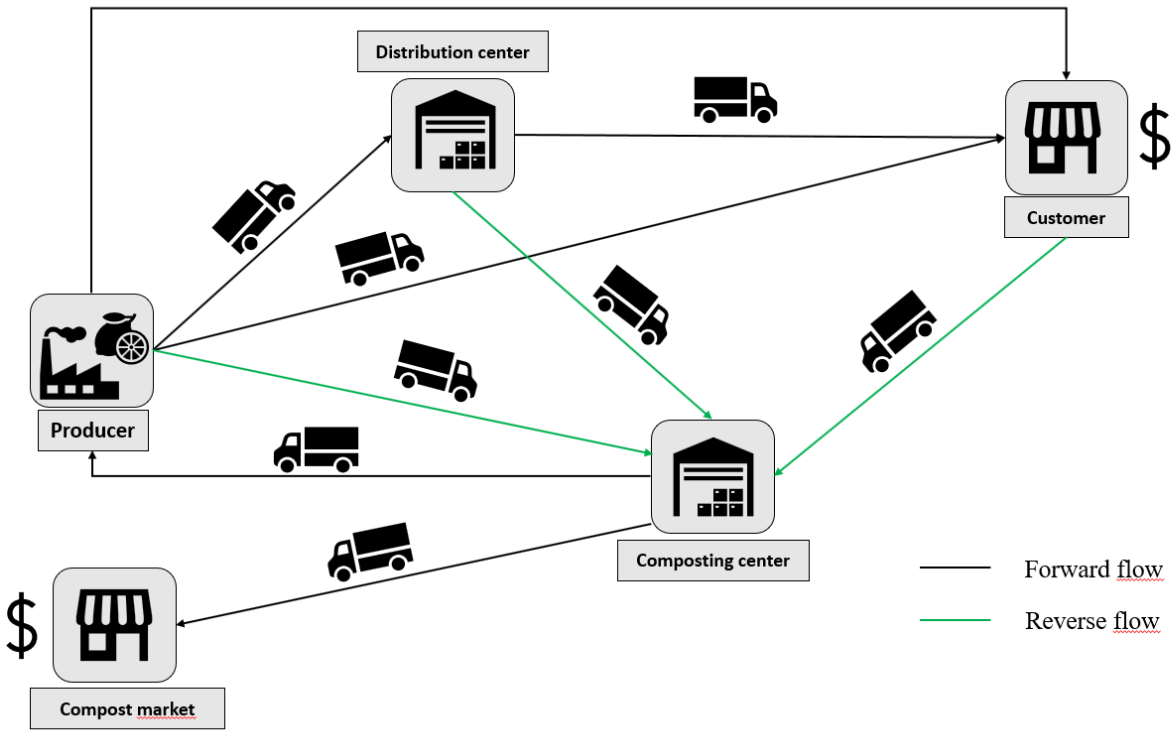

Figure 2: Closed loop supply chain network for a citrus producer (own illustration)[3]

Figure 2 shows a typical Closed-loop supply chain network (CLSCN), which includes five participants.[4] These participants are connected via logistical interdependences. Forward flows

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[3] Following Cheraghalipour/Paydar/Hajiaghaei-Keshteli (2018): 5.

[4] The figure itself is a simplification of CLSCN. Real-life CLSCN tend to be much more complex.

indicate routine logistical activities such as transport, which could be found in a typical supply chain network.[5] The citrus producer in Figure 2 can deliver its product directly to the customer but also has the option to deliver the product to a distribution center. The main difference is the inclusion of reverse flows, in which cases, participants go backward in the supply chain. Citrus fruits have a high probability of decaying and becoming inedible. The decaying of these fruits results in increased costs for the network since workers must collect, transport, and discard the rotten fruits. The decay can occur as early as in the harvesting process and late after the placement in the market. An SCN intends to minimize its occurring costs to ensure profit maximization for all participants. Therefore, implementing reverse logistics (RL) is imperative to guarantee these objectives.[6] Rotten fruits can be recycled using a method called vermicomposting. The result is a large amount of organic fertilizer, which one can use to cultivate the plants for citrus production. As stated by Cheraghalipour/Paydar/Hajiaghaei-Keshteli (2018) as well as Guertal/Green (2012), further cultivation of the plants results in more nutritious fruits and, therefore, various benefits for the human health.[7] The fertilizer can also be sold to compost markets to gain more revenue. Another aspect is the use of plastic packages. After the farmers have finished harvesting the fruits, they use plastic crates for packaging. Plastic containers are popular in the packaging process because of their low costs and accessibility. In an ideal network, one must collect these crates from the end customers to minimize waste However, as specified by Lao et al. (2020), actual data indicates that the recycling rate of plastic packaging paste is nowhere where it should be.

[5] As shown in figure 2.

[6] Real-life CLSCN tend to be multi-objective planning problems, see Ch.3

[7] Forward flow from the compost center to the producer.

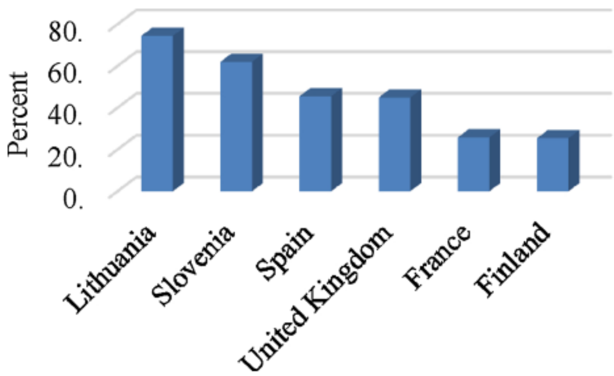


Figure 3: Recycling rate of plastic packaging waste in some European countries in 2016 (in percent)[8]

One typical optimization problem, which is relevant in literature and practical applications, is the facility location problem.[9] One must open several facilities to fulfill the customer's demand. As seen before in the outline of a typical CLSCN, the correct location of facilities is crucial for a company's long-term success. The location of the facilities directly influences the number of variable costs (e.g., transport costs). Therefore, one should open facilities next to promising clients.[10] Another vital aspect is the availability of skilled labor. One should open production plants in an area where much essential personnel is available. Of course, this could contradict a location next to customers. Maybe, a region with promising customers could lack a variety of general labor. Reality is often not as simple as that. There are a lot of other restrictions a company must face in determining locations for open facilities.[11]

[8] See Lao et al. (2020): 200.

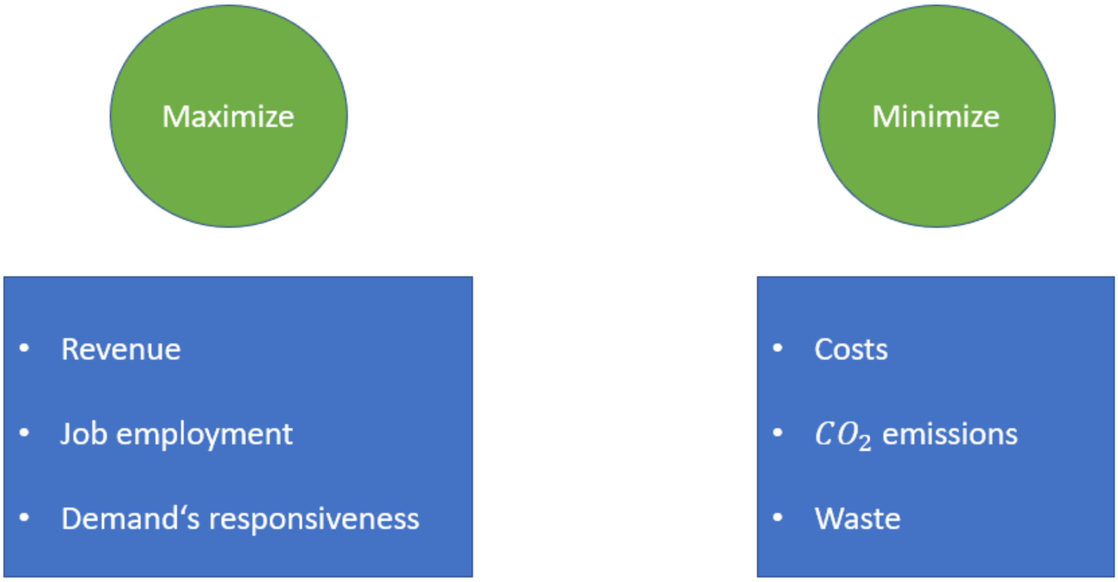
[9] The term "facility" can either refer to a production plant or a distribution center.

[10] In our case, supermarkets, or compost markets.

[11] These restrictions could be related to other important task in the project (e.g., budget restrictions, legal issues, etc.)

2 Framework of CLSCN

2.1 Objectives in a CLSCN



CLSCN planning problems include various objectives. From a more monetary perspective, revenue and costs are essential objectives. For revenue maximization, one must sell many citrus fruits and fertilizer to end customers. The revenue depends on a) the amount of sold units, b) pricing, and c) the total costs. Therefore, one could argue that costs and revenue objectives can coexist efficiently. However, the amount of waste and emissions increase with higher production and job employment. In consequence, those objectives might contradict each other. For example, if one can successfully implement reverse logistics, one can minimize the amount of waste even with an increased production volume. However, efficient waste management (e.g., recycling) consumes costs and results in rivaling objectives. Nevertheless, one must differentiate between fixed costs and variable costs. Fixed expenses occur if one opens a facility at a specific location.[12] According to Jabarzadeh/Yamchi (2020), the size of a facility influences its capacity to produce. Therefore, investing in a more extensive facility could benefit-cost minimization.[13] On the other hand, variable costs are essential in logistical planning.

[12] The opening costs might depend on the size of a facility, for instance.
[13] Especially if it is a facility next to many customers.

Moreover, one can diversify variable costs in a lot of categories. In our case, according to Cheraghalipour/Paydar/Hajiaghaei-Keshteli (2018), transportation costs, holding and processing costs (e.g., preparation and packaging of the fruits tor the delivery to the markets) of distribution centers, production costs of production plants and reprocessing costs of composting centers are the most prominent ones. DRM refers to the forward and reverses responsiveness of the CLSCN, and one can measure it in percentages.

Figure 4: Variable Costs in a CLSCN and their carriers (own figure)

Corresponding to Jabarzadeh/Yamchi (2020), one can also distinguish the number of emissions into fixed and variable parts. Fixed emissions transpire due to opening new facilities, while (variable) emissions result from the activities, which result in variable costs. Variable emissions are also influenced by the type of vehicle used for transporting the fruits. Existing cars require different types of fuel. Therefore, according to Roghanian/Cheraghalipour (2019), part of the variable emissions depends on the type of vehicle and fuel. One could eliminate these emissions in the foreseeable future by using electric cars, though. Production plants with a bigger size and capacity have a greater availability for job employment. Next to employment maximization, which focuses on quantitative aspects, employment efficiency maximization focuses on more qualitative aspects (For instance, the contribution of the hired workers in the production or processing process). Employment maximization, according to Salehi-Amiri et al. (2022), compliments DRM and, therefore, revenue optimization.

2.2 Constraints in a CLSCN

One can only achieve economic and environmental objectives by considering various constraints. They are worth considering because they give a good overview of the potential of fulfilling relevant purposes. Their size influences the production of plants; therefore, a plant can only produce as much as its capacity allows them to.[14] Another constraint should concern inventory control. Efficient inventory management is a critical factor for success. For instance, producing and harvesting many fruits might be beneficial because production requires set-up costs, which could be higher than holding costs. Reverse logistic flows can be performed if some constraints are ensured. Citrus fruits, which have been spoiled or are no longer edible, will be delivered to composting centers from producers. The number of spoiled fruits is correlated to the waste rate of production. As mentioned before, one can convert reprocessed products into vermicompost. They are conforming to Cheraghalipour/Paydar/Hajiaghaei-Keshteli (2018). The amount of it equals the reprocessed fruits multiplied by the conversion rate.

[14] Capacity also concerns distribution centers and other participants in the CLSCN.

3 Utilization of mathematical methods to solve logistical planning problems

According to Domschke et al. (2015), Operations research (OR) is a scientific discipline that interfaces economists, engineers, computer scientists, and mathematicians. It is also referred to as management science. In OR, planning problems are represented by mathematical formulations. Economic or logistical planning problems tend to have specific objectives.[15] These pursuits are represented by objective functions, which can be divided into maximization or minimization functions.

$$\text{Minimize} \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij} \cdot x_{ij} \quad (1)$$

(1) shows a typical objective function, which minimizes the costs for a logistical operation (e.g., transportation of goods). I is the number of distribution centers, where citrus fruits are stored and J is the number of fruit markets. This objective intends to find logistical connections between locations, which are cost-wise the best choice. c_{ij} is a parameter that indicates the costs for transporting citrus fruits from distribution center i to fruit market j. Parameters are values, that are known before the actual operation is executed. x_{ij} is a decision variable and indicates the number of citrus fruits that must be transported to fulfill the customer's demand. A decision variable is an unknown value, which is only known if the problem is solved correctly. For instance, transportation costs can be calculated beforehand to make an economic decision. Of course, one could argue that the transportation costs between two locations depend not only on the distance but also on the type of vehicle. Therefore, one can easily modify the objective function into the following formulation:

$$\text{Minimize} \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{v=1}^{V} c_{ij}^{v} \cdot x_{ij}^{v} \quad (1.1)$$

Now, the choice of logistical connections also depends on the type of vehicle v. Of course, other modifications are conceivable. The advantage of mathematical formulations lies in the infinite

[15] As seen in chapter 2.1

possibility of changes. To achieve this objective, one must also consider the restrictions that lie beneath a planning operation. Possible restrictions are described in chapter 2.2. The following limitation shows a balance equation from Roghanian/Cheraghalipour (2019):

Sets

I ... Number of gardens

t' ... Number of time periods (e.g., days, weeks, months)

V ... Number of vehicles

J ... Number of distribution centers

K ... Number of fruit markets

Parameters

α_t ... Percentage of the rotten products at fruit markets in period t

Decision variables

X_{ijvt} ... Products distributed by vehicle v from garden i to distribution center j in period t

S_{ijkt} ... Products distributed by vehicle v from garden i to fruit market k in period t

$$\lambda_{it} \cdot (1 - \alpha_t) = \sum_{v=1}^{V} \sum_{j=1}^{J} X_{ijvt} + \sum_{v=1}^{V} \sum_{k=1}^{K} S_{ikvt} \qquad \forall i \in I, \forall t \in t' \qquad (2)$$

Restriction (2) ensures the balance between produced fruits and distributed fruits.[16] The left term describes the product's availability. For instance, 20 % of the harvest was rotten in garden 1 in week 2 and 150 fruits were produced, then $\lambda_{12} \cdot (1 - a_2) = 150 \cdot (1 - 0{,}2) = 120$. The term on the right side includes the number of fruits, which are delivered to distribution centers

[16] One cannot deliver more fruits than is available.

(X_{ijvt}) and fruit markets (S_{ikvt}). Therefore, only 120 fruits can be delivered to all available centers.[17] The expression on the right side $\forall i \in I, \forall t \in t'$ indicates that this balance equation must be calculated for every garden i and every period t.

[17] The summation operator indicates that all distribution centers and fruit markets can be reached from a particular garden.

4 Literature overview

Alfonso-Lizarazo/Montoya-Torres/Gutiérrez-Franco (2013) proposed a CLSCN for the palm oil industry. They performed a scenario analysis, in which they emphasized the advantages of the consideration of reverse flows. They examined four scenarios: 1) CLSCN, 2) SCN, 3) forward flows and recovery process and 4) forward flows within a green supply chain. They conclude that the consideration of reverse benefits highly benefits the outcome of a computation regarding social as well as economic factors.[18]

Cheraghalipour et al. (2018) present a Bi-objective model, which includes a CLSCN with various participants (e.g., farmers, distribution centers, etc.). They highlight the importance of reverse logistics by focusing on converting rotten fruits into reusable products. Objective-wise they concern themselves with the minimization of costs and the maximization of demand responsiveness. Since the model is a variation of a facility location problem, its complexity rises with more potential locations. In operations research, solutions can be divided into optimal and feasible solutions. An optimal solution could represent a facility opening schedule and a transportation plan, which is the best possible outcome regarding the accurate fulfillment. However, with more possible locations and potential transport routes, the number of restrictions rises exponentially. Therefore, the computation of an optimal solution requires more and more time. To deal with this issue, the authors represent a few algorithms and conclude that implementing a non-dominated ranking genetic algorithm (NRGA) delivers the most efficient solutions. They validate their observations with a real-life case study in Iran.[19]

Roghanian and Cheraghalipour (2019) choose to include an objective that aims to minimize the amount of CO_2 emissions while also considering a CLSCN with citrus fruits. They introduce several meta-heuristics, while a tree growth algorithm (MOTGA) proves to be the most efficient algorithm. In addition, they perform a sensitivity analysis to validate the efficiency of their introduced algorithms and conclude that multiple vehicles improve demand responsiveness and can also decrease the amount of CO_2 emissions. abarzadeh and Yamchi (2020) describe a similar

[18] Alfonso-Lizarazo/Montoya-Torres/Gutiérrez-Franco (2013), p. 9661.

[19] Iran has a similar infrastructure to other Mediterranean countries (Egypt, Tunisia, Algiers, etc.). For more information see Cheraghalipour et al. (2018), p. 59.

network as Cheraghalipour et al. (2018). While the latter was more focused on economic objectives, Jabarzadeh and Yamchi (2020) tackle a more extensive ground of primary goals, which ensure a sustainable network, mainly optimizing "economic, social and environmental performance".[20] To ensure this, an objective function for the minimization of CO_2 emissions is introduced. They also distinguish citrus fruits into three different categories. 1) New fruits, which can be delivered to distribution centers and sold to customers; 2) spoiled fruits, which either will be disposed of or processed into 3) composted products, which will be delivered to the gardens or sold to the compost markets. The authors used the Tchebycheff method to solve the problem This method transforms a multi-objective-formulation into a singular-objective-formulation. It gives every objective a weighted factor based on their importance for the planning problem.[21] The focus of the paper is to find solutions, who prove to be pareto optimal. According to Domschke et al. (2015), Pareto optimality refers to a solution being efficient; meaning that an alteration of the solution would be worse for a lot at least one of the objectives.[22]

Liao et al. (2020) also observe a CLSCN with citrus fruits as the main product while exploring a new aspect, this being the consideration of citrus fruit rates.[23] Collection centers assume the functions of a customer in the reverse logistics department. They also use a variety of algorithms while evaluating their mathematical formulations with a case study in Iran. Variations of the Keshtel algorithm deliver the best results in this case. The algorithm itself was named after a duck named "Keshtel," whose unique feeding behavior served as an outline for the algorithm.[24] They conclude that the aspect of water pollution should be considered in future papers. Water pollution seems to be a good factor because broken and returned crates must be washed, after they have been brought to the sorting centers.[25]

Salehi-Amiri et al. (2021), while developing a CLSCN for the walnut industry, use a similar outline for the network like the other authors. They also consider specified customers rather than

[20] See Jabarzadeh and Yamchi (2020), p. 6.

[21] See Jabarzadeh and Yamchi (2020), p. 13.

[22] See Domschke et al. (2015), p. 61.

[23] As explained in chapter 1.

[24] See Liao et al. (2020), p. 208.

[25] See Liao et al. (2020), p. 215.

one simplified customer. The authors also use a Kesthel algorithm as Liao et al. (2020). In addition, they consider a Simulated Annealing algorithm, which structure is based on the metallurgy industry.[26]

Salehi-Amiri et al. (2022), while also focusing their research on the agricultural industry, consider avocado fruits their main product. Compared to existing papers, which deal with CLSCN in the farming industry, they implement a new objective function that aims to maximize job employment in different locations. They propose a similar supply chain network as the authors before while specifying the other potential customers in the avocado industry. They examine the impact of changes in different parameters (e.g., changing demand, capacity, transportation costs, etc.) with a sensitivity analysis.[27] They further validate their research with a case study in Mexico. They conclude that high demand and large facility capacity benefit the employment rate of people. A consideration of social factors could also help developing countries in ImPUlSe, especially in countries where many people are not employed.[28]

[26] See Salehi-Amiri et al. (2021), p. 13, for more information.

[27] See Salehi-Amiri et al., (2022), pp. 616-627, for more information.

[28] See Salehi-Amiri et al., (2022), p. 627-628.

5 Importance for the project ImPulSe

Supply chain networks, as seen before, significantly impact economic, social, and environmental aspects. A lot of objectives could be pursued by structuring those supply chains as a network. The complexity lies in the conflicts of objectives. Multi-criteria optimization problems require methods that sufficiently satisfy all interest groups

Authors	Paper	Year	Product	Objective function	Distinctive features
Armin Cheraghalipour, Mohammad Mahdi Paydar, Mostafa Hajiaghaei-Keshteli	A Bi-objective Optimization for Citrus Closed-Loop Supply Chain Using Pareto-Based Algorithms	2018	Citrus fruits	Cost minimization and responsiveness maximization Main concern: Spoiled fruits in each echelon of the chain	Case study in Iran
Younis Jabarzadeh and Hossein Reyhani Yamchi,Vikas Kumar and Nader Ghaffarinasab	A multi-objective mixed-integer linear model for sustainable fruit closed-loop supply chain network	2020	Citrus fruits	Minimization of Carbon dioxide (CO_2) emission and costs in forward logistics as well as the minimization of SC costs only in reverse logistics	Emphasis on Pareto optimal solutions
Emad Roghanian & Armin Cheraghalipour	Addressing a set of meta-heuristics to solve a multi-objective model for closed loop citrus supply chain considering CO2 emissions	2019	Citrus fruits	1. Cost minimization 2. Forward and reverse demand's responsiveness maximization 3. CO_2 emissions minimization	Cost function was considered as the main objective function, while the other two objective functions were converted to constraints.
Amirhossein Salehi-Amiri, Ali Zahedi, Fatemeh Gholian-Jouybari, Ericka Zulema Rodríguez Calvo, Mostafa Hajiaghaei-Keshtelib	Designing a Closed-loop Supply Chain Network Considering Social Factors; A Case Study on Avocado Industry	2022	Avocado	1. Total cost minimization 2. Job employment maximization in various opened locations	Case Study in Puebla,Mexico
Yi Liaoa, Mohammad Kaviyani-Charatib, Mostafa Hajiaghaei-Keshtelic, Ali Diabat	Designing a closed-loop supply chain network for citrus fruits crates	2020	Citrus fruits	Total cost minimization	Consideration of citrus fruits' crates in the model formulation
Amirhossein Salehi-Amiri, Ali Zahedi, Navid Akbapour, Mostafa Hajiaghaei-Keshteli	Designing a sustainable closed-loop supply chain network for walnut industry	2021	Walnut	Total cost minimization	First application for the walnut industry
Edgar H. Alfonso-Lizarazo, Jairo R. Montoya-Torres, Edgar Gutiérrez-Franco	Modeling reverse logistics process in the agro-industrial sector: The case of the palm oil supply chain	2013	Palm oil	Revenue maximization	First application for the palm oil industry

Table 1: Literature overview (own illustration)

Even though most relevant research papers tackle economic objectives, such as those from Jabarzadeh et al. (2020) and Salehi-Amiri (2021), which concern themselves more with social and environmental aspects of CLSN, variations of the mathematical models introduced in chapter 3, can be used to conduct cost-benefit analyses for different possible scenarios. In this way, mathematical models could help to evaluate specific approaches for the project ImPulSe. Therefore, further alterations and in-depth evaluations of mathematical models are recommended to assist the project by building efficient and sustainable CLSN.

6 References

Alfonso-Lizarazo, E., Montoya-Torres, J., Gutiérrez-Franco, E., (2013), Modeling reverse logistics process in the agro-industrial sector: The case of the palm oil supply chain, Applied Mathematical Modelling, Vol. 37, pp. 9652-9664.

Cheraghalipour, A., Paydar, M., Hajiagheai-Keshteli, M., (2018), A Bi-objective Optimization for Citrus Closed-Loop Supply Chain Using Pareto-Based Algorithms, Applied Soft Computing, Vol. 69, pp. 33-59.

Domschke, W., Drexl, A., Klein, R., Scholl, A., (2015), Einführung in Operations Research, Berlin-Heidelberg: Springer, 9th edition.

Günther, H., Tempelmeier, H., (2020), Supply Chain Analytics: Operations Management und Logistik, Norderstedt: BoD – Books on Demand, 13th edition.

Jabarzadeh Y., Yamchi H., Kumar V., Ghaffarinasab N., (2020), A multi-objective mixed-integer model for sustainable fruit closed-loop supply chain network, Management of Environmental Quality, Vol. 31(5), pp. 1351-1373.

Liao, Y., Kaviyani-Charati, M., Hajiagheai-Keshteli, M., Diabat, A., (2020), Designing a closed-loop supply chain network for citrus fruit rates considering environmental and economic issues, Journal of Manufacturing Systems, Vol. 55, pp. 199-220.

Roghanian E., Cheraghalipour, A, (2019), Addressing a set of meta-heuristics to solve a multi-objective model for closed-loop citrus supply chain considering CO_2 emissions, Journal of Cleaner Production, Vol. 239, Article 118081.

Salehi-Amiri, A., Zahedi A., Akbapur N., Hajiagheai-Keshteli M., (2021a), Designing a sustainable closed-loop supply chain network for walnut industry, Renewable and Sustainable Energy Reviews, Vol. 141, Article 110821.

Salehi-Amiri A., Zahedi A., Gholian-Jouybari F., Calvo E., Hajiagheai-Keshteli M. , (2021b) , Designing a Closed-loop Supply Chain Network Considering Social Factors; A case study on Avocado Industry, Applied Mathematical Modelling, Vol. 101, pp. 600-631.

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