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A Novel Hybrid Whale Optimization Algorithm to Solve a Production-Distribution Network Problem Considering Carbon Emissions

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ABSTRACT

Nowadays, there is a great deal of attention for regulations of carbon emissions to enforce the decision-makers of production and distribution networks to redesign their systems satisfactorily. The literature has seen a rapid interest in developing novel metaheuristics to solve this problem as a complicated optimization problem. Such difficulties motivate us to address a production-distribution network design problem considering carbon emissions policies among the first studies in this area by a novel hybrid whale optimization algorithm. Accordingly, a mixed integer non-linear programming model has been developed. To tackle the proposed problem, a new hybrid metaheuristic based on whale optimization algorithm and simulated annealing as a successful optimizer is employed to solve the proposed problem. The calibration of the algorithms has been designed by Taguchi method, comprehensively. Finally, an extensive analysis has been evaluated through a comparative study along with some assessment metrics of Pareto solutions.

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1. INTRODUCTION

The production-distribution systems have been investigated and analyzed in the recent years due to a rapid growth in sustainability attentions [1]. The sustainability should be considered in all of organizations due to recent governments' policies in the developed countries [2]. Generally, the sustainability dimensions should be adjusted based on economic, environmental and social aspects for a production-distribution supply chain system [3]. Similarly, recent years have seen a rapid interest in environmentalism to consider the carbon emissions to design the supply chain network [4-6]. In most of case studies, optimization of a supply chain is based on economic factors (profit maximization or cost minimization), with less or no regards to the negative impacts on the environment [7-9]. By another point of view, recent protocols committed by international organizations and governments are mainly decided to control and to reduce the carbon emission levels, more efficiently till 2020 [7]. Therefore, mitigating and reducing carbon emissions are one of main concerns in developing the sustainable supply chain network design [10]. This reason has been motivated to redesign of supply chain networks to incorporate goals from all dimensions of sustainability based on the triple line, i.e., economic, environmental and social aspects [1-3].

Overall, there are several options which have to be weighed, taking into consideration of numerous constraints and requirements [11]. Most of developed decision-making models mainly focus on the location of facilities and the right allocation between each level [12-14]. In this regard, there are a few works proposing the inventory decisions in addition to the sustainable dimensions [14-17]. Regarding the analytical based operations management adopted from the literature, the sources of green and environmental emissions should be

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eliminated and reduced from a robust production-distribution supply chain system [12-15].

It is generally believed that assigning effective and efficient operations among design and management of supply chain networks, especially with carbon policies is a great challenge [17-20]. Therefore, reduction of emissions at each stage of the supply chain will induce an overall reduction in emissions [21]. A sustainable supply chain emphasizes on being environmentally balanced while being economically viable [22, 23]. This includes strict carbon capping indicating some firms which should be regulated the main emissions of a sustainable production-distribution supply chain [24, 25]. The main limitations are regularly to set the carbon taxation [26], carbon capping and trading [27], and buying carbon credits from another firm [28]. All in all, this study employs all these three carbon policies to consolidate in a sustainable production-distribution and inventory control decisions model. There are many works concerning the sustainable supply chain network design in the last decades. As explored by Sahebjamnia et al. [28], only seven papers in high rank related journals have been published for the period of 2015 to 2017 to address the sustainable supply chain network design problem. As mentioned earlier, economic, environmental and social aspects are three main sustainability dimensions [25, 29]. One of suppositions of environmental aspects is considering the carbon policies. In regards to the both single period and single stag, the study conducted by Zhang and Xu [10] revealed that more efforts on considering carbon emissions to evaluate multi-item supply chain networks are needed to be investigated. Xiaoping et al. [30] studied the same problem to indicate that one of main issues of Pareto improvements in supply chain networks is to consider the green technology. Recently, Hajighaei-Keshteli and Fathollahi-Fard [25] emphasized that more attemps on the environmental sustainabiliy aspects such as carbon emissions policies are needed to be evluatd. This reason motivate our attempts to contribute a new production-distribution system considering carbon emissions policies.

The rest of the paper is organized as follows. Section 2, addresses the proposed problem along with main assumptions and formulation. Section 3, the introduced hybrid algorithm along with its encoding scheme are explained. Computational results are investigated in section 4. Finally, discussion and suggestions for the future works are investigated in section 5.

2. PROBLEM DESCRIPTION AND MODLING

This work aims to develop a new sustainable supply chain network with three echelons as a type of location and allocation problems by considering the carbon emissions policies. Generally, the model provides these important factors to design a sustainable supply chain network including the manufacturing cost, the holding cost, the transportation cost, the ordering cost, the regular and overtime of manufacturing process and the environmental emissions regarding the transportation, manufacturing and holding cost of system. As mentioned earlier, there are three carbon emissions policies in this study including strict carbon capping, carbon taxation and considering the cap-and-trade of carbon. In this regard, a Mixed Integer Non-Linear Programming (MINLP) model has been developed with two conflicting objective functions including the minimization the total cost of system and carbon emissions considerations. Overall, there are three echelons in our study including suppliers (A), manufacturers (B) and distributers (C). A planning horizon with multiple time and a set of routings (I) have been considered. In regards to illustrated problem, following assumptions are set for the model proposed:

- There is no flow between the same facilities in each echelon.
- All demand must be satisfied.
- The lead-time of manufacturer B to the item I is a fixed parameter.
- The standard normal distribution value is fixed for all members of supply chain network.
- There is no capacity limitation for the order quantity.
- The setup times of products are considered by the times of assembly and obtained shortage item to assemble the eventual products.
- Similar to other production systems, there is only one upstream node for a set of initial input products for each facility B. In this regard, it is possible that there are several upstream nodes for each facility B. There are a group of external suppliers or some other plants for manufacturing. In this case, an external supplier can supply facility B with several products.

Overall, the used sets, parameters and decision variables are presented as follows:

Sets:

A	Suppliers
B	Manufacturers
C	Distributers
I	Items to be supplied to manufacturers
P	Products delivered to distributers
D	Demand
t	Time of periods

Parameters:

LT_{BI}	Lead time
r_{BI}	Reorder point
$Z_{1-\alpha}$	Service level of proposed supply chain
∂_{LT}	Demand variance during the lead time
HC_{BI}	Holding cost of item I at manufacturer B
Q_{BI}	Order quantity for the item I at manufacturer B
OC_{BI}	Order cost of item I at manufacturer B

F_B	Opening cost of manufacturer *B*
μ_{CP}	Mean demand of products
∂_{CP}	Variance demand of products
HC_{CP}	Holding cost at distributer *C* for product *P*
CBpt	Regular time production cost per unit
CCPBt	Cost of per unit over-time production
TCBAI	Cost of transforming each unit item *I* from supplier *A* to manufacturer *B*
TCCBP	Cost of transforming each unit product *P* from manufacturer *B* to distributer *C*
EMFB	Fixed emissions from manufacturer *B*
EMVB	Variable emissions from manufacturer *B*
EOFPB	Fixed environmental emissions due to transportation of product *P* from manufacturer *B*
EOV_{PB}	Variable environmental emissions due to transportation of product *P* from manufacturer *B*
EOFIA	Fixed environmental emissions due to transportation of item *I* from supplier *A*
EOVIA	Variable environmental emissions due to transportation of item *I* from supplier *A*
EIPC	Environmental emissions due to inventory at distributer *C*
EIPBt	Environmental emissions due to inventory at manufacturer *B*
T	Carbon Tax
F	Fine at exceeding carbon cap
Ψ	Trading cost of carbon credits
CCap	Carbon cap
M	A big scalar

Decision variables:

X_B	It gets 1, if the manufacturer *B* is open; otherwise 0.
Y_{CBP}	It gets 1, if the materials *P* transported to distributer *C* from manufacturer *B*; otherwise 0.
Z_{BAI}	It gets 1, if supplier A serves item *I* to manufacturer *B;* otherwise 0.
QRCPBt	Regular time of production quantity
QOCPBt	Over-time of production quantity

Here, the proposed formulation has been presented. The model has been inspired by the main previous works in this area i.e. [29-31]. For a distributer, the inventory would be stocked by supplying the demand of customers based on 1-α probability during the lead time *LTBI*. Therefore, following function may be used to estimate this probability.

$$\Pr(D(LT_{BI}) \leq r_{BI}) = 1 - \alpha \tag{1}$$

where D(LTBI) during the lead time is item demand D. So, as may be seen in the following equation, a normal distribution function is utilized to estimate the reordering point:

$$r_{BI} = E(D_{BI}) \times E(LT_{BI}) + Z_{1-\alpha} \times \sqrt{(ED_{BI})^2 \times \partial_{LT}{}^2 + E(LT_{BI} \times V_{BI})} \tag{2}$$

Similar to other production systems, the variance may be neglected due to the lead time is fixed. As a result, the reordering point can be reconsidered as follows:

$$r_{BI} = D_{BI} \times LT_{BI} + Z_{1-\alpha} \times \sqrt{LT_{BI} \times V_{BI}} \tag{3}$$

where the value of standard normal distribution value is calculated by *Z1-α*. As suggested in Equation (3), the computation of holding cost has been illustrated. From the calculation presented by Equation (4), the first term computes the holding cost average of ordering quantity. As such, the safety stock cost is calculated in the second term.

$$(HC_{BI} \times Q_{BI})/2 + HC_{BI} \times Z_{1-\alpha} \times \sqrt{LT_{BI}} \times \sqrt{V_{BI}} \tag{4}$$

Taken together, all cost of holding and order system can be estimated as seen in Equation (5).

$$\sum_B \sum_I HC_{BI} \times Z_{1-\alpha} \times \sqrt{LT_{BI}} \times \sqrt{V_{BI}} + (HC_{BI} \times Q_{BI})/2 + \frac{OC_{BI} \times D_{BI}}{Q_{BI}} \tag{5}$$

As mentioned earlier, there is no capacity constraints in our proposed formulation. Hence, there is a set of differences between Equation (5) in terms Q and equating it to zero. To do this end, the following formula is calculated:

$$\frac{H_{BI}}{2} + \frac{OC_{BI} \times D_{BI}}{Q_{BI}{}^2} = 0 \tag{6}$$

Based on the Equation (6), the amount of Q_{BI} is equal to:

$$Q_{BI} = \sqrt{\frac{2 \times OC_{BI} \times D_{BI}}{HC_{BI}}} \tag{7}$$

After the calculation of Equations (7) and (5), the total cost of production and distribution system can be given in the first objective function as seen in Equation (8). In this equation, the first term considers the opening cost which is required to open the manufactures. The second term considers the ordering and holding cost of manufacturers. As such, the third term computes the buffer stock holding cost. The knowledge of manufacturing cost for manufacturers is imparted by the fourth term. At the end, the two last terms give the transportation costs between the suppliers and manufacturers as well as the manufacturers and distributers.

$$\min Z_1 = \sum_B F_B \times X_B + \sum_B \sum_I \sqrt{2 \times HC_{BI} \times OC_{BI}} + \sum_B \sum_I HC_{BI} \times Z_{1-\alpha} \times \sqrt{LT_{BI}} \times \sqrt{V_{BI}} + \sum_C \sum_P \mu_{CP} \times HC_{CP} + \sum_C \sum_B \sum_P \sum_t [QR_{CBPt} \times C_{BPt} + QO_{CBPt} \times C_{CBPt}] + \sum_B \sum_A \sum_I TC_{BAI} \times D_{BI} \times Z_{BAI} + \sum_C \sum_B \sum_P TC_{CBP} \times \mu_{CP} \times Y_{CBP} \tag{8}$$

The second objective function is given in Equation (9). This objective aims to minimize the environmental and carbon emissions of all supply chain network members by using four main parts. The carbon emission of manufacturing activities is accounted by the first part. Both second and third parts support the carbon emission of transportation activities from suppliers to manufacturers and similarly, from manufacturers to distributers. The fourth term of second objective function provides the carbon emissions by the inventory.

$$\min Z_2 = \sum_B [EMF_B \times X_B + EMV_B (QR_{CPBt} + QO_{CPBt})] + \sum_C \sum_P \sum_B (Y_{CBP} \times EOF_{BI} + EOV_{PB} \times \mu_{CB}) + \sum_A \sum_B \sum_I [EOF_{IA} \times Z_{BAI} + EOV_{IA} \times D_{BI}] + \sum_C \sum_B \sum_P (EI_{CP} \times \mu_{CP} + \sum_t EI_{PBt} \times Z_{1-\alpha} \times \sum_I \sqrt{LT_{BI}} \times \sqrt{V_{BI}}) \quad (9)$$

Regarding the carbon taxation, certain tax may be considered as the total emissions computed by Equation (9). There is a supposition for each environmental emissions unit; we assumed the tax to be τ. Accordingly, Equation (10) presents the total cost of supply chain system with the supposition of carbon tax:

$$Z_1 + \tau Z_2 \quad (10)$$

As such, there is a limitation for the carbon emissions amount to be under strict carbon policy, there is a constraint on the amount of carbon emitted across the supply chain network under the presented carbon policy. Here, this supposition is existed to impose the cap on the entire of all supply chain network. Assume that *Ccap* is the amount of carbon cap. Accordingly, a limitation would be considered as follows:

$$Z_2 \leq Ccap \quad (11)$$

As discussed before, the carbon cap-and-trade policy is also considered by this study. Generally, there are two cases based on a positive and negative value of carbon credit as the result of Equation (12). If the environmental emissions are greater than the cap, a positive carbon credit would be considered. Conversely, if the environmental emissions are lower than the cap, a negative carbon credit value would be traded.

$$Z_2 - Ccap \quad (12)$$

If it is assumed that ψ would be the unit carbon emission cost. Accordingly, the total cost of proposed system after the conditions of carbon cap and trade would be as follows:

$$Z_1 + \psi \times (Z_2 - C_{cap}) \quad (13)$$

The other constraints of model can be listed as follows:

$$\sum_B Y_{CBP} = 1;\ \forall C, P \quad (14)$$

$$\sum_A Z_{BAI} = X_B;\ \forall I, B \quad (15)$$

$$\sum_A \sum_I D_{BI} \times S_I \times Z_{BAI} \leq S_{capB} \times X_B;\ \forall B \quad (16)$$

$$\sum_C \sum_P \mu_{CP} \times T_P \times Y_{CBP} \leq P_{capBP};\ \forall B, P \quad (17)$$

$$\sum_C \sum_I \mu_{CP} \times b_{PI} \times Y_{CBP} \leq \sum_I D_{BI};\ \forall B, P \quad (18)$$

$$\sum_C \sum_P \sigma_{CP} \times Y_{VBP} \times b_{PI}^2 = V_{BI};\ \forall B, I \quad (19)$$

$$L_{CP(t-1)} + QR_{CBPt} = L_{nPt};\ \forall C, B, P, t \quad (20)$$

$$\sum_C \sum_P QR_{CBPt} \times T_P \leq T_{PBt};\forall B, t \quad (21)$$

$$\sum_P L_{NCPt} \times U_P \leq S_{capC};\forall C, t \quad (22)$$

$$\sum_t (QR_{CBPt} + QO_{CBPt}) \leq Y_{CBPt} \times M;\forall C, B, P \quad (23)$$

$$X_B, Y_{CBP}, Z_{BAI} \in \{0,1\} \quad (24)$$

$$QR_{CBPt}, QO_{CBPt} \geq 0 \quad (25)$$

As detailed by Equation (14), this constraint guarantees that for all products, the demand of distributers (warehouses) should be satisfied by only one established manufacturer or plant center. As being indicated by Equation (15), the supplier *A* must provide its supplying, operationally. As such, Equations (15) and (16) also proposed that manufacturer *B* is restricted by a specific capacity storage and production limitation. To compute the average and variance of production to manufacture at manufacturer *B*, Equations (17) and (18) are provided to do this end. An interaction between the demand of distributors by considering previous, current and the production quantity periods for each product *P* as the main inventory decisions is considered by Equation (19). The production quantities restriction during regular and overtime hours are decided by Equations (20) and (21). The distributer capacity storage is determined by Equation (22). To support that a product *P* can be manufactured by only an opened manufacturer *B*, Equation (23) confirms this issue. At the end, the binary variables are guaranteed by Equation (24). Similarly, the positive continuous variables are ensured by Equation (25).

To the best of our knowledge, the presented model has not been introduced by a similar study. Hence, the proposed model has addressed a sustainable production-distribution supply chain network with carbon emissions policies. Generally, the simplest case of a location-allocation problem is NP-*hard* [31-33]. In this regard, the presented model as a type of location-allocation problem is very difficult to solve due to inventory and multi-period decisions as well as considering a multi-echelon supply chain network. Therefore, metaheuristics are needed to be considered for solving such models when especially the size of problem increases.

3. PROPOSED HYBRID METAHEURISTIC ALGORITHM

Another main contribution of this study is to propose a new hybrid metaheuristic algorithm based on the Whale Optimization Algorithm (WOA) as a recently-developed optimizer and Simulated Annealing (SA) as a well-known algorithm utilized in the literature repeatedly. Accordingly, a comparative study based on these three algorithms i.e. SA [34], WOA [35] and a Hybrid of WOA and SA (HWS) has been applied.

Generally, the proposed HWS considers WOA as the main loop and SA as the local loop. Due to the best of our knowledeg, there is no similar algorithm to combine these two algorithms by our methodology. In the developed HWS, instead of spiral updating positions of each search agent, a local search based on SA is considered for each agent. Actually, in the proposed algorithm, SA does the local search based on the spiral procedures and accepting and or rejecting of solutions have been formulated regarding the SA structure. Based on our treatments, this SA rules help the algorithm to improve both intensification and diversification phases. Except of this operation of WOA, the other steps of HWS is completely similar to the main original idea of WOA. Note that this applied optimizer is also developed in a multi-objective version. To consider more details about the proposed HWS, its pseudo-code is provided as shown in Figure 1.

3. 1. Encoding Scheme Whenever a metaheuristic procedure is used, coding and decoding the solution of mathematical problem is required [26-30]. The proposed problem has three main binary decision variables i.e. X_B, Y_{CBP} and Z_{BAI}. Two other continuous variables i.e. QR_{CBPt} and QO_{CBPt} can be calculated based on the binary variables. Among them, X_B is a type of location variables. As such, Y_{CBP} and Z_{BAI} are two allocation variables. For both groups, a popular technique called random-key is utilized to transform an infeasible representation to a feasible one. Figure 2 shows the representation for selection of manufacturers. Regarding this example, there are four potential sites for manufactures and among them, only two of them must be selected to be opened. In the first step, a number of random numbers distributed by uniform function (0, 1) has been generated. Accordingly, if this value greater than 0.5, it get 1 to be considered as an open manufacturer. Otherwise, it gets 0. Notably, the higher values generally get 1. Based on this rule, the second and fourth manufacturer should be opened. More details can be seen in Figure 2, as well.

Regarding the allocation variables, based on the located manufacturers, a priority-based representation has been utilized similar to recent similar studies [7-8]. The considered example for representation of allocation has been considered in Figure 3. There are two suppliers and three distributers by considering two items to be supplied from suppliers to manufacturers as well as four products delivered from manufacturers to distributers. Note that all items and products should be assigned in all levels. Therefore, as represented in Figure 3, for each selected manufacturer, a number distributed by uniform function (0, 2) is generated. As such, for each distributer, based on the selected manufacturers, a uniform distributed function should be designed. Therefore,

Tune the parameters of HWS.
Initialize the whale's population.
Calculate the fitness of each search agents by considering the proposed encoding schemes.
Set the Pareto optimal solutions.
while (t< maximum number of iteration)
    for each search agent
        Update A, a, C, l, and p; */they are some random parameters of WOA/*
        if1 (p<0.5)
            if2 (|A|< l)
                Update the position of current search agent by Encircle prey.
            elseif2 (|A|> l)
                Select a random search agent;
                Update the position of current search agent by search for prey.
            endif2
        elseif1 (p≥0.5)
            Do the spiral updating procedures and generate X_{new} for each search agent.
            if $\Delta f_1 \leq 0$ && $\Delta f_2 \leq 0$
            Update this search agent
            else ***if*** $\Delta f_1 \geq 0$ && $\Delta f_2 \leq 0$ || $\Delta f_1 \leq 0$ && $\Delta f_2 \geq 0$
            Put this solution in Pareto set
            else $\Delta f_1 \geq 0$ && $\Delta f_2 \geq 0$
            $P_1 = \exp\left(\frac{-\Delta f_1}{T}\right)$, $P_2 = \exp\left(\frac{-\Delta f_2}{T}\right)$, *h=rand*
                if $h < P_1$ && $h < P_2$
                Update this search agent
                endif
        endif1
    endfor
    Check if any search agents goes beyond the search space and amend it.
    Update T and its reduction rate.
    Update the Pareto optimal frontiers.
    t=t+1;
endwhile
return the non-dominated solutions;

Figure 1. The pseudo-code of proposed multi-objective of HWS

Figure 2. The used technique for selecting manufactures to be opened

from Figure 2, a uniform distributer between (1,2) and (3,4) was considered. Taken together, supplier one was allocated to both selected manufacturers. As such, the second manufacturer is considered for the first and third distributers. The fourth manufacturer is assigned to the second and fourth distributers, as well. More details are given by Figure 3.

4. COMPUTATIONAL EXPERIMENTS

A number of efficient evaluation metrics is required to assess the metaheuristics in an efficient way. Considerably, this study utilizes four well-known evaluation metrics including Number of Pareto Solutions (NPS) [28, 34], Mean Ideal Distance (MID) [25-27], Spread of Non-dominance Solution (SNS) [1-2] and Maximum Spread (MS) [29-30]. Thus, these metrics are well-known and have been utilized in several studies, more explanations along with their formulations are referred to their main papers referred to literature [25-29]. Note that all test problems are generated using a benchmarked method from the literature [25-29].

From Table 1, the results obtained by each algorithm based on the evaluation metrics under each instances are reported. The best values in each test problem are revealed in bold. Except the *MID*, for other metrics, higher values are more preferable. Meanwhile, the lower value of *MID* brings the better capability of algorithms. Overall, from the tables, the proposed HWS shows a better performance in comparison of other algorithms.

Figure 4 divides into four sub-figures to show the LSD interval regarding each assessment metric. Regarding the NPS (Figure 4(a)), there is a clear difference between the performance of SA and two other algorithms. As can be seen, the SA is the worst optimizer. However, WOA is slightly better than WHS in this item. Based on the MID (Figure 4(b)), it can be resulted that the proposed HWS is clearly outperformed both WOA and SA. As such, the SA brings the worst capability in this analysis. Similar to the MID, as can be seen from the MS (Figure 4(c)), the HWS is generally better than other metaheuristics. At the last, as can be resulted from Figure 4(d), the results of SA in the issue of SNS is the worst behaviour. In addition, there is a set of similarities between the WOA and HWS. Nevertheless, the WOA is better than the HWS in this case.

Overall, the performance of both WOA and HWS provides a competitive result. Although the WOA shows a better performance in term of NPS and SNS, the proposed HWS generally outperform the other algorithms. Note that the main demerit of HWS is the computational time of algorithm.

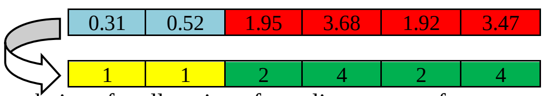

Figure 3. The used technique for allocation of suppliers to manufacturers and manufacturers to distributers

TABLE 1. Comparison of applied optimizers based on the evaluation metrics of Pareto optimal frontiers

Test problem	NPS			MID			MS			SNS		
	SA	WOA	HWS	SA	WOA	HWS	SA	WOA	HWS	SA	WOA	HWS
P1	5	**9**	8	2.3656	**1.4909**	2.1668	322971	364337	**367835**	**357683**	284855	252546
P2	9	**11**	**11**	2.1409	**1.1119**	1.1781	583346	**673114**	659895	699981	**786742**	696675
P3	6	12	**13**	3.0635	2.1143	**2.0267**	674618	**724566**	711843	889612	981314	**996440**
P4	8	11	**12**	4.6701	3.6118	**2.1146**	756024	**1017213**	995784	1500420	1400858	**1634697**
P5	9	12	**13**	2.9635	3.6959	**2.6112**	894850	574956	**1525546**	2355835	2136201	**2484306**
P6	9	**13**	12	5.7248	3.1876	**2.8049**	1261434	968246	**1545794**	**2701689**	2586113	2481696
P7	10	11	**12**	7.3716	**5.0146**	5.4399	1053899	1057282	**1129750**	3219535	**3467159**	2868420
P8	11	13	**14**	**4.5463**	5.8759	5.6609	1035657	919442	**1129797**	3463876	**3718771**	3506257
P9	12	**14**	12	6.8472	4.8438	**4.0797**	1506496	**1865527**	1855450	5140232	**5409774**	5375823
P10	10	**14**	12	3.6925	3.9634	**3.1708**	1750385	1839931	**2248624**	5210873	5702810	**5973421**
P11	11	14	**15**	5.7481	5.8276	**4.0531**	1668077	1399581	**2302254**	5185450	6044003	**6090874**
P12	8	13	**14**	**2.6435**	4.8701	6.3874	1585811	**1761960**	1457975	5801526	**6319580**	6249123
P13	10	**15**	**15**	3.2891	4.2675	3.2895	1547389	1475869	**1563762**	5833145	6657432	**7057842**
P14	11	**16**	**16**	4.4763	4.9788	3.8537	1453687	1564587	**1674284**	5437869	6935741	**7125647**
P15	10	15	**16**	5.8767	4.4633	**3.1704**	1546738	1564372	**1748523**	6647315	6457823	**6962358**

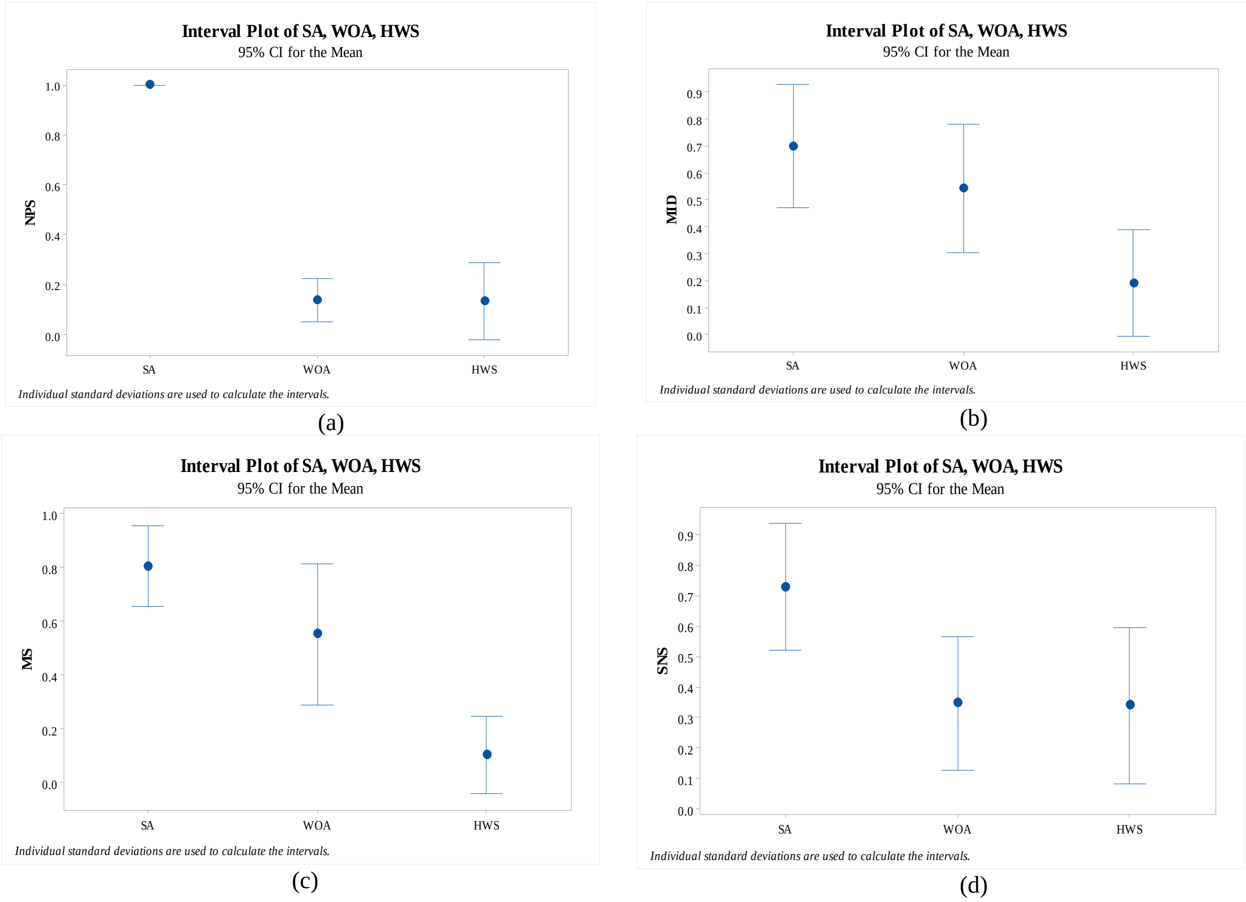

Figure 4. LSD intervals based on the RDI the assessment metrics

5. CONCLUSIONS

Generally, decision makers in supply chain systems face many challenges in the sustainable supply chain management. During the study of literature on carbon policies for multi-level supply chain network design, we explored a coordinated carbon policies in a supply chain system, which helps organization to design a supply chain based on economic advantages and environmental benefits. The review of extant literature revealed that the supply chain activities including but not limited to manufacturing, transportation and inventory planning are the core reasons of carbon emission. Taking all of this into account, this finding motivated us to propose an integrated supply chain based on both production and distribution models for a forward supply chain network based on the environmental aspects with uncertain customer demands. The model provided was included the location of manufacturers, allocation, and the inventory decisions of different items of products. Whole of them were formulated by a mixed integer non-linear programming model. The main contribution of model was to add three different carbon emission policies for a forward supply chain network design problem considering lead time constraints.

Another main novelty of this study was to develop a new hybrid metaheuristic algorithm called as HWS based on the WOA and SA. This algorithm was compared with its original ideas i.e. WOA and SA. The algorithms were tuned by Taguchi method. In addition, four well-known multi-objective assessment metrics were utilized to evaluate the algorithms with a comprehensive analysis. Based on the statistical analyses, the proposed HWS outperform two other algorithms and give the competitive results. Based on the sensitivity analyses, the correlation of environmental emissions and some main decisions of an economic supply chain network to cover the activities of distributing, manufacturing and storing have been analyzed. In addition, the impact of lead time on the environmental emissions along with distribution policy, and three-echelon supply chain system were evaluated through a set of test problems with different difficulties. Taken together, these considerations in a forward supply chain network design give this ability to have a comparison with three carbon policies employed by this paper. Among them, carbon cap-and-trade may be more beneficial for such systems.

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A Novel Hybrid Whale Optimization Algorithm to Solve a Production-Distribution Network Problem Considering Carbon Emissions

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چکیده

امروزه، توجه زیادی به به مقررات انتشار کربن برای تعیین تصمیم گیرندگان شبکه های تولید و توزیع برای تدوین سیستم های آنها به طور رضایت بخش وجود دارد. این ادبیات، علاقه زیادی به توسعه روش های ریاضی جدید برای حل این مشکل، هوشمندانه ای داشته است. چنین مشکلی انگیزه ما را برای حل یک مساله طراحی شبکه توزیع و تولید با توجه به سیاست های انتشار کربن در میان اولین مطالعات در این حوزه تحقیقاتی با الگوریتم بهینه سازی نهنگ ترکیبی جدید مطرح می کند. بر این اساس، یک مدل برنامه ریزی غیر خطی عدد صحیح ترکیبی توسعه یافته است. برای مقابله با مساله پیشنهادی، نوآوری دیگری از این کار این است که یک الگوریتم روش حل جدید ترکیبی مبتنی بر الگوریتم بهینه سازی نهنگ و الگوریتم تبرید شبیه سازی شده به عنوان یک بهینه ساز موفق اخیر برای حل مشکلات پیچیده و غیر خطی معرفی شود. همکاری الگوریتم های کاربردی توسط روش تاگوچی به طور جامع طراحی شده است. در پایان، تجزیه و تحلیل گسترده با استفاده از یک مطالعه مقایسه ای همراه با برخی از تجزیه و تحلیل چند هدفه انجام شده است.

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