Innovation in Reverse Supply Chain Model through Industry 4.0 Revolutions

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Abstract. One of the most important recent topics that has been considered by researchers, is the fate of industrial products and goods with the end customer which has led to the creation of the concept of reverse supply chain. Reverse supply chain management includes all the processes of collecting products used by the customer, recycling, reproducing (repairing) and disposing of some unusable parts. Considering the importance of using reverse logistics in waste collection and also the importance of the fourth industrial revolution, the present study has been formed with the aim of Innovation in reverse supply chain model through industry 4.0 revolutions. In this research, a mathematical model for the reverse supply chain of municipal waste in conditions of uncertainty based on the pattern of the Industrial Revolution 4 is presented. This supply chain is the levels of distribution centers, customers, collection centers, recycling centers and destruction centers. Innovations of this research present and solve the mathematical model of the reverse supply chain of municipal waste recycling with the approach of Industrial Revolution Four, considering the dimensions of sustainability in the reverse supply chain of municipal waste recycling with the approach of Industry 4 Revolution, considering the location-routing phase in The reverse supply chain for municipal waste recycling is four with the Industrial Revolution approach. The understudy model is multi-objective and its objectives include minimizing transportation costs and environmental impacts and maximizing the amount of demand responded to the customer. Determining and identifying the dimensions of the Industrial Revolution Model 4, weighting the dimensions of the Industrial Revolution Model 4 in the sustainable reverse supply chain of municipal waste recycling, designing an integrated model of the sustainable reverse supply chain of municipal waste recycling based on the weight dimensions of the Industrial Revolution Model 4 and designing Implementation of meta-heuristic algorithms to solve the model

Keywords: Innovation, Industry 4.0 revolution, Reverse supply chain, Technological factors , Environmental factors

1. Introduction

As was mentioned, the concept of reverse logistics has emerged over the past decades due to environmental pollution and the increasing waste of resources and greenhouse gas emissions. Reverse logistics is defined as all logistics activities for products that have reached the end of their life or require a series of processes to further improve. Other definitions of reverse logistics include all supply chain activities that occur in reverse. The most important principle in reverse logistics is that many unusable or unused materials of customers are valuable and can be re-introduced into the supply chain with a little modification. According to the above-mentioned definition, one of the applications of reverse logistics and one of the most essential logistics activities in the present era is the process of collecting municipal waste, which starts with garbage collection and ends with the waste recycling process [1]. Today, an important concept in the environment is urban recycling management. Recycling is to utilize used goods to recycle them into the same good or other usable goods. For example, used paper becomes newspaper and egg combs after recycling. The first point is that resources are limited and non-renewable, and eventually will run out. Recycling makes it less likely to use these raw materials. Its second advantage is saving energy and consuming less energy to make a product. The third advantage is that it allows less waste to enter the environment, which has irreparable consequences in addition to creating an ugly view in the environment.

On the other hand, the Industry 4.0 Revolution can be defined by a range of new technologies. This revolution has brought together the physical, digital, and biological worlds and affected all of the fields. Hence, the categories of the 4th industrial revolution will not only reflect on the future industries and technologies, but will also have a positive effect on the nature of the individual, economy, and the business world [2].

Presented a multi-objective model for designing a multi-level, multi-product, and multi-period closed-loop logistics network in a fuzzy environment. The objectives of the problem included profit and maximization of service levels through minimizing transport time and maximize quality. The model had four levels in the forward direction including suppliers, factories, distribution centers, and customers, and two levels in the backward direction, including collection and landfill centers [3] investigated innovative digital strategies and developed a managerial framework for improving digital products as well as service innovation. In the study, factors such as user experience and knowledge, skills, evaluation, and scanning have been utilized to develop this framework and it has been shown that implementation of this framework in companies accelerates the increase of competitive advantages and improves products and services. In [4] developed a robust closed-loop environmental supply chain network that included manufacturing centers, customer centers, collection centers, and landfill centers. They proposed a mixed multi-objective integer nonlinear planning model that considered two contradictory objectives

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simultaneously. The first objective was to minimize economic costs and the second was to minimize the effect of the supply chain on the environment. They solved the model using LP metric method. Finally, they demonstrated the efficiency of the model by providing a sample problem. In [5] investigated the internet of Things as a stimulator (reinforcing) of the reverse supply chain. In the study, a real-time data measurement model with IoT capability has been designed to sense and record real-time logistics data. Real-time information-based dynamic optimization has been also recommended to optimize logistics model configuration and decrease costs, energy consumption, and distribution distance as well as decrease environmental pollution [6]reverse logistics in-vehicle reproduction, packaging, and transportation and reverse material flow management. The purpose of their case study was to a framework for reverse material flow management n the automotive industry with an emphasis on reproducing activities. Various methods and techniques were used to obtain and confirm the necessary information of above problems: 1) related literature on this topic was investigated; 2) data and documents were requested directly from relevant market experts, 3) cluster data were analyzed and samples were highlighted, and 4) the data were evaluated and suggested practical courses were recommended. The share of wastes' GWP in different locations and different technologies varies among waste producers. For this reason, the problem of network flow was proposed to accurately identify the wastes [7]

2. Methodology

The understudy model is multi-objective and its objectives include minimizing transportation costs and environmental impacts and maximizing the amount of demand responded to the customer. Determining and identifying the dimensions of the Industrial Revolution Model 4, weighting the dimensions of the Industrial Revolution Model 4 in the sustainable reverse supply chain of municipal waste recycling, designing an integrated model of the sustainable reverse supply chain of municipal waste recycling based on the weight dimensions of the Industrial Revolution Model 4 and designing Implementation of meta-heuristic algorithms to solve the model. The gray relational analysis method with the fuzzy number and fuzzy VIKOR method was used to weigh the effective criteria of technology (main dimensions and sub-components) and technologies, respectively. Also, the archive-based multi-objective whale optimization algorithm was used to solve the mathematical model and its results were comprised of the results of the NSGA-II algorithm.

2-1.The theory of gray relations with distance fuzzy

Assume that a multi-criteria decision problem has M non-profit options including A1, A2, …, Am and n criteria including C1, C2,. . . , Cn. Each option is measured by n criteria. All evaluation/ranking values are related to the options by considering the decision matrix shown by X $X\left(=(x_{ij})_{m\times n}\right)$. The technique of gray relational analysis includes the following steps:

Step 1: normalized decision matrix is calculated; Step 2: determine R_0the series; Step 3: forming a distance table; Step 4: calculation of gray relational coefficient; Step 5: estimate the degree of gray relation γ_i; Step 6: ranking the options based on their gray relational value so that whateverγ_i is greater A_i is a better option.

2-2. VIKOR method algorithm

Step 1: Forming the decision matrix; Step 2: Data normalizing; Step 3: Determine the ideal positive and negative point; Step 4: Determining utility (S) and regret (R) ; Step 5: Calculation of VIKOR Index

2-3 .The Proposed Algorithms Structure

2-3-1.Whale Optimization Algorithm (WOA)

This algorithm starts with a set of random solutions. For any iteration, search agents update their position according to other agents randomly or with the best solution. The parameter (a) has been decreased from two to zero to provide exploration and exploitation, respectively. Two modes are considered to update the position of search agents. If the variable is | A |> 1, then the random search agent is selected, and if it is | A | <1, then the best solution is selected. Depending on the value of p, the whale can change the position between two movements of spiral and rotational. Finally, WOA ends with reaching the specified satisfaction criterion the quasi-code of this algorithm has been presented to continue.

In all meta-heuristic algorithms, it is necessary to store the solution according to a specific structure due to the need for a solution at the beginning of the operation, in which the structure is called the solution display method. In the present study, a matrix has been used to display each solution. Each solution consists of several matrices, which have been designed according to the outputs of the model. As an example, a line matrix (one-dimensional) has been defined for variable (a_j), which the number of its arrays equals to J. The following matrix shows an example of this part of the solution (assume that the number of potential locations of dismantling plant is 6 and the maximum allowable value of this plant is 4). In Figure 1, dismantling plants have been established in locations 1, 3, 4, and 6. A line matrix has been also used to display Variable (b_k), which the number of its arrays equals to K. The following matrix shows an example of this part of the solution (assume that the number of potential locations of the processing plant is 5).

1	0	1	0	0	1

Variable aj representation

As shown, processing plants have been established in locations 1, 2, and 5. A one-dimensional matrix has been also used to display Variable (α_ij), which the number of its arrays equals the number of collection centers and the values of its cells indicate the number of dismantling plants that the collection center can send the product to it. Assume that the number of potential locations for the establishment of dismantling plant is 6 and the number of collection centers is 8, then the following matrix is a way of displaying the solution to this variable, which has been given according to the example of variable (a_j).

0	1	0	0	1

Variable b_k representation

As shown above, the collection centers No. 1 has been allocated to dismantling plant No. 1, the collection centers No. 3 and 7 to dismantling plant No. 2 and 3, the collection centers No. 4 and 6 to dismantling plant No. 6 and the collection centers No. 5 and 8 to dismantling plant No. 4. Also,

1	3	6	4	6	3	6	1

Variable α_ij representation

The characteristics and capabilities of this model in the supply chain have been used to design a mathematical model based on industry 4.0 Revolution. . Effective factors of selecting technology in waste management of municipal wastes are Technological, Economic, social and environmental issues.

Table 1. The decision matrix

Main / Sub	Technological	Economic	Social	Environmental
Intelligent & connected devices	[(3.5,1.5); 5; (6.5,7.5)]	[(0,1.5); 3(4.5,6.5)]	[(1,0.5); 1; (2.5,3.5)]	[(1,5,2.5); 3(4.5,5.5)]
new data acquisition and communication technologies	[(1,0.5); 1; (2.5,4.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(0,1.5); 3(4.5,5.5)]	[(0,0.5); 1; (2.5,3.5)]
Resilient infrastructure	[(2.5,3.5); 5; (6.5,7.5)]	[(2.5,3.5); 5; (6.5,6.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]
Technology standards	[(0,1.5); 3(4.5,5.5)]	[(0,1.5); 3(4.5,5.5)]	[(0,1.5); 3(4.5,5.5)]	[(0,1.5); 3(4.5,5.5)]
Investment costs for technology development and localization	[(0,0.5); 1; (2.5,3.5)]	[(0,1.5); 3(4.5,5.5)]	[(0,0.5); 1; (2.5,3.5)]	[(0,1.5); 3(4.5,5.5)]
The effectiveness of selection process in the commercial term	[(0,1.5); 3(4.5,5.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(0,1.5); 3(4.5,5.5)]	[(2.5,3.5); 5; (6.5,7.5)]
The cost of technology transfer	[(0,0.5); 1; (2.5,3.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(0,1.5); 3(4.5,5.5)]	[(2.5,6.5); 5; (6.5,7.5)]
Citizen participation	[(2.5,3.5); 5; (6.5,7.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]
Green behavior	[(2.5,3.5); 5; (6.5,7.5)]	[(0,0.5); 1; (2.5,3.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]
Intelligently collaboration between stakeholders	[(2.5,3.5); 5; (6.5,7.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(0.5,3.5); 5; (6.5,7.5)]
Green collection, disposal and recycling	[(2.5,3.5); 5; (6.5,7.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(2.5,3.5); 5; (6.5,7.5)]
The issues related to energy and contamination emissions	[(2.5,3.5); 5; (6.5,7.5)]	[(5.5,7.5); 9; (9.5,10)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]
Dangerous effects of the end of technology	[(2.5,3.5); 5; (6.5,7.5)]	[(2.5,3.5); 5; (6.5,7.5)]	[(4.5,5.5); 7(8,9.5)]	[(2.5,3.5); 5; (6.5,7.5)]

The proposed model is including minimizing transportation costs and environmental effects and maximizing customer response demand. Also, some parameters of the model such as customer demand have been considered uncertain and fuzzy.

4-1.The proposed mathematical model

$$
\begin{aligned}
\text{Min z1} = & \sum_{m=1}^{M} \tilde{f}_m z_m + \sum_{p=1}^{P} \tilde{f}_p z_p + \sum_{n=1}^{N} \tilde{f}_n z_n + \sum_{k=1}^{K} \sum_{g=1}^{G} (1 \\
& - w_g)[\sum_{s=1}^{S} \sum_{t=1}^{T} [\sum_{l} (w_s C_k c_l^{sg} L_l \, x_{lk}^{tsg} + c_0 \times L_l (\widetilde{\rho_0} \\
& + \tilde{\alpha} x_{lk}^{tsg}) y_{lk}^{tg}) \\
& + \sum_{l1=1}^{L} \sum_{l2=1, l2 \neq l1}^{L} (w_s C_k c_{l1l2}^{sg} L_{l1l2} x w_{l1l2k}^{tsg} + c_0 \times L_{l1l2} (\widetilde{\rho_0} \\
& + \tilde{\alpha} x w_{l1l2k}^{tsg}) y_{l1l2k}^{tg}) + \\
& + \sum_{m=1}^{M} [\sum_{i=1}^{I} (w_s C_k c_{mi}^{sg} L_{mi} x_{mik}^{tsg} + c_0 \times L_{mi} (\widetilde{\rho_0} \\
& + \tilde{\alpha} x_{mik}^{tsg}) y_{mik}^{tg}) + \sum_{n=1}^{N} (w_s C_k c_{mn}^{sg} L_{mn} x_{mnk}^{tsg} + c_0 \times L_{mn} (\widetilde{\rho_0} \\
& + \tilde{\alpha} x_{mnk}^{tsg}) y_{mnk}^{tg}) \\
& + \sum_{p=1}^{P} (w_s C_k c_{mp}^{sg} L_{mp} x_{mpk}^{tsg} \\
& + c_0 \times L_{mp} (\widetilde{\rho_0} + \tilde{\alpha} x_{mpk}^{tsg}) y_{mpk}^{tg})]]] \\
& + \sum_{t \in T} \sum_{s=1}^{S} \sum_{g=1}^{G} (1 - w_g) [\sum_{k=1}^{K} [\sum_{m=1}^{M} cost_{sg} x_{mk}^{tsg} \\
& + \sum_{p=1}^{P} (costp_{sg} x_{mpk}^{tsg} - value_{sg} x_{mpk}^{tsg}) \\
& + \sum_{n=1}^{N} costn_{sg} x_{mnk}^{tsg}]]
\end{aligned}
$$

4-2.Model defuzzification

It observed from the model that the capacity and cost parameters of facility construction have been considered as fuzzy numbers. The fuzzy number ranking method of [5] was used for the defuzzification of the model. Several methods have been proposed to solve fuzzy mathematical planning problems. In the present study, the ranking method provided by Jimenez was used. Jimenez proposed a method of ranking fuzzy numbers based on comparing their expected interval. The Triangular fuzzy number can be written as following from (Figure 4) if :

$$
\mu A(x) = \begin{bmatrix} f_A(x) = \dfrac{X - L}{M - L} & L \leq X \leq M \\ 1 & X = M \\ g_A(x) = \dfrac{X - L}{M - U} & M \leq X \leq U \end{bmatrix}
$$

3. Computational results

3-1.Weighting of Criteria

In this section, a questionnaire in the form of a table was provided to 10 statistical sample individuals, the data were gathered and their mean was calculated. Then, the calculated mean values were converted into integer numbers in the ranges of 1 to 7. Then, the integer numbers were converted into distant fuzzy numbers and finally, the data analysis method was performed step-by-step. After converting data into distant fuzzy numbers, the decision matrix was obtained as Table 2.

After the formation of the decision matrix, the normalized decision matrix R˜ was calculated. In the third step, the distance between reference values and each of the comparative values was calculated, in which the results have been shown in Table 2 and Table 3.

Table 2. The δij value

Sub / main	Information	Technological	Economic	Social	Environmental	Legal
Intelligent & connected devices	0.652	0.801	0.799	0.683	0.498	0.920
new data acquisition and communication	0.689	0.598	0.576	0.571	0.570	0.594
Resilient infrastructure	0.591	0.624	0.556	0.538	0.541	0.546
Technology standards	0.518	0.558	0.539	0.585	0.542	0.541
Investment costs for technology developmen	0.613	0.600	0.508	0.563	0.601	0.535
The effectiveness of selection process in the commercial term	0.678	0.506	0.597	0.602	0.564	0.574
The cost of technology transfer	0.579	0.546	0.668	0.896	0.610	0.830

Citizen participation	0.624	0.628	0.623	0.526	0.606	0.560
Green behavior	0.587	0.519	0.553	0.506	0.600	0.538
Intelligently collaboration between stakeholders	0.853	0.613	0.552	0.605	0.548	0.544
Green collection, disposal and recycling	0.586	0.920	0.625	0.648	0.528	0.535
The issues related to energy and contamination emissions	0.644	0.498	0.492	0.622	0.567	0.526
Dangerous effects of the end of technology life	0.544	0.585	0.571	0.602	0.604	0.527

Table 3. The δij((2)) value

Sub / main	Information	Technological	Economic	Social	Environmental	Legal
Intelligent & connected devices	0.589	0.501	0.525	0.521	0.558	0.529
new data acquisition and communication technologies	0.658	0.538	0.538	0.533	0.539	0.553
Resilient infrastructure	0.702	0.575	0.525	0.516	0.519	0.516
Technology standards	0.452	0.527	0.511	0.544	0.511	0.506
Investment costs for technology development	0.600	0.567	0.850	0.524	0.569	0.508
The effectiveness of selection process in the commercial term	0.460	0.586	0.555	0.569	0.525	0.537
The cost of technology transfer	0.548	0.514	0.528	0.512	0.568	0.520
Citizen participation	0.640	0.586	0.579	0.501	0.565	0.629
Green behavior	0.752	0.491	0.531	0.488	0.557	0.507
Intelligently collaboration between stakeholders	0.542	0.573	0.517	0.557	0.523	0.616
Green collection, disposal and recycling	0.549	0.503	0.866	0.899	0.501	0.811
The issues related to energy and contamination emissions	0.603	0.476	0.868	0.977	0.732	0.496
Dangerous effects of the end of technology life	0.719	0.743	0.739	0.590	0.689	0.760

In this step, the maximum values of $\delta_{\max}^{(1)}$and $\delta_{\max}^{(2)}$ as well as the minimum values of $\delta_{\min}^{(1)}$and $\delta_{\min}^{(2)}$) were also calculated. In the fourth step, the values of gray rational coefficients of $\xi_{ij}^{(1)}$ and $\xi_{ij}^{(2)}$were calculated, in which the results have been shown in in Table 4 and Table 5.

Table 4. The $\xi_{ij}^{(1)}$value

Sub / main	Information	Technological	Economic	Socia l	Environmental	Legal
Intelligent & connected devices	0.989	0.998	0.988	0.992	0.9789	0.988
new data acquisition and communication technologies	0.973	0.980	0.978	0.988	0.979	0.990
Resilient infrastructure	0.974	0.969	0.988	0.988	0.987	0.949
Technology standards	0.993	0.983	0.988	0.976	0.986	0.992
Investment costs for technology development and localization	0.969	0.972	0.996	0.981	0.972	0.989
The effectiveness of selection process in the commercial term	0.994	0.996	0.973	0.971	0.981	0.978
The cost of technology	0.977	0.986	0.983	0.989	0.969	0.983
Citizen participation	0.966	0.965	0.966	0.991	0.970	0.982
Green behavior	0.975	0.993	0.984	0.996	0.972	0.988
Intelligently collaboration between stakeholders	0.979	0.969	0.984	0.971	0.985	0.986
Green collection, disposal and recycling	0.975	0.989	0.966	0.960	0.991	0.989
The issues related to energy and contamination emissions	0.961	0.998	1	0.966	0.980	0.991
Dangerous effects of the end of technology life	0.986	0.976	0.979	0.971	0.971	0.991

Table 5: The $\xi_{ij}^{(2)}$value

Sub / main	Information	Technological	Economic	Social	Environmental	Legal
Intelligent & connected devices	0.984	0.991	0.984	0.985	0.975	0.983
new data acquisition and communication technologies	0.974	0.981	0.980	0.982	0.980	0.976
Resilient infrastructure	0.977	0.970	0.984	0.987	0.986	0.986
Technology standards	0.992	0.983	0.988	0.979	0.988	0.989
Investment costs for technology development	0.971	0.973	0.995	0.984	0.972	0.989
The effectiveness of selection process in the commercial term	0.993	0.994	0.976	0.972	0.984	0.981
The cost of technology transfer	0.978	0.987	0.983	0.988	0.972	0.985
Citizen participation	0.978	0.995	0.969	0.991	0.973	0.983
Green behavior	0.976	0.994	0.982	0.994	0.975	0.989
Intelligently collaboration between stakeholders	0.979	0.998	0.986	0.975	0.985	0.987
Green collection, disposal and recycling	0.989	0.989	0.967	0.964	0.991	0.988
The issues related to energy and contamination	0.999	0.998	0999	0.969	0.982	0.9920
Dangerous effects of the end of technology life	0.986	0.979	0.980	0.974	0.975	0.991

In the next step, the degree of gray relations should be estimated using the weight of evaluation criteria have been shown in Table 6. After determining the weight of sub-criteria, the degree of estimated gray relations, and the final weight of the main factors were determined as shown in Table 7.

Table 6. The weight of criteria

Sub-criteria	Weight
Intelligent & connected devices	0.0487
new data acquisition and communication technologies	0.0485
Resilient infrastructure	0.0488
Technology standards	0.0492
Investment costs for technology development	0.0485
The effectiveness of selection process	0.0488
The cost of technology transfer	0.0485
Citizen participation	0.0472
Green behavior	0.0491
Intelligently collaboration between stakeholders	0.0483
Green collection, disposal and recycling	0.0484
The issues related to energy and emission	0.0489
Dangerous effects of the end of technology life	0.0491

Table 7. The Major weight of criteria

Main factor	Weight	Rank
Technological	0.0832	3
Economic	0.0833	2
Social	0.0833	2
Environmental	0.0831	4

5-2.Weighing of waste collection technologies

The purpose of this section was to prioritize existing options through the fuzzy VIKOR method as a multi-criteria group decision-making technique in fuzzy space. Decision-makers evaluated the options for waste collection technologies relative to the effective factors of technology selection. For this purpose, the expression variables of Table 8 were used.

Table 8. Linguistic variable for alternatives evaluation

Linguistic term	Fuzzy number
Very poor (VP)	(0, 0.0.2, 0.4)
Poor (P)	(0 ,0.2 0.4)
Medium poor (MP)	(0.2و 0.4و 0.5)
Fairly good (FG)	(0.4, 0.5 0.6)
Medium good (MG)	(0.5 0.6 0.8)
Good (G)	(0.6 0.8 1)
Very good (VG)	(0.8, 1, 1)

Table 9. Positive and negative criteria

Main factor	Positive	Negative
Technological	X	
Economic	X	
Social	X	
Environmental	X	

The criteria have positive and negative aspects. For example, the legal dimension has a negative aspect i.e. lower legal restriction is better. In contrast, higher positive information is better. After determining the positive and negative criteria, the normalized cumulative fuzzy decision matrix was formed. After calculating the normal fuzzy decision matrix, the size of the utility measure ($\tilde{S}$_i) and regret measure ($\tilde{R}$i) of ith option was calculated, which the results have been presented in Table 11 and Table 12.

Table 10. The Si and $\tilde{R}$i value

Option	$\tilde{S}_i$	$\tilde{R}_i$
IoT-based technologies	(3,01,3.96,4.99)	(0.39,0.57,0.68)
Mobile-based technologies	(2.72,3.95,4.99)	(0.32,0.49,0.65)
GIS-based technologies	(0.52,0.48,0.82)	(0.41,0.58,0.72)
Web-GIS-based technologies	(0.29,0.52,0.75)	(0.33,0.48,0.72)

Table 11. Parameters value

Factor	Value
S^-	(3,01,3.96,4.99)
S^*	(2.72,3.95,4.99)
R^-	(0.52,0.48,0.82)
R^*	(0.29,0.52,0.75)

Table 12. The Q i values

Option	$\tilde{Q}_i$
IoT-based technologies	(0.811,0.979,1)
Mobile-based technologies	(0,0.198,0.189)
GIS-based technologies	(0.299,0.348,0.464)
Web-GIS-based technologies	(0.85,1,1)

Table 13. Alternative priority

Option	$\tilde{Q}_i$	Rank
IoT-based technologies	0.943	3
Mobile-based technologies	0.1301	1
GIS-based technologies	0.3803	2
Web-GIS-based technologies	0.97	4

5-3.Algorithm parameters tuning

Taguchi experimental design and analysis in the MINITAB software were used to adjust some of the parameters of the two proposed algorithms. To adjust the parameters of the whale algorithm, the values of each of these parameters have been investigated at three levels shown in Table 14. Moreover, to adjust the parameters of the genetic algorithm, the values of the two parameters of mutation rate and intersection rate at 3 levels and the population size at three levels have been investigated, in which the levels have been shown in Table 15.

Table 14. Whale algorithm parameters

No. of Neighborhood	Population size	No. of iteration
5	150	150
10	300	300
15	500	500

Table 15. NSGAII algorithm parameters

Population size	Crossover rate	Mutation rate	iteration
150	0.75	0.006	150
300	0.85	0.009	300
500	0.95	0.01	500

5-4 Solving results

In this section, the designed experimental problems have been solved using whale algorithms and a genetic algorithm and their results have been analyzed.

Table 16. Solution results of sample problems

	Prob.	WOA(whales optimization algorithm)					NSGA-II				
		Quality	Spacing	Diversity	cpu time	Pareto	Quality	Spacing	Diversity	ime	Pareto
Small	1	86.55	1	1320,1	0.049	75	13.45	0.82	789	0.042	45
	2	80.03	1.2	1043.1	0.067	92	19.97	0.73	734.2	0.035	43
	3	82.14	0,99	1340.6	0.055	39	17.86	0.76	551.4	0.039	84
	4	90.43	0.78	1449	0.083	91	9.57	0.90	604.3	0.047	58

Medium	1	98	1.08	3004. 6	0.11	41	1	0.70	1658	0.088	23
	2	78.2	0.97	4721	0.14	69	23.4	0.45	1947.5	0.086	22
	3	87	0.96	5326.9	0.18	77	13.4	0.52	2181.8	0.094	58
	4	78,3	0.93	5401	0.27	73	24.3	0.79	2266.6	0.101	38
	5	92,15	1.21	5999	0.25	77	8.7	0.68	2496.8	0.16	33
	6	96.8	0,99	5846	0.37	40	3.2	0.74	2686.7	0.19	30
	7	92.01	1.09	6217.7	0. 38	46	7.99	0.44	2842.8	0.18	33
	8	86.3	0.76	6949.4	0.43	36	13.7	0.62	2776.1	0.24	33
	9	79.5	0.91	7084.7	0.56	82	20.5	0.56	2838.2	0.29	62
Large	1	93.6	1.25	6431,2	7,1	55	6.4	0.73	3372.4	3.06	54
	2	93,4	0.94	7771.5	8.04	90	7.8	0.74	4164.9	3.93	51
	3	93.6	1.04	8193.7	10.9	79	6.4	0.79	4327.1	3.95	74
	4	94,9	1.31	7964,5	13.4	98	4.79	0.76	4788.9	4.32	60
	5	89,1	1,02	9773.4	19.9	95	12.6	0.65	4848.2	4.63	71
	6	99	1.28	10721.2	22.3	83	0	0.64	5037.8	4.78	72
	7	88,8	1.12	10953.2	29.6	53	10.6	0.71	5821.6	6.57	69
	8	85	0.96	12234.8	27.5	68	19.2	0.77	7363.4	8.45	58
	9	97	1.03	16845.8	30.6	59	5.7	0.66	8110.6	13.40	54

According to Table 17, the values of dispersion and quality were higher in the whale optimization results compared to the genetic algorithm for all problems with small, medium and large scales, which indicates the superiority of whale algorithm compared to the genetic algorithm in the term of exploring and extracting the possible points and achieving optimal solutions.

6. Conclusion and Recommendations

To solve the proposed model, experimental sample problems were designed in three groups of small, medium and large size according to the forecast study and the results of two whale optimization algorithms and NSGA-II algorithm according to standard indicators of quality, dispersion, uniformity and dissolution time are compared. The results show that in all cases, the whale algorithm has the power to use to explore and extract the possible area of the answer and achieve near-optimal results. In terms of uniformity and resolution time, the NSGA-II algorithm performed better than the whale algorithm. As can be seen in the research background section, many researchers have studied the problem of inverse logistics and presented and solved a mathematical model for this problem. A small number also examined the reverse logistics model of municipal waste recycling. But as can be seen, so far inside and outside Iran, the model of sustainable reverse supply chain collection and recycling of municipal waste with the approach of the Industrial Revolution four has not been studied and the present study is completely new in this regard and the innovations are as follows:

- Presenting and solving the mathematical model of the reverse supply chain of municipal waste recycling with the approach of the Industrial Revolution IV; - Considering the dimensions of sustainability in the reverse supply chain of municipal waste recycling with the approach of industrial revolution four; - Considering the location-routing phase in the reverse supply chain of municipal waste recycling with the approach of industrial revolution four; The main objective: Innovation in reverse supply chain model through industry 4.0 revolutions; Determining and identifying the dimensions of the pattern of the Industrial Revolution 4; - Weighting the dimensions of the Industrial Revolution Model 4 in the sustainable reverse supply chain of municipal waste recycling

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