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DESIGNING A SUSTAINABLE LOGISTICS MODEL WITH A HETEROGENEOUS COLLABORATION APPROACH

Zahra Hassanzadeh[1], Iraj Mahdavi[1], Ali Tajdin[1], Hamed Fazlollahtabar [2]*

[1] Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran
[2] Department of Industrial Engineering, School of Engineering, Damghan University, Damghan, Iran

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Research paper

Abstract: *This paper aims at designing a sustainable logistics model with a heterogeneous collaboration approach. In this regard, we worked on a logistics system by transmitting raw materials to a factory and then sending various products to consumption centers. Accordingly, three logistics layers of supply, production, and consumption were designed and the parameters of collaboration within and between the logistics layers were evaluated. After that, as novelty of our paper, the interactions of sustainability indicators with the logistics network and their effects on the collaboration were analyzed through productivity. In this paper, we use two objectives includes minimizing the supply chain costs and maximizing the productivity of the collaboration parameter affecting the sustainability indicators at different levels. Finally, the developed mathematical model is solved and validated in GAMS optimization software to analyze the performance of the proposed approach using epsilon constraint method.*

Key words: *sustainable logistic model, heterogeneous collaboration, epsilon constraint method, multi-level model*

1. Introduction

Today, rapid developments and changes have led organizations to research logistics and supply chain to overcome their uncertain environment. Supply chain management is a two-way interaction with new technologies such as outsourcing, lean logistics, virtual logistics, etc. This volume of theory shows that different organizations consider the major significance of supply chain and logistics (Shafizadeh, 2004). In 2021, the global logistics industry that hit from COVID-19

* Corresponding author.
zahrahassanzadeh.s@gmail.com (Z. Hassanzadeh), irajarashrediffmail.com (I. Mahdavi), ali_tajdin@yahoo.com (A. Tajdin), h.fazl@du.ac.ir (H. Fazlollahtabar)

pandemic, recovered with market size of 8.43 trillion euros approximately. By 2027, the logistics industry scale is forecasted to exceed 13.7 billion euros that is very huge value (data gathered from statista[1]). Logistics is a big part of the supply chain, which includes matters related to supply, transportation, storage, distribution, etc. Logistics and supply chain variables can be used to assess the logistics status of an organization (David et al., 2004). Figure 1 show the North American net revenue of leading logistics companies in the United States in 2021.

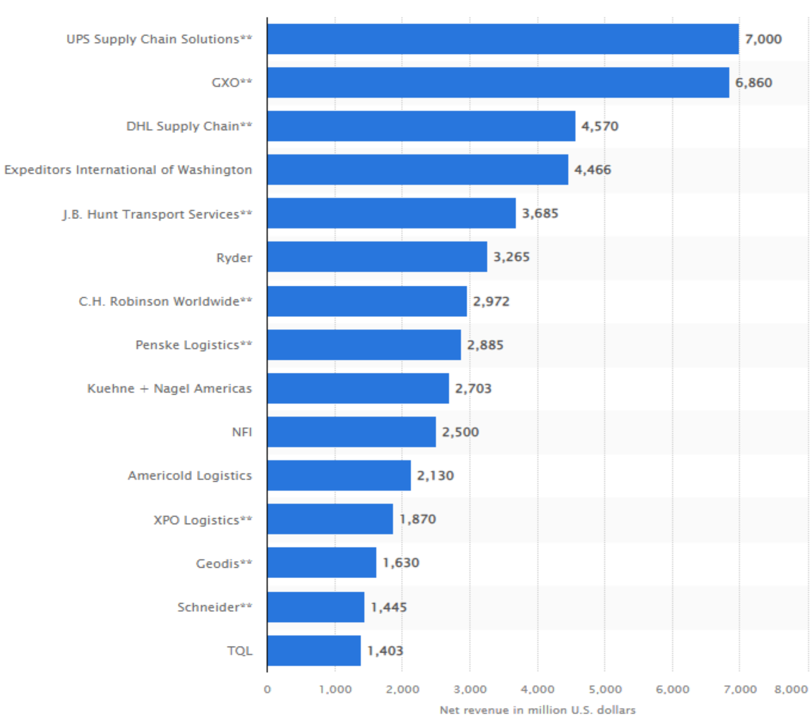

Figure 1- the North American net revenue of leading logistics companies in the United States in 2021

Today, with improvements in production processes, many industry executives have realized that improving internal processes and flexibility in just the company's capabilities is not enough to stay in the market. Rather, suppliers of parts and materials must produce the required supplies with the best quality and lowest cost; in addition, distributors of products must be closely related to the development policies of the producer market (Kazimieras Zavadskas et al., 2020). With such an attitude, logistics, supply chain, and supply chain management approaches have emerged. Logistics is a planning orientation and a framework that seeks to create a unique program for the production and flow of information through businesses. The concept of Supply chain management is presented after this approach and seeks to create the link and coordination between the processes of other organizations in this

[1] https://www.statista.com/

linking line (Zakeri et al., 2015). Logistics processes directly or indirectly affect almost all areas of activity in the industry sector.

In this regard, coordination is a strategic response to the challenge posed by supply chain partners. Coordination is the act of controlling the institutions' affiliations by working together to achieve mutually defined goals. The benefits of coordination include better use of resources, reduced operating costs, increased profits, improved customer satisfaction, and increased productivity in developing productions (KASSAMI et al., 2022). The concept of collaboration is both linked to supply chain coordination and seen as a complementary aspect of a comprehensive concept of coordination. Collaboration can be between members of a supply chain or between multiple supply chains. It occurs when several organizations and companies work together and engage in normal business relationships. It is the response to the fact that organizations and companies cannot separately solve common problems to achieve the expected performance indicators (Nu et al., 2004).

The concept of sustainability led to the formation of a new approach to designing logistics networks. Evidently, there are sustainability dimensions that lead to the formation of differences when comparing general logistics networks. It is the use of various resources to meet the needs of the present generation industries without jeopardizing the ability of the next generation. Sustainable supply chain management comprises all dimensions of sustainability, including economic, environmental, and social dimensions. These processes include the entire life cycle of an organization or factory supply chain from the purchase of raw materials to the stage of product design and development, storage and distribution, and finally, the delivery of the final product. The important features of sustainable supply chain management are the sustainability based on environment and social responsibility (Hassanpour and Pamucar, 2019). Therefore, by taking the sustainability of the supply chain and financial profitability into account, disadvantageous environmental effects and social effects can be decreased.

The most important aspects of sustainability are the economic dimension, which deals directly with cost and benefit parameters. In logistics networks, economic decision-making concerning costs leads to a profitable optimal design. Another important dimension of sustainability is the environmental dimension, which is generally focused on clean air and land, as well as the reduction of any pollution or encroachment on nature. The main difference between general logistics networks and sustainable logistics networks is the focus on the pollution caused by the transport fleet. Accordingly, in a sustainable logistics network, transmission routes and the location of logistics facilities in nature are designed with an environmental approach. Another dimension is the social factor which includes partner satisfaction, coordination, and collaboration leading to greater sustainability.

On the other hand, in today's business world, influenced by the globalization of markets, there is a basic need to understand customers' changes to maintain the sustainability of systems. As a result, companies are constantly looking for new strategies to improve their logistics performance and ensure their competitiveness in today's market (Allaoui, et al., 2020), especially in the distribution network of their goods, which represents a key component in all supply chains (Williamser et al., 2019). In this regard, logistics collaboration is deemed as one of the most effective mechanisms for companies that want to increase their logistic efficiency and achieve their goals of economic, environmental, and social sustainability (Vanovermeire, &

Sörensen, 2017; Jouida et al., 2014). Collaboration is critical to the success of sustainable logistics operations. Modern logistics systems are under increasing pressure to achieve environmental goals, reduce rush hours, and make parking spaces and vehicles accessible. For example, regulations on the timing, access, and size of cars, areas, timing, and size of vehicles restrict cargo delivery. Similarly, tax relief policies may encourage people to use vehicles consuming clean energy or apply methods of distributing energy-efficient goods. Under these circumstances, it seems that collaboration is a logical and performable strategy for many logistics systems to create sustainability and achieve operational performance as well as successfully achieve environmental goals (Soysal et al., 2018). Accordingly, the concepts of collaboration and sustainability are very important in supply chain and logistics networks.

Therefore, this study aims at designing a sustainable multilevel logistics model with a heterogeneous participation approach based on the uncertainty approach. In order words, in this study we use two objectives includes minimizing the supply chain costs and maximizing the productivity of the collaboration parameter affecting the sustainability indicators at different levels. In this study, coordinated sustainable logistics is taken into account in terms of economic factors (time and cost), social factors (general consumer satisfaction and 3PL system satisfaction), and environmental factors (co2, vehicle depreciation, and less damage to natural resources). Also, in this study, Collaboration is considered between members of the supply chain and between layers of the supply chain. The parameters of collaboration in this research include Communication, Bargaining Power, and Opportunism.

The research design consists of different sections including section 2, in which previous studies will be reviewed and the research gap will be illustrated. Then, in section 3, the research problem is stated. In section 4, the developed model will be reviewed and in the next section, i.e., section 5, the operation of the model will be examined and analyzed using a real example in Gamz software, and sensitivity analysis will be performed. Finally, in section 6, the research results will be discussed.

2. Literature Review

Liotta et al. (2014) developed a new solution method based on optimization and simulation for multilevel production and transportation problems with precise dynamic distribution schemes under the influence of demand uncertainty. The objective function of the optimization model, the costs of supply, production, transportation, and emission of CO_2 as well as collaboration in a multilevel network are all taken into account. In this research, the computational experiments are based on real samples. The results showed that the developed approach can be effectively used for CO_2 emission swap analysis, the effects of demand uncertainty, and Joint distribution strategies on the economic and environmental function of supply chains. Reverse logistics (RL) can be applied as a proper tool and technique to achieve loyalty and satisfaction of customer and also decrease operating costs with maximizing the used products recovery. Nowadays, industries face different problems that is as a barrier to suitable implementation of RL, including lack of financial constraints, capabilities, facilities, and market constraints.

Basiri et al. (2017) examined the subject of green channel coordination in a two-stage supply chain (SC). Demand for the products is a function of the retail price, the green quality of the products, and the efforts of the retailer. Both the retail price and the amount of effort for selling the green product are determined by the retailer, while the green quality of the product is a variable of the manufacturer. Three decision scenarios are modeled and compared: (1) a non-integrated scenario in which each member decides independently based on their benefits, (2) an integrated scenario in which there is one decision-maker in the system, and (3) a participatory scenario in which the goal is to increase the channel's overall profit provided that Pareto is improved for each member. Numerical studies showed that the proposed collaboration model can increase SC profit almost close to the integrated model; it also guarantees higher profits for both channel members than that of the non-integrated decision-making scenario. Vargas et al. (2020) proposed a Freight Share Laboratory Platform (FSLP) and introduced its embedded business model intending to facilitate and encourage horizontal collaboration in transportation logistics. The idea of FSLP is to create collaborative clusters of transport operators and related joint operational plans, through specialized decision support algorithms and multi-fleet optimization. In addition, a profit-sharing business model embedded in FSLP algorithms guarantees that participants, mainly logistics service providers and transport operators, can maintain their profit margins and fairly share the profits of the partnership. A case study focusing on a major UK transport operator is presented to evaluate key FSLP algorithms in a real-world context. The results show the potential for significant financial and environmental benefits to industry and society.

Aloui et al. (2019) proposed a joint decision-making method for planning of the sustainable supply chain. This structure improves the development of multilateral partnerships across a network in order to improve the sustainability of the offered products. The platform supports the new ICT system and creates an insightful platform for infrastructure. The proposed decision support system simultaneously offers collaboration and sustainability capabilities that are not available in many supply chain planning systems. Konstantakopoulos et al. (2021) describe a sustainable approach in which logistics companies collaborate in routing and scheduling operations by sharing fleets and resources. To estimate the improvement in the system, in terms of pollution and cost reduction, the state in which companies operate independently is compared to the state of partnership. The data used in their study are derived from the daily distribution cases encountered by third-party logistics companies in Greece. These are examined daily by a meta-heuristic algorithm, either separately to study how they work today, or jointly to determine common benefits.

Given that sustainability in different aspects has become increasingly important in today's supply chain, Emamian et al. (2021) presented an integrated model for production routing in the sustainable closed-loop supply chain. A three-objective mathematical model is also proposed for minimizing supply chain costs, maximizing social responsibility, and ultimately minimizing environmental emissions. The data of proposed method analyzed for different scales groups with considering the BCO technique. Also, the results of this mentioned method eventually compared with the experimental results of NSGA-II technique for different features for example quality, variability, and distance as well as execution time to solution. Mancini et al. (2021) investigated a centrally organized multi-period partnership automobile routing problem in which telecommunications companies could exchange customers who regularly need services. In addition, telecommunications companies may only be willing to cooperate if a minimum market share can be guaranteed. To consider all these issues, the matter of common automobile routing was proposed while considering the sustainability of time and service. An iterative local search algorithm was used to solve the developed model. They showed that both methods reach near-optimal solutions in very short computational times. Ding et al. (2018) develop a model for examining the opportunity to outsource a pollutant reduction service to overcome environmental constraints. The service supply chain consists of a coal-fired power plant (end user) and a pollution reduction service provider that the former outsources the services to the latter. They studied the profit improvement policy of this service supply chain according to which, profit allocation is made through outsourcing price negotiations between the two partners. The results showed that the price of outsourcing green services is related to the government's incentive policy that defines the shares of two partners. Finally, they hey examined the integration of complex factors affecting supply chain cooperation, such as green services, profit-sharing and etc.

The concept of emergency energy supply chain collaboration has become a business necessity with various energy trading organizations so that its problems could be solved in consensus. Jiang (2020), developed an intelligent model for emergency power supply chain cooperation, which bridges the gap between optimizing emergency supply chain collaboration with consensus decision-making and reinforcement learning. The simulation results show that the proposed model has a significantly less running time of 40%, reducing the minimum cost of energy recovery by 7% and CO2 emissions by an average of 10.8%. The two-tier supply chain model consists of two separate components with different purposes. Yaldim et al. (2022), provided a model of a two-tier supply chain consisting of a supplier, a retailer, and a product in a drug supply chain (P-SC). The main goal of their proposed model is to maximize the profit of whole of the supply chain.

Akbari-Kasgari et al. (2022) designed a new supply chain based on resilience and sustainable concepts in copper industry. Aloui et al. (2022) proposed the integrated planning problem to design two-echelon green logistics model based on collaborative and non-collaborative conditions. They assess the benefits of collaboration between different layers in integrated transportation optimization. Anes et al. (2022) developed a new model for evaluating risk value in logistics companies with considering collaborative networks. Proposed model increases the sustainability of collaborative model in the logistics network by reducing reputational risk. In another research, Mishra et al. (2022) investigated a new structure to environmental collaboration between logistic network layers to consider sustainability in production. The sale takes place in a drug retailer and the demand is random and the order periods are determined by the number of visits by the drug supplier. By considering these visits, the drug retailer follows a periodic review inventory model. For the retailer, the decision variable is the safety factor, which is determined by the level of the announced order. The problem stated in this paper was optimized with two different scenarios and two different models: the traditional SC model and the two-tier supply chain model. Table 1 presents the studies conducted by research indicators.

Table 1. Literature Review

	Author(s)	Year	Logi-stics	Mathematical model		Collabo-ration	sustainability		
				Single-purpose	Multi-purpose		environ-mental	eco-nomic	social
1	Lyut et al.	2014	✓	✓		✓			
2	Basiri et al.	2017	✓		✓	✓			
3	Vargas et al.	2020	✓	✓		✓	✓	✓	
4	Alvi et al.	2019	✓	✓		✓			✓
5	Constantako-poulos et al.	2021	✓	✓		✓	✓	✓	
6	Imams et al.	2021	✓		✓		✓	✓	✓
7	Mansini et al.	2021	✓	✓		✓			
8	Ding et al.	2018	✓		✓	✓	✓	✓	
9	Jiang et al.	2020	✓		✓	✓	✓	✓	
10	Yildet al.	2022	✓	✓		✓			
11	Akbari-Kasgari et al.	2022	✓		✓		✓	✓	✓
12	Aloui et al.	2022	✓		✓	✓	✓	✓	
13	Anes et al.	2022	✓	✓		✓		✓	
14	Mishra et al.	2022	✓	✓		✓	✓		
15	Present study		✓		✓	✓	✓	✓	✓

According to the studies given in Table (1), it is recognized that collaboration and sustainability in all dimensions have been less addressed simultaneously. Also, due to the importance of collaboration in logistics systems and its impact on sustainability in economic, social, and environmental dimensions, the previous research has not addressed the role of intra-layer and inter-layer collaboration at all levels. Also, the gap of studied research show that the collaboration parameter affecting the sustainability indicators are not considered at different levels of supply chain. Therefore, in the present study, it is dealt with designing a sustainable logistics network with a heterogeneous participation approach in which the issue of intra-layer and inter-layer collaboration at different levels of the supply chain and its impact on supply chain sustainability have been considered under conditions of uncertainty.

3. Statement of the Problem

Logistics is a planning orientation and framework that seeks to create a unique program for the production and flow of information through a business. Supply chain management is created after this framework and aims at achieving links and coordination between the processes of other organizations in this link line. Logistics processes directly or indirectly affect almost all areas of human activity. One of the important subjects of logistics processes is coordination within the overall structure of the supply chain. Coordination is the act of controlling the dependencies of an institution by working together to achieve mutually defined goals. Supply chain coordination can be supported through functions such as forecasting, production management, maintenance management, distribution, and transportation management, product design, and upstream and downstream interfaces. It may also be related to simple activities. Collaboration can be between members of the supply chain or between layers of the supply chain. Such collaboration occurs when several organizations and companies work together and engage in normal business relationships. It is the answer when organizations and companies alone cannot find solutions for common problems to achieve the expected performance indicators.

On the other hand, the concept of sustainability led to the formation of a new paradigm in the design of logistics networks. Clearly, there are sustainability dimensions that lead to the formation of differences compared to general logistics networks. The most important dimension of sustainability is the economic dimension, which deals directly with cost and benefit parameters. In logistics networks, economic decision-making concerning costs leads to a profitable optimal design. Another important dimension is the environmental one, which is generally focused on clean air and land and the reduction of any pollution or encroachment on nature. One of the differences between general logistics networks and sustainable logistics networks is the special focus on the pollution of the transport fleet. Additionally, the design of transport routes and location of logistics facilities in nature is created with an environmental approach in a sustainable logistics network. Another dimension is the sustainability of the social factor, including the satisfaction of partners, coordination, and collaboration that leads to greater sustainability. The proposed model in the present study deals with the design of a sustainable logistics network with a heterogeneous collaboration approach. In other words, due to the necessity to reduce environmental hazards such as greenhouse gas emissions, use of natural resources, energy consumption, costs such as transportation, and delay in operations, and also to increase access to facilities, the concept of designing a sustainable multilevel logistics network with a heterogeneous collaboration approach is investigated. Accordingly, the logistics system is designed based on sending raw materials to the factory and then sending different products to consumption centers. The main purpose of this study is to investigate the effect of the collaboration parameter on sustainability indicators for nodes within a layer and between different layers of the supply chain. The proposed model has two objectives, the first target function includes minimizing the supply chain costs and the second one is to maximize the productivity of the collaboration parameter affecting the sustainability indicators at different levels. In this study, coordinated sustainable logistics is taken into account in terms of economic factors (time and cost), social factors (general consumer satisfaction and 3PL system satisfaction), and environmental factors (co2, vehicle depreciation, and less damage to natural resources). Also, the parameters of collaboration in this research include Communication, Bargaining Power, and Opportunism.

Communication indicator ensures that tasks are augmented and transferred from one point to the other without delay. In addition, the Bargaining Power index refers to the pressure that suppliers can put on different firms by decreasing the availability of their products, increasing their prices, or lowering their quality. The Opportunism index also is defined as behavior that is self-interest seeking with guile. It is manifested in behaviors such as stealing, cheating, dishonesty, and withholding information. Essentially, these concepts lead institutions to cooperate (Doodi et al., 2016).

4. The Developed Mathematical Model

In this section, the developed model will be described.

4.1. Indices:

Index for nods	$i = 1, \ldots, I$ $j = 1, \ldots, J$, $i' = 1, \ldots, I'$
Index for layer	$k' = 1, \ldots, K'$, $k = 1, \ldots, K$
Index for collaboration parameter	$w = 1, \ldots, W$
Index for sustainability indices	$s = 1, \ldots, S$

4.2. Variables:

$X_{ikjk'}^{ws} : \begin{cases} 1 \\ 0 \end{cases}$	If collaboration parameter w is established about sustainability index s with node i in layer k and node j in layer k’
$Y_{ii'k}^{ws} : \begin{cases} 1 \\ 0 \end{cases}$	If node i with node i’ in layer k has a collaboration parameter w about sustainability index s

4.3. Parameters:

B^{ws}	Budget available to establish the collaboration parameter W affecting the sustainability index S
$p_{ii'k}^{ws}$	The efficiency of collaboration parameter w affecting the sustainability index s between nodes i and i’ in layer k
$p_{ikjk'}^{ws}$	The efficiency of collaboration parameter w affecting the sustainability index s from node i in layer k to node j in layer k’
A_{ik}^{ws}	The degree of collaboration w affecting the sustainability index s for node i in layer k
$CA_{ii'k}^{ws}$	Collaboration capacity of collaboration parameter w affecting the sustainability index s between nodes i and i’ in layer k
$CA_{ikjk'}^{ws}$	Collaboration capacity of collaboration parameter w affecting the sustainability index s from node i in layer k to node j in layer k’
$C_{ii'k}^{ws}$	Cost of creating the collaboration parameter w affecting the sustainability index s between nodes i and i’ in layer k
$C_{ikjk'}^{ws}$	Cost of creating the collaboration parameter w affecting the sustainability index s from node i in layer k to node j in layer k’

4.4. Mathematical Model:

$$\min z_1 = \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{k'=1}^{K'} C_{ikjk'}^{ws} \cdot X_{ikjk'}^{ws} + \sum_{i=1}^{I} \sum_{i'=1}^{I'} \sum_{k}^{K} C_{ii'k}^{ws} \cdot Y_{ii'k}^{ws} \quad (1)$$

$$\max z_2 = \sum_{i=1}^{I} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{k'=1}^{K'} P_{ikjk'}^{ws} \cdot X_{ikjk'}^{ws} + \sum_{i=1}^{I} \sum_{i'=1}^{I'} \sum_{k}^{K} P_{ii'k}^{ws} \cdot Y_{ii'k}^{ws} \quad (2)$$

S.t.

$$\sum_{i}\sum_{j\neq i}\sum_{s}\sum_{w} X_{ikjk'}^{ws} \geq 1 \qquad \forall k < K, k' = k+1 \tag{3}$$

$$\sum_{i}\sum_{i'\neq i}\sum_{s}\sum_{w} y_{ii'k}^{ws} \geq 1 \qquad \forall k \tag{4}$$

$$\sum_{i}\sum_{k<K}\sum_{j}\sum_{k'=k+1} C_{ikjk'}^{ws}.X_{ikjk'}^{ws} + \sum_{i}\sum_{i'\neq i}\sum_{k} C_{ii'k}^{ws}.Y_{ii'k}^{ws} \leq B^{ws} \qquad \forall w, s \tag{5}$$

$$\sum_{i}\sum_{k<K}\sum_{j}\sum_{k'=k+1} A_{ik}^{ws}.X_{ikjk'}^{ws} \leq \sum_{i}\sum_{k<K}\sum_{j}\sum_{k'=k+1} CA_{ikjk'}^{ws} \qquad \forall w, s \tag{6}$$

$$\sum_{i}\sum_{i'}\sum_{k} A_{ik}^{ws}.Y_{ii'k}^{ws} \leq \sum_{i}\sum_{i'}\sum_{k} CA_{ii'k}^{ws} \qquad \forall w, s \tag{7}$$

$$\sum_{k'=k+1}\sum_{j}\sum_{i'}\sum_{s} X_{ikjk'}^{ws}.Y_{ii'k}^{ws} = 1 \qquad \forall i, k < K, w \tag{8}$$

$$X_{ikjk'}^{ws} = 0 \qquad \forall k > 1, s, w, i, j, k' = k \tag{9}$$

$$X_{ikjk'}^{ws}, Y_{ii'k}^{ws} \in \{0,1\} \tag{10}$$

4.5. Model Description:

This research consists of a two-objective mathematical model. The first target function represents the minimization of the total costs created by the collaboration parameter effective on the sustainability index between and within the different mentioned layers. The second target function represents the maximization of productivity resulting from the collaboration parameter affecting the sustainability index. Equation (3) shows that between each of the two different layers and according to the collaboration and sustainability, at least one connection between different nodes of the mentioned layers should be selected. Equation (4) shows that between two nodes in a particular layer, at least one connection between different nodes should be selected concerning collaboration and sustainability. Equation (5) is the total costs incurred by the collaboration parameter affecting the sustainability index from one node to another in each layer with the costs incurred by the collaboration parameter affecting the sustainability index between different layers that should be less than the total budget available for establishing a collaboration parameter. Equations (6) and (7) indicate that the amount of collaboration between and within different layers should not exceed the collaboration capacity of the collaboration parameter. Equation (8) shows that for each layer and its corresponding node, there is exactly one collaboration parameter for each sustainability index. Equation (9) ensures that communication between the two layers is done sequentially. Equation (10) shows the type of decision variables.

5. Solution methodology

In this paper, a bi-objective sustainable logistic model presented based on a heterogonous collaboration approach. The first objective function represents the minimization of the total costs created by the collaboration parameter effective on the sustainability index between and within the different layers. The second objective function represents the maximization of productivity resulting from the collaboration parameter affecting the sustainability index. To reformulating bi-objective mathematical model to a single one, we used epsilon-constraint method. Finally, the developed model of the present study was encoded using GAMZ 24.1.2 software and the program was written by a computer with 2.3 GHz processor specifications, core i7 with 4GB RAM memory.

6. Numerical Study

In this section we present a numerical example to illustrate and analyze the performance of proposed bi-objective model based on problem goals. As mentioned, the proposed model was solved by GAMZ 24.1.2 software. After solving the proposed model, with regarding to 3237 repetitions, the model reached its optimal value and the time to achieve the optimal answer took 3.00 seconds. Some of the used data and parameters are applied in the model using real data that are shown in Table (2). Other data are generated to handle the optimization model. Also, the validity of the model was performed by analyzing the sensitivity of some effective parameters in the model and the efficiency of the model was evaluated. In the developed model, sustainability with index s = 1,2,3 includes three economic, social, and environmental indices. Also, the parameter of collaboration with index w = 1,2,3 includes Communication, Bargaining Power, and Opportunism. Table (2) shows the available budget for establishing the collaboration parameter W affecting the sustainability index S (B^{ws}).

Table 2. Budget available for the establishment of collaboration (B^{ws})

B^{ws}		s: 1	2	3
w	1	787	579	647
	2	523	577	574
	3	663	566	753

After solving the developed model using the values defined for the problem parameters, the model achieves the optimal answer and the values of the variables $X_{ikjk'}^{ws}$ (if the collaboration parameter w is established in relation to the sustainability index S with node i in layer k with node j in layer k') and $Y_{ii'k}^{ws}$ (if node i with node i' in layer k has parameter collaboration w in relation to the sustainability index S) which are equal to 1 and shown in Tables (3) and (4).

Table 3. Operation of the developed model and the optimal value of the objective function

Total solver iterations	Extended solver steps	Gams	
		Obj	Time
3237	268	291.000	3.00

The results of Table (3) show that the optimal value of the weighted integrated objective function of the developed model after running in GAMS software with 1265 repetitions, the value of 269,000 has been obtained. The results also show that the running time of the model to achieve the optimal answer was 3 seconds. The results related to the optimal values of the developed model variables including $Y^{ws}_{ii'k}$ and $X^{ws}_{ikjk'}$ are shown in Table (4). This table shows the establishment of collaboration parameters with respect to sustainability indices in the interlayer mode and between different layers. For example, the value obtained Y^{13}_{211} shows that between nodes 2 and 1 in the first layer, the collaboration parameter 1 (Communication parameter) affects the sustainability index 3 (environmental index) that reduces system costs and increases the efficiency resulted from the collaboration parameter affecting the sustainability index. Also, the value obtained X^{21}_{3223} shows that between node 3 from the second layer and node 2 from the third layer, the collaboration parameter 2 (Bargaining Power parameter) affects the sustainability index 1 (economic index) that reduces the cost of the entire system and increases the efficiency of the cooperation.

Table 4. Optimal values of the variables in the developed model

	VARIABLE
1	Y(1,1,3,1,1)
2	Y(1,2,1,3,3)
3	Y(1,2,2,3,2)
4	Y(1,2,3,1,2)
5	Y(1,3,1,2,1)
6	Y(1,3,1,3,2)
7	Y(1,3,2,1,1)
8	Y(2,1,3,2,1)
9	Y(2,2,1,3,1)
10	Y(2,2,2,1,2)
11	Y(2,2,3,1,2)
12	Y(2,3,1,3,2)
13	Y(2,3,2,3,1)
14	Y(3,3,1,2,1)
15	Y(3,3,1,2,2)
16	Y(3,3,2,1,1)
17	Y(3,3,2,1,2)
18	Y(3,3,3,1,2)
19	Y(3,3,3,2,1)
20	X(1,1,3,1,1,2)
21	X(1,2,2,2,2,3)

22	X(1,2,3,2,1,3)
23	X(1,3,1,1,1,2)
24	X(1,3,1,2,2,3)
25	X(1,3,2,1,3,2)
26	X(2,1,3,1,3,2)
27	X(2,2,1,1,1,2)
28	X(2,2,2,2,2,3)
29	X(2,2,3,2,1,3)
30	X(2,3,1,2,3,3)
31	X(2,3,2,1,2,2)
32	X(3,3,1,1,3,2)
33	X(3,3,1,2,1,3)
34	X(3,3,2,1,1,2)
35	X(3,3,2,2,1,3)
36	X(3,3,3,1,3,2)
37	X(3,3,3,2,3,3)

Also, the results of the proposed model based on the optimal values of the variables $Y_{ii'k}^{ws}$ and $X_{ik\,jk'}^{ws}$ are shown in Fig. 2 and 3. In these figures, collaboration parameters and sustainability indicators are shown with symbols w and s, respectively. Also, layers 1 to 3 including nodes within layers 1 to 3 are considered for each layer. With respect to the Fig. 2 and 3, the relations of collaboration parameters and sustainability indices in different layers and nodes are shown with arrows and they are assigned to each other based on the optimal values obtained for the mentioned variables.

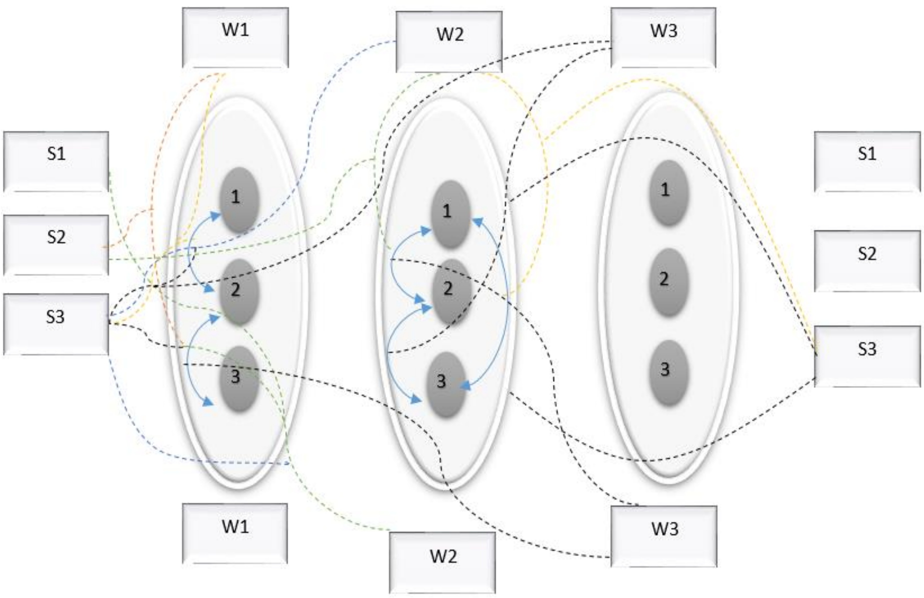

Figure 2. Optimal values of the variable $Y_{ii'k}^{ws}$ in the developed model

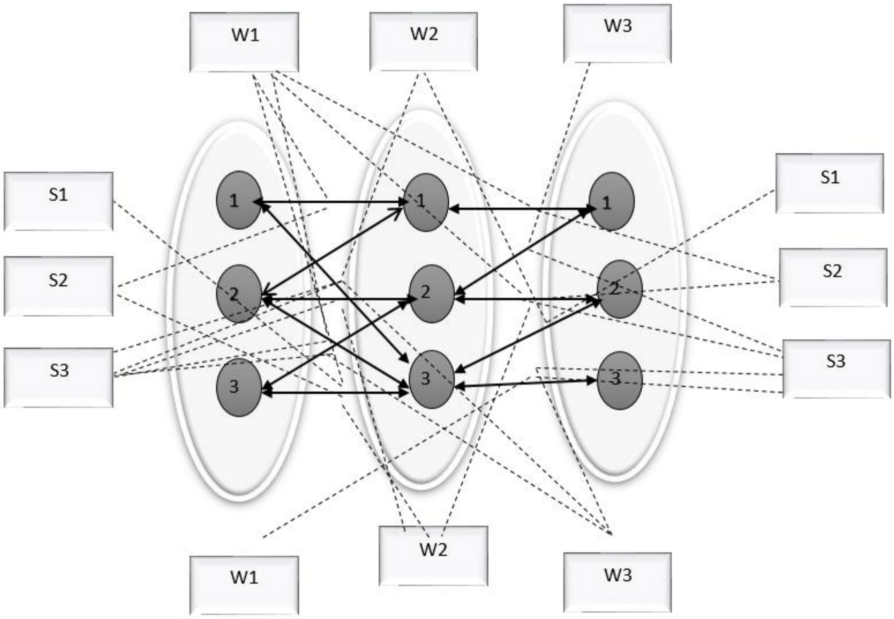

Figure 3. Optimal values of the variable $X^{ws}_{ik\,jk'}$ in the developed model

7. Conclusion

In this paper, a model is developed to evaluate the sustainability interaction with inter-layer and intra-layer collaboration of a two-tier logistics network. First, indices of economic, social, and environmental sustainability along with the parameters of collaboration, Communication, Bargaining Power, and Opportunism on different layers of logistics were examined. According to the capacity of collaboration and the cost required to establish collaboration, the problem was modeled and solved with the objectives of minimizing costs and maximizing productivity resulting from collaboration and improving sustainability indices. One of the advantages of this sustainable logistics model with a heterogeneous collaboration approach is that the decision maker or policy maker with the capabilities of this model can identify the effective parameters of collaboration on sustainability in each layer of the logistics network and also can improve the efficiency of collaboration in the logistics system by focusing on the parameters with the greatest impact on the degree of sustainability. Evaluation of the proposed method based on fuzzy robust uncertainty can be considered as a future research suggestion. Also using multi-product and multi time with a tri-level programming structure can be considered as another area of future study.

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