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Research Article

A Multi-Objective Green Supply Chain: Multi-Product Model Considering Uncertainty

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Abstract

Increasing environmental pollution, which causes global warming and endangers human health and environmental degradation, has led to the concern of many supply chain managers and designers. The purpose of this research is to provide a mathematical model for designing the purchase, production, and distribution in a multi-level and multi-product supply chain network such that the environmental impact and total costs of supply chain is minimized and the customers' satisfaction level is maximized. Due to the unspecified demands level, demand uncertainty has been considered in the problem. Regarding the complexity of the proposed mathematical model and difficulties in solving the problem with exact methods in large size, a NSGA II has been proposed. To evaluate the proposed NSGA II, five sample instances are generated in different size and solved by Epsilon constraints method and NSGA II. According to the results, the proposed NSGAII is a reliable method to find efficient Pareto frontiers in a reasonable time.

Keywords : Green Supply Chain; Multi-Objective Optimization; Non-Dominated Sorting Genetic Algorithm; Uncertainty; Epsilon Constraint.

1 Introduction

Economic activities (e.g. industrial, agricultural and service activities)rely on the use of natural resources, while they inherently and potentially pollute the environment. So, if the consequences and environmental issues of such activities are not taken into account, high costs should be devoted to eliminating damages caused by the lack of attention to this issue [15].As far as the adverse environmental effects are likely to occur at all stages of the product's life cycle, and the management of environmental programs and operations is not limited to the internal boundaries of the organization, green supply chain management has attracted the attention of researchers as a comprehensive view that covers all flows from suppliers to manufacturers and ultimately to consumers [22].Observing environmental considerations in combination with supply chain management creates a win-win situation for the organi-

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zations and helps them to create a strong global market advantage (through cost reduction and competition improvement) [4].Considering green issues in the supply chain can improve the competitive position of the company by reducing costs. In addition to the cost reduction, close collaboration with the suppliers can lead to the green products. Because it makes companies review their products to make them more environment friendly. In this regard, in order to succeed, there should be a greater and closer cooperation with their suppliers [13].

Meanwhile, in the 1980s, with increasing the diversity of customers' tastes, manufacturing organizations that were highly interested in increasing the flexibility of production lines, improving products and processes, started to develop new products to satisfy customers, which, in turn, brought new challenges to them. In the 1990s, along with improving manufacturing capabilities, industry managers realized that the materials and services received from different suppliers had a significant impact on improving the organization's capabilities to meet customer requirements, which had a drastic influence on the focus of organizations and funding bases. Managers also found that supplying products with the desired criteria of the customer (when, where, how), and with the desired quality and cost, brings new challenges. In such a situation, as a conclusion of the mentioned changes, they found that these changes were not sufficient for the management of the organization on the long run. Therefore, the necessity of presenting this research is highly revealed.

purpose of this research is to provide a mathematical model for designing the purchase, production, and distribution in a multi-level and multi-product supply chain network and proposing meta-heuristic algorithms to achieve near-optimal solutions. The proposed model aims to determine the best combination of facilities in each level as well as find the optimal route among the facilities. This model has a high degree of flexibility to be implemented in the real world such as automotive industries, electronic industries, and pharmaceutical industries. In this research, we seek to answer the following questions:

1. How are environmental parameters considered in the design of the supply chain network?
2. How can the supply chain model be considered with quality levels?
3. How will be the green supply chain model under uncertainty?

2 Literature review

The literature expresses that green supply chain management is able to improve the efficiency of companies [26]. Boosting the efficiency of companies via environmental activities is consistent with the integration strategies and economic performance which can lead to the improvement of manufacturing and production sustainability [23]. So, these are the measures that provide sustainable, competitive profits for Companies, distinguishing them from the other ones as green companies [18].

To enjoy the competitive advantage in green manufacturing, organizations should direct the researchers to scientific studies and development, deliver more novelty and creativity, notice the requirements of the market, recruit talented expertise, and broaden their knowledge horizons. Therefore, green production can be mentioned as a scientific process [14]. Green production aims to design products and goods with the least consumption of environmental resources and to reduce the emission of greenhouse gases [10].

As the first research in this area, Fleischmann et al. studied green reverse logistics considering environmental factors. Also, there are some other studies which concentrated on reverse and green logistics [6].

Hu et al.[9] presented a discrete-time, multi-period multi-product (hazardous-waste) model in order to minimize the cost. They developed a number of constraints to consider business strategies and governmental issues with internal and external metrics.

Quariguasi Frota Neto et al. [16] proposed a closed-loop supply chain for a recycling system. They found several environmental strategies with significant number of economic and environmental criteria. Finally, they solved the model by software called ADBASE.

Cardoso et al. [3] developed a supply chain network with reverse flows, demand uncertainty and considering the existence of production, distribution, and reverse logistics centers. The target, in this study, is to maximize the net present value (NPV), and to find the size and location of the centers, warehouses, and retailers.

Ramezani et al. [17] presented a stochastic multi-objective model for both forward and reverse logistic networks. In their study, two and three stages were considered for reverse and forward logistics, respectively. The objective functions were to maximize the profits and optimize customer responsiveness and quality, while the condition is uncertain.

Zohal and Soleimani [27] suggested a multi-objective model which studied a closed-loop supply chain including four levels for forward flow and three levels for reverse flow. They implemented a case study in the gold industry where CO2 emission is a vital issue.

Zhalechian et al. [24] presented a research entitled "The Sustainable Design of Inventory routing of closed loop Supply under Uncertainty." In this research, they considered the economic, social and environmental impacts of a new closed-loop inventory routing model under uncertainty. They also presented a metaheuristic algorithm to solve the model.

Guo et al. [8] conducted a study entitled Optimization of the car supply chain model under macroeconomic fluctuations. They solved the supply chain model of suppliers selection and the problem of transporting and distributing products using a Tabu search algorithm.

Yang et al. [21] presented a multi-objective model to optimize the design of a supply chain network based on Biogeography under uncertainty. They proposed a novel two-stage optimization method for designing a multi-objective supply chain (MO-SCND) with uncertain shipping costs and uncertain customer demand. They used LINGO software to solve small-scale problems and genetic algorithm to solve large dimensions. Finally, an example of a dairy company was presented as a case study to examine the applicability of the model.

Martinez et al. [12] presented a multi-objective metaheuristic MBSA approach to design and plan a green supply chain. In their proposed algorithm, they plan the capacities of supply chain entities (factories, warehouses, and distribution centers) for inventory and flow of materials through the time horizons. Their model aimed to maximize the profits and minimize the environmental impacts.

Zhao et al. [25] presented an optimization model for green supply chain management using a large data set. They offered three scenarios to improve green supply chain management. The first scenario of optimization is divided into three options: The first option involves minimizing the risk (and thus minimizing economic costs); the second option minimizes both risk and carbon and the third option aims to minimize risk, carbon emissions, and economic costs, simultaneously.

3 Problem description and mathematical model

In this section, the mathematical model of the problem is presented. Also, assumptions and conditions of the problem are fully described.

3.1 problem description

The supply chain network in this problem consists of multi products and multi echelon whose components a include production centers, inspection centers, distribution center, customers, recycle center and waste center. According to these, a multi-product network for the markets with stochastic demands is designed. Also, the possibility of chaos and market disturbance is considered in the model. Therefore, the supply chain includes 1) production/ recycle center, 2) distribution/ inspection center, 3) customers and 4) waste center.

Finished products are delivered to the customers by distribution centers. These centers first inspect the products and distinguish the recyclable or repairable products from the others.

Recyclable and repairable products are sent back to the producers and flawless products are packed and tagged in order to be delivered to the customers. The model aims to determine the optimal structure of supply chain to minimize the total costs and environmental effects and maximize the customer satisfaction with regards to the product quality level. Due to the unspecified demands level, it is considered as a stochastic variables with discrete values for the scenarios. Also, cost uncertainties should be described in the solution part with different scenarios.

In the model, production and distribution centers work in a dual-purpose way. In other words, production center is served as a place to recycle and repair the returned products. Distribution centers are also used as a location for inspection. This two-sided use of the centers results in cost and pollution reduction due to the mutual use of infrastructures and transportation vehicles.

3.2 Problem conditions

- The problem includes multi products and single period.
- The network consists of four levels: 1) production/ recycle center, 2) distribution/ inspection center, 3) customers and 4) waste center.
- The number of facilities and their locations are pre-specified.
- The flow of materials, parts and products can only be between two sequential levels of the network. - Production centers are not capable of producing raw materials or semi-produced products.
- There is a high variety of raw materials and finished products in the corresponding centers.
- The supplier of raw materials and distribution centers produce the goods with different quality levels due to their technological equipment and production policies.
- Production capacities (resources) of production centers, distribution centers and waste centers are uncertain (stochastic), as well as production costs.
- Customers demand is uncertain.
- Customers are allowed to satisfy their requirements by connecting to more than one center.
- A product is considered as classy (highest quality level), when all its components and raw materials are first class. In other words, when a production center is able to produce a product with the first quality level, it is just allowed to provide its raw materials and parts from the suppliers whose product quality is categorized in quality level of 1.
- For uncertain parameters, probability distribution function is defined.

Moreover, the most important decisions which are made by mathematical model are:
Selecting the suppliers of raw materials
Selecting the part suppliers
Selecting the producers (factories)
Selecting the distribution centers
Allocating various raw materials, parts and finished products (with various quality levels) to the selected facilities
Optimal quantity of raw materials, parts and finished products which are sent from one level to another
The target is designing a supply chain network in order to minimize the total costs of supply chain, minimizing the environmental effects and maximizing customers' satisfaction level.

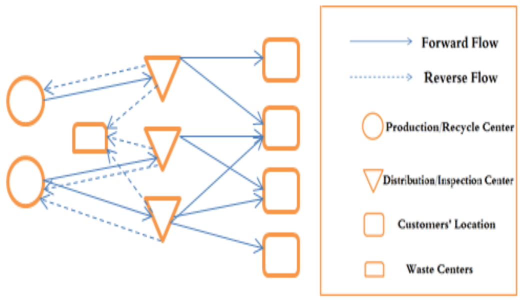

Figure 1: Forward and reverse structure of the problem.

3.3 Indices, parameters and variables

Indices used in the model are as follows: K set of the suppliers of raw materials (first level) (k=1,,k) I set of raw materials $(i = 1, , I)$
S set of part suppliers (second level) $(s = 1, , S)$

R set of parts $(r = 1, , R)$
C set of customers $(c = 1, , C)$

Table 1: Solution representation for NSGA II (a)

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	..	..	..	a_{A-1}	a_A
b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	..	..	..	b_{B-1}	b_B

Table 2: Solution representation for NSGA II (b)

k_1	k_2	k_3	k_4	k_5	k_6	k_7
k_8	..	..	..	k_{K-1}	k_K	
s_1	s_2	s_3	s_4	s_5	s_6	s_7
s_8	..	..	..	s_{S-1}	s_S	
p_1	p_2	p_3	p_4	p_5	p_6	p_7
p_8	..	..	..	p_{P-1}	p_P	
w_1	w_2	w_3	w_4	w_5	w_6	w_7
w_8	..	..	..	w_{W-1}	w_W	
$i_1q_1k_1$	$i_1q_1k_2$	..	$i_1q_1k_K$	..	$i_1q_2k_K$	$i_1q_3k_K$
..	..	..	$i_1q_Qk_K$	..	$i_Iq_Qk_K$	
$r_1q_1s_1$	$r_1q_1s_2$	..	$r_1q_1s_S$	..	$r_1q_2s_S$	$r_1q_3s_S$
..	..	..	$r_1q_Qs_S$	..	$r_Rq_Qs_S$	
$f_1q_1p_1$	$f_1q_1p_2$	..	$f_1q_1p_P$	..	$f_1q_2p_P$	$f_1q_3p_P$
..	..	..	$f_1q_Qp_P$	..	$f_Fq_Qp_P$	
$f_1q_1w_1$	$f_1q_1w_2$	..	$f_1q_1w_W$	..	$f_1q_2w_W$	$f_1q_3w_W$
..	..	..	$f_1q_Qw_W$	..	$f_Fq_Qw_W$	
$i_1q_1k_1s_1$	$i_1q_1k_1s_2$	$i_1q_1k_1s_3$	$i_1q_1k_1s_4$	..	..	..
..	..	..	..	$i_Iq_Qk_Ks_{S-1}$	$i_Iq_Qk_Ks_S$	
$r_1q_1s_1p_1$	$r_1q_1s_1p_2$	$r_1q_1s_1p_3$	$r_1q_1s_1p_4$	..	..	..
..	..	..	..	$r_Rq_Qs_Sp_{P-1}$	$r_Rq_Qs_Sp_P$	
$f_1q_1p_1w_1$	$f_1q_1p_1w_2$	$f_1q_1p_1w_3$	$f_1q_1p_1w_4$	..	..	..
..	..	..	..	$f_Fq_Qp_Pw_{W-1}$	$f_Fq_Qp_Pw_W$	
$f_1q_1w_1c_1$	$f_1q_1w_1c_2$	$f_1q_1w_1c_3$	$f_1q_1w_1c_4$	..	..	..
..	..	..	..	$f_Fq_Qw_Wc_{C-1}$	$f_Fq_Qw_Wc_C$	

D set of demands $(d = 1, , D)$
P set of production facilities $(p = 1, , P)$

F set of finished products $(f = 1, , F)$
W set of distribution centers $(w = 1, .., W)$

Q set of quality levels $(q = 1, , Q)$
N set of scenarios $(n = 1, , N)$

A set of potential sites for production and recycle centers
B set of potential sites for distribution and inspection centers
E set of fixed waste centers

The parameters of mathematical model are:

a^ir: The amount of needed raw material i to produce a unit of part r
b^rf: The amount of required part r to produce a unit of finished product f

D_cfq^n: Demand of customer c for product f with the quality q under the scenario n
CK_k: Fixed cost of supplier selection in first level (raw materials) k

Table 2, Continue.

k_8	..	..	..	k_{K-1}	k_K
s_8	..	..	..	s_{S-1}	s_S
p_8	..	..	..	p_{P-1}	p_P
w_8	..	..	..	w_{W-1}	w_W
..	..	..	$i_1 q_Q k_K$	..	$i_I q_Q k_K$
..	..	..	$r_1 q_Q s_S$	..	$r_R q_Q s_S$
..	..	..	$f_1 q_Q p_P$	..	$f_F q_Q p_P$
..	..	..	$f_1 q_Q w_W$	..	$f_F q_Q w_W$
..	..	..	..	$i_I q_Q k_K s_{S-1}$	$i_I q_Q k_K s_S$
..	..	..	..	$r_R q_Q s_S p_{P-1}$	$r_R q_Q s_S p_P$
..	..	..	..	$f_F q_Q p_P w_{W-1}$	$f_F q_Q p_P w_W$
..	..	..	..	$f_F q_Q w_W c_{C-1}$	$f_F q_Q w_W c_C$

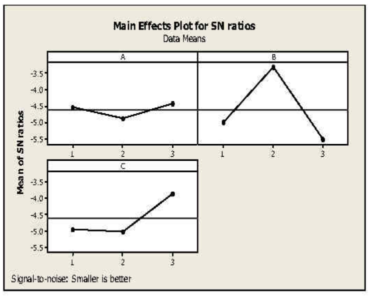

Figure 2: Parameter adjustment for NSGA II.

CS_s: Fixed cost of supplier selection in second level (parts) s
CP_p: Fixed cost for selection of producer p

CW_w: Fixed cost for selection of distribution center w
CK_iqk: Fixed cost of allocating raw material i with quality q to supplier of first level k

CS_rqs Fixed cost of allocating part r with quality q to supplier of second level s
CP_fqp: Fixed cost of allocating finished product f with quality q to producer p

CW_fqw: Fixed cost of allocating finished product f with quality q to distribution center w
CKS_iqks Fixed cost of providing raw material i with quality q by the supplier of first level k for the supplier of second level s

CSP_rqsp: Fixed cost of providing part r with quality q by the supplier of second level s for the factory p
CPW_fqpw: Fixed cost of providing finished product f with quality q by the factory p for the distribution center w

CWC_fqwc: Fixed cost of providing finished product f with quality q by the distribution center w for customer c
dks_iqks^n: Unit cost of providing raw material i with quality q by the supplier of first level k for the supplier of second level sunder the scenario n

dsp_rqsp^n: Unit cost of providing part r with quality q by the supplier of second level s for the factory p under the scenario n
dpw_fqpw^n: Unit cost of providing finished product f with quality q by the factory p for the distribution center w under the scenario n

dwc_fqwc^n: Unit cost of providing finished product f with quality q by the distribution center w for customer c under the scenario n
P^n: Possibility of occurrence of scenario n

qk_iqk^n: Upper bound for raw material i with the quality q which delivered by the first level supplier k under scenario n
qs_rqs^n: Upper bound for part r with the quality

q which delivered by the second level supplier s under scenario n

qp_fqp^n: Upper bound for the finished product f with the quality q which delivered by the producer p under scenario n
qw_fqw^n: Upper bound for the finished product f with the quality q which delivered by the distribution center w under scenario n

qks_iqks^n: Upper bound for raw material i with the quality q which delivered by the first level supplier k to the second level supplier s under scenario n
qsp_rqsp^n: Upper bound for part r with the quality q which delivered by the second level supplier to the producer p under scenario n

qpw_fqpw^n: Upper bound for the finished product f with the quality q which delivered by the producer p to the distribution center w under scenario n
qwc_fqwc^n: Upper bound for the finished product f with the quality q which delivered by the distribution center w to the customer c under scenario n UK_k^n: The capacity of first level supplier k under scenario n

US_s^n: The capacity of second level supplier s under scenario n
UP_p^n The capacity of producer p under scenario n

UW_w^n: The capacity of distribution center w under scenario n
UK_iqk: Used resources of the first level supplier k to provide a unit of raw material i with quality q

US_rqs: Used resources of the second level supplier s to provide a unit of part r with quality q
UP_fqp: Used resources of the producer p to provide a unit of finished product f with quality q

UW_fqw: Used resources of the distribution center w to provide a unit of finished product f with quality q
M: A very large number

E_cfq^n: 1 if the demand of customer c for the product f with the quality of q under scenario n is greater than zero, otherwise 0.
HK_iqk: 1 if raw material supplier k provides the raw material i with the quality of q, otherwise 0.

HS_rqs: 1 if supplier s provides part r with the quality of q, otherwise 0.
HP_fqp: 1 if producer p provides finished product f with the quality of q, otherwise 0.

HW_fqw: 1 if distribution center w demands finished product f with the quality of q, otherwise 0.
ei_r^rro: Environmental impact of producing product r per unit

ei_abr^rd: Environmental impact of transporting product r from location a to b per unit
ei_bcr^dc: Environmental impact of transporting product r from location b to c per unit

ei_bar^ar: Environmental impact of transporting product r from location b to a per unit
ei_ber^ad: Environmental impact of transporting product r from location b to e per unit

ei_br^an: Environmental impact of inspecting product r in location b per unit
ei_ar^re: Environmental impact of recycling product r in location a per unit

ei_er^da Environmental impact of disposing product r in location e per unit
Also, variables used in the mathematical model are:

XKS_iqks^n: Quantity of raw material i with quality q provided by the first level supplier k for the second level supplier s under scenario n
XSP_rqsp^n: Quantity of part r with quality q provided by the second level supplier s for producer p under scenario n

XPW_fqpw^n: Quantity of finished product f with quality q provided by producer p for

distribution center w under scenario n
XWC_fqWC^n: Quantity of finished product f with quality q provided by distribution center w for customer c under scenario n

YK_k: 1 if the first level supplier k is selected, otherwise 0.
YS_s: 1 if the second level supplier s is selected, otherwise 0.

YP_p: 1 if producer p is selected, otherwise 0.
YW_w: 1 if distribution center w is selected, otherwise 0.

YK_iqk: 1 if raw material i with quality q is allocated to the first level supplier k, otherwise 0.
YS_rqs: 1 if part r with quality q is allocated to the second level supplier s, otherwise 0.

YP_fqp: 1 if finished product f with quality q is allocated to producer p, otherwise 0.
YW_fqw: 1 if finished product f with quality q is allocated to distribution center w, otherwise 0.
YKS_iqks: 1 if raw material i with quality q is provided for the second level supplier s by the first level supplier k, otherwise 0.

YSP_rqsp: 1 if part r with quality q is provided for producer p by the second level supplier s, otherwise 0.
Ypw_fqpw: 1 if finished product f with quality q is provided for distribution center w by producer p, otherwise 0.

YWC_fqwc: 1 if finished product f with quality q is provided for customer c by distribution center w, otherwise 0.
$T_(cfq)^n$: 1 if the demand of customer c for finished product f with quality q is satisfied under scenario, otherwise 0.

Y customers' satisfaction level
x_abr: Quantity of product r delivered from production center a to distribution center b

u_bcr: Quantity of product r delivered from distribution center b to customer place c
v_bar: Quantity of product r delivered from distribution center b to recycle center a

T_ber: Quantity of product r delivered from distribution center b to waste center e
w_a: 1 if production center a is established, otherwise 0.
y_b: 1 if distribution center b is established, otherwise 0.

$$
\begin{aligned}
&Minimize \sum_k CK_k.YK_k + \sum_s CS_s.YS_s \quad (1)\\
&+\sum_p CP_p.YP_p + \sum_w CW_w.YW_w\\
&+\sum_i\sum_q\sum_k CK_{iqk}.YK_{iqk}\\
&+\sum_r\sum_s\sum_q CS_{rqs}.YS_{rqs}\\
&+\sum_f\sum_q\sum_p CP_{fqp}.YP_{fqp}\\
&+\sum_f\sum_q\sum_w CW_{fqw}.YW_{fqw}\\
&+\sum_i\sum_q\sum_k\sum_s CKS_{iqks}.YKS_{iqks}\\
&+\sum_r\sum_q\sum_s\sum_p CSP_{rqsp}.YSP_{rqsp}\\
&+\sum_f\sum_q\sum_p\sum_w CPW_{fqpw}.YPW_{fqpw}\\
&+\sum_f\sum_q\sum_w\sum_c CWC_{fqwc}.YWC_{fqwc}\\
&+\sum_{nN} P^n[\sum_i\sum_q\sum_k\sum_s dks^n_{iqks}.XKS^n_{iqks}\\
&+\sum_r\sum_q\sum_s\sum_p dsp^n_{rqsp}.XSP^n_{rqsp}
\end{aligned}
$$

$$+\sum_f\sum_q\sum_p\sum_w dpw^n_{fqpw}.XKS^n_{iqks}$$
$$+\sum_f\sum_q\sum_p\sum_w dpw^n_{fqpw}.XPW^n_{fqpw}$$
$$+\sum_f\sum_q\sum_w\sum_c dwc^n_{fqwc}.XWC^n_{fqwc}]$$

$$Maximize\ \ y \quad (2)$$

$$Min\sum_{a,b,r}\left(ei^{rd}_{abr}+ei^{rro}_{ar}\right)x_{abr} \quad (3)$$
$$+\sum_{b,c,r}\left(ei^{dc}_{bcr}+ei^{an}_{br}\right)u_{bcr}$$
$$+\sum_{a,b,r}(ei^{ar}_{bar}+ei^{re}_{ar})v_{bar}$$
$$+\sum_{b,e,r}\left(ei^{ad}_{ber}+ei^{da}_{er}\right)T_{ber}$$

s.t.

$$\sum_k XKS^n_{iqks}-\sum_r\sum_p a^{ir}.XSP^n_{rqsp}=0 \quad (4)$$
$\forall n,i,q,s$

$$\sum_s XSP^n_{rqsp}-\sum_f\sum_w b^{rf}.XPW^n_{fqpw}=0 \quad (5)$$
$\forall n,r,q,p$

$$\sum_p XPW^n_{fqpw}-\sum_c XWC^n_{fqwc}=0 \quad (6)$$
$\forall n,f,q,w$

$$\sum_i\sum_q\sum_s UK_{iqk}.XKS^n_{iqks}\le UK^n_k.YK_k \quad (7)$$
$\forall n,k$

$$\sum_r\sum_q\sum_p US_{rqs}.XSP^n_{rqsp}\le US^n_s.YS_s \quad (8)$$
$\forall n,s$

$$\sum_f\sum_q\sum_w UP_{fqp}.XPW^n_{fqpw}\le UP^n_p.YP_p \quad (9)$$
$\forall n,p$

$$\sum_f\sum_q\sum_c UW_{fqw}.XWC^n_{fqwc}\le UW^n_w.YW_w \quad (10)$$
$\forall n,w$

$$\sum_s XKS^n_{iqks}\le qk^n_{iqk}.YK_{iqk} \quad (11)$$
$\forall n,i,q,k$

$$\sum_p XSP^n_{rqsp}\le qs^n_{rqs}.YS_{rqs} \quad (12)$$
$\forall n,r,q,s$

$$\sum_w XPW^n_{fqpw}\le qp^n_{fqp}YP_{fqp} \quad (13)$$
$\forall n,f,q,p$

$$\sum_c XWC^n_{fqwc}\le qw^n_{fqw}.YW_{fqw} \quad (14)$$
$\forall n,f,q,w$

$\forall n,i,q,k,s$

$\forall n,r,q,s,p$

$$XPW^n_{fqpw}\le HP_{fqp}.qpw^n_{fqpw}.Ypw_{fqpw}$$
$\forall n,f,q,p,w$

$$XWC^n_{fqwc}\le HW_{fqw}\ .\ qwc^n_{fqwc}.YWC_{fqwc}$$
$\forall n,f,q,w,c$

$$\sum_k \left(\sum_{n\in N} P^n.UK_k^n\right)/UK_{iqk} . YK_{iqk} \geq \sum_r a^{ir}.\sum_f b^{rf}.\sum_c (\sum_n P^n. D_{cfq}^n) \qquad \forall i,q$$

$$\sum_s \left(\sum_{n\in N} P^n.US_s^n\right) / \qquad US_{rqs} . YS_{rqs} \geq$$

$$\sum_f b^{rf}.\sum_c (\sum_{n\in N} P^n. D_{cfq}^n) \qquad \forall r,q$$

$$\sum_p \left(\sum_{n\in N} P^n.UP_p^n\right)/ \qquad UP_{fqp} . YP_{fqp} \geq$$

$$\sum_c \left(\sum_{n\in N} P^n. D_{cfq}^n\right) \qquad \forall f,q$$

$$\sum_w \left(\sum_{n\in N} P^n.UW_w^n\right)/UW_{fqw} . YW_{fqw} \geq \sum_c \left(\sum_{n\in N} P^n. D_{cfq}^n\right) \qquad \forall f,q$$

$$\sum_w XWC_{fqwc}^n - D_{cfq}^n < M. T_{cfq}^n \quad \forall n,f,a,c$$

$$\sum_w XWC_{fqwc}^n - D_{cfq}^n \geq M. (T_{cfq}^n - 1) \quad \forall n,f,q,c$$

$$(\sum_f \sum_q T_{cfq}^n)/(\sum_f \sum_q E_{cfq}^n) \geq y \quad \forall n,c$$

$$XKS_{iqks}^n, XSP_{rqsp}^n, XPW_{fqpw}^n, XWC_{fqWC}^n, y \geq 0$$

$$\forall i,r,f,s,p,w,c,n,q$$

$$YK_k, YS_s, YP_p, YW_w, YK_{iqk}, YS_{rqs}, YP_{fqp}, YP_{fqp} \in \{0,1\}$$

$$\forall i,r,f,s,p,w,c,q$$

$$YKS_{iqks}, YSP_{rqsp}, YPW_{fqpw}, YWC_{fqwc},\ T_{cfq}^n \in \{0,1\}$$

$$\forall i,f,s,p,w,c,n,q$$

$$\sum_a x_{abr} - \sum_{a,e} (v_{bar} + T_{ber}) = \sum_c u_{bcr} \quad \forall b \in J\ , \quad \forall r \in P$$

$$\sum_c u_{bcr} - (1 - s1_r - s2_r) \sum_a x_{abr} = 0 \quad \forall b \in J\ , \quad \forall r \in P$$

$$\sum_e T_{ber} - s1\ _r \sum_a x_{abr} = 0 \quad \forall b \in J\ , \quad \forall r \in P$$

$$\sum_a v_{bar} - s2\ _r \sum_a x_{abr} = 0 \quad \forall b \in J\ , \quad \forall r \in P$$

$$\sum_b v_{bar} - \sum_b x_{abr} \leq 0 \quad \forall a \in I\ , \quad \forall r \in P$$

$$\sum_b u_{bcr} \geq d_{cr} \quad \forall c \in C\ \forall r \in Pv$$

$$\sum_b u_{bcr} \geq d_{cr} \quad \forall c \in C\ , \ \forall r \in P$$

The proposed model is multi-objective. The first objective minimizes the total costs of supply chain (e.g. fixed and variable costs). The second objective function maximizes customers' satisfaction level (service level) by considering the quality levels. The third objective function minimizes the network environmental effects, such as the harmful influences which production, distribution, inspection and waste centers have on the environment and also the pollution which is imposed on nature as a result of transportations. To obtain the coefficients used in the equation, an LCA-based method, such as the Eco-indicator 99, has been used [7]. Constraints (4) indicate that the total raw material i which has been sent to supplier s, is equal to the quantity of all raw materials which are needed by this supplier to

Table 3: Candidate values for NSGA II parameters

parameter	**levels**
Crossover rate	0.9, 0.75, 0.65
Mutation rate	0.30, 0.20, 0.10
Initial population	150, 100, 50

Table 4: Optimal values for NSGA II parameters

Crossover	Mutation	Initial	Stopping
rate	rate	population	criteria
0.9	0.2	150	50

Table 5: Sample instances

Sample	E	B	A	N	Q	W	F	P	D	C	R	S	I	K
1	2	2	2	3	2	3	2	2	5	3	3	2	1	1
2	2	2	2	3	2	4	2	2	7	5	3	2	3	2
3	3	3	3	4	3	6	3	3	10	8	5	5	4	3
4	4	4	4	9	8	8	5	5	18	15	9	9	8	5
5	5	5	5	12	10	10	6	6	25	20	14	12	12	8

produce the parts. Constraints (5) ensure that the total part r which has been sent to producer p, is equal to the quantity of all parts which are needed by this producer to produce the finished products. Constraints (6) guarantee that all the products which enter a center, exit from the same center indeed. Constraints (7) to (10) represent that the amount of applied resources in each facility must be less than or equal to their maximum available resources. Constraints (11) to (14) show that the used raw materials, parts or finished products must be less or equal to the upper bound of that specific product. Constraints (15) to (18) indicate that the units of a product will be provided to be delivered from an origin to a destination, if only the origin is selected. Constraints (19) to (22) ensure that the total capacity of open facilities is greater than or equal to the total demand. Constraints (23) and (24) act as sensors to fulfill the demand. In other words, if the demand is fulfilled, the sensor$T_c f q^n$ is 1, otherwise 0. Constraints (25) necessitate that the average number of the sensors which are equal to 1, must be greater than the satisfaction level. Constraints (26) and (27) shows the domain of variables in the mathematical model. Constraints (28) to (34) balance the flow of products forwardly and reversely. Constraints (35) guarantee that all of the demands would be satisfied.

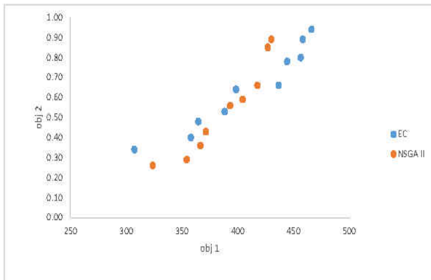

Figure 3: Obtained Pareto solution in sample 3 for the first and second objectives

4 Solution Method

In previous section, the mathematical model was presented. Due to the fact that the proposed mathematical model contains so many binary variables, it is very hard to solve it especially in large samples. To resolve this problem, genetic algorithm can be an appropriate method. There-

Table 6: Domain of parameters for sample instances

parameter	**value**	**parameter**	**value**
a^{ir}	uniform(1,2)	qp^n_{fqp}	uniform(5,7)
b^{rf}	uniform(2,3)	qw^n_{fqw}	uniform(5,7)
D^n_{cfq}	uniform(4,8)	qks^n_{iqks}	uniform(5,7)
CK_k	uniform(20,26)	qsp^n_{rqsp}	uniform(5,7)
CS_s	uniform(20,26)	qpw^n_{fqpw}	uniform(5,7)
CP_p	uniform(20,26)	qwc^n_{fqwc}	uniform(5,7)
CW_w	uniform(20,26)	UK^n_k	uniform(50,80)
CK_{iqk}	uniform(20,26)	US^n_s	uniform(50,80)
CS_{rqs}	uniform(20,26)	UP^n_p	uniform(50,80)
CP_{fqp}	uniform(20,26)	UW^n_w	uniform(50,80)
CW_{fqw}	uniform(20,26)	UK_iqk	uniform(50,80)
CKS_{iqks}	uniform(20,26)	US_rqs	uniform(50,80)
CSP_{rqsp}	uniform(20,26)	UP_fqp	uniform(50,80)
CPW_{fqpw}	uniform(20,26)	UW_fqw	uniform(50,80)
CWC_{fqwc}	uniform(20,26)	ei^{rro}_r	uniform(0.2,0.4)
dks^n_{iqks}	uniform(20,26)	ei^{rd}_{abr}	uniform(0.2,0.4)
dsp^n_{rqsp}	uniform(20,26)	ei^{dc}_{bcr}	uniform(0.2,0.4)
dpw^n_{fqpw}	uniform(20,26)	ei^{ar}_{bar}	uniform(0.2,0.4)
dwc^n_{fqwc}	uniform(20,26)	ei^{ad}_{ber}	uniform(0.2,0.4)
P^n	$1/n$	ei^{an}_{br}	uniform(0.2,0.4)
qk^n_{iqk}	uniform(5,7)	ei^{re}_{ar}	uniform(0.2,0.4)
qs^n_{rqs}	uniform(5,7)	ei^{da}_{er}	uniform(0.2,0.4)

Table 7: Optimal values of objective functions for solving individually

Sample	obj	f1	f2	f3
	$Minf1$	164	0	1015
3	$Maxf2$	178	1	929
	$Minf3$	923	0	854

Table 8: Values of objective functions and epsilon for sample 3

No.	ε_2	ε_3	Obj 1	Obj 2	Obj 3
1	0.1	861.9173	307	0.34	1302
2	0.2	869.4276	358	0.4	1280
3	0.3	876.9379	365	0.48	1229
4	0.4	884.4482	388	0.53	1140
5	0.5	891.9585	398	0.64	992
6	0.6	899.4688	437	0.66	957
7	0.7	906.9791	444	0.78	930
8	0.8	914.4894	456	0.8	876
9	0.9	921.9997	458	0.89	870
10	1	929.51	466	0.94	861

fore, in this research, a NSGA II (Non-dominated Sorting Genetic Algorithm) is used to solve the large size problem. Meanwhile, to solve the small size samples, the exact method of EC (Epsilon

Constraint) is implemented by means of GAMs software. Finally, the obtained results from both methods are presented and compared.

4.1 Solution representation for NSGA II

To represent a feasible solution in the proposed NSGAII, two binary chromosomes with the length of A and B (number of bits) are defined, Where A and B are the number of potential sites for production/recycle centers and distribution/inspection centers, respectively. Table 1 shows the defined chromosomes for NSGA II.
In the first chromosome of Table 1, if a production center is established at the potential site a, the ath cell (bit) is 1, otherwise 0. Also, in the second chromosome of Table 1, if a distribution center is established at the potential site b, the bth cell (bit) is 1, otherwise 0. Also, a binary matrix with 12 rows is applied to represent the solution. The row 1 to 12 shows the values for the variables YK_k, YS_s, YP_p, YW_w, YK_iqk, YS_rqs, YP_fqp, YW_fqw, YKS_iqks, YSP_rqsp, Ypw_fqpw, YWC_fqwc respectively.

4.2 Crossover and mutation operators

To generate new offspring, crossover and mutation operator is used. In this research, one-point crossover is utilized. So that, one of the bits is selected randomly and the chromosomes is divided to two parts (part one before the selected bit, part two from the selected bit to the end). Then, the first parts of the first chromosome are changed with the second part of the second chromosome and new offspring is generated. Also, the second part of the first chromosome is combined with the first part of the second chromosome for another new offspring. Likewise, a one-point method is used for the mutation. To do this, one of the bits is selected randomly and the value of the selected bit is reversed. In other words, if its value is 1, it is changed to 0, vice versa.

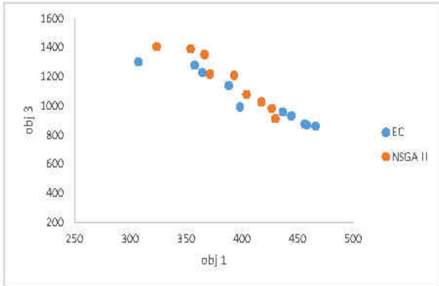

Figure 4: Obtained Pareto solution in sample 3 for the first and third objectives

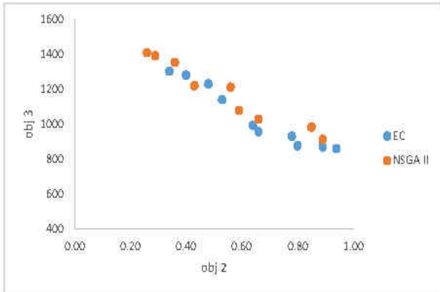

Figure 5: Obtained Pareto solution in sample 3 for the second and third objectives

4.3 Parameter adjustment for NSGA II

NSGA II consists of many factors and parameters all of which can affect the final solution and algorithm efficiency. Therefore, appropriate arrangement of these factors can improve the algorithm efficiency significantly. In this research, Taguchi method in Minitab software is applied to adjust the critical parameters of NSGAII [20]. Table 3 presents the candidate values for important parameters of NSGA II.
Due to this, the proposed model was solved in each of 27 levels with NSGA II and the results were inserted into Minitab software to implement Taguchi design of experiments. Figure 2 shows the parameter adjustment of the proposed NSGA II.
According to Figure 2, the best combination of parameters value can be obtained. Table 4 shows the optimal values for each parameter. Regarding Table 6, crossover rate, mutation rate and initial population are 0.9, 0.2 and 150 respectively. Moreover, due to the initial tests, the stopping criteria is supposed to be 50 sequential iterations

Table 9: Pareto optimal solution for sample 3 by EC and NSGA II

No.	EC			NSGA II		
	Obj1	Obj2	Obj3	Obj1	Obj2	Obj3
1	307	0.34	1302	324	0.26	1408
2	358	0.4	1280	354	0.29	1391
3	365	0.48	1229	367	0.36	1352
4	388	0.53	1140	371	0.43	1219
5	398	0.64	992	393	0.56	1211
6	437	0.66	957	404	0.59	1079
7	444	0.78	930	418	0.66	1028
8	456	0.8	876	427	0.85	982
9	458	0.89	870	430	0.89	912
10	466	0.94	861	-	-	-

Table 10: Validation of NSGA II for sample 1

Index / Method	**MID**	**SM**	**DM**	**SAW**
E-constraint	0.93	0.95	1.56	**1.23**
NSGA II	0.97	0.98	1.22	**1.09**

Table 11: Validation of NSGA II for sample 2

Index / Method	**MID**	**SM**	**DM**	**SAW**
E-constraint	0.78	0.66	1.62	**1.47**
NSGA II	0.81	0.73	1.47	**1.36**

Table 12: Validation of NSGA II for sample 3

Index / Method	**MID**	**SM**	**DM**	**SAW**
E-constraint	1.14	0.74	2.41	1.55
NSGA II	1.15	0.82	2.21	1.43

Table 13: Validation of NSGA II for sample 4

Index / Method	**MID**	**SM**	**DM**	**SAW**
E-constraint	-	-	-	-
NSGA II	1.12	0.47	1.46	1.49

Table 14: Validation of NSGA II for sample 5

Index / Method	**MID**	**SM**	**DM**	**SAW**
E-constraint	-	-	-	-
NSGA II	1.02	1.18	0.89	0.91

Table 15: Solution time for samples (second)

Index / Method	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
E-constraint	2.6	49.2	412.8	3600	3600
NSGA II	112.4	241.2	463.7	754.9	921.5

without improvement in the solution.

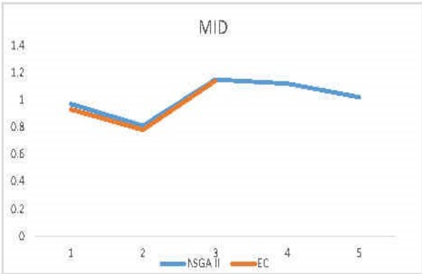

Figure 6: Mean Ideal Distance for NSGA II and EC

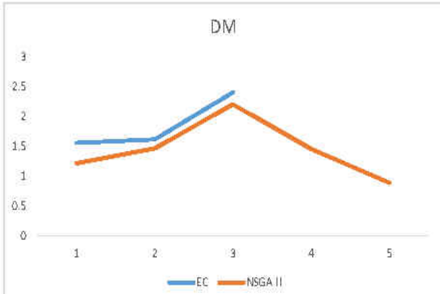

Figure 8: Diversity metric for NSGA II and EC

Figure 7: Space metric for NSGA II and EC

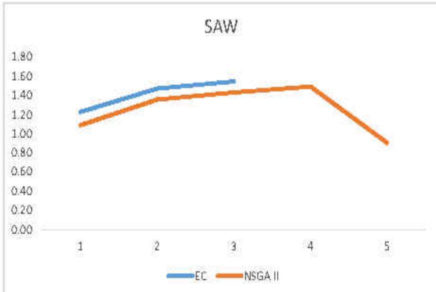

Figure 9: Final comparison of the performance of NSGA II and EC

4.4 Computational results

In order to validate the proposed model and examine the efficiency of the proposed NSGA II, five sample instances are generated with different size which are shown in Table 5. Also, Table 6 presents distribution function and domain of the parameter of mathematical model. Moreover, sample instances 1 to 3 are considered as small size, while 4 and 5 are considered as large problems.

In Table 6 , the first column indicates the problem number, second column is the number of suppliers of raw materials (first level), third column is the number of raw materials, fourth column is the number of parts suppliers (second level), fifth column is the number of parts, sixth column is the number of customers, seventh column is the number of demand, eighth column is the number of producer facilities, ninth column is the number of finished products, tenth column is the number of distribution centers, eleventh column is the number of quality levels, twelfth level is the number of scenarios, thirteenth level is the number of potential sites for distribution/recycle centers, fourteenth column is the number of potential sites for distribution/inspection centers and fifteenth column is the number of waste centers in each samples. Additionally, the parameters in Table 6 are generated randomly and by the use of a uniform distribution function. After generating random samples in different size, the samples are solved in GAMs software and the results are presented. In EC, the first objective function is considered as the main objective function and the other objectives served as constraints. 10 breakpoints are considered for the problem and so, 10 Pareto solutions will be generated for each sample. For example, sample 3 is solved by EC method and the result are presented in Table 7 and 8. Table 7 shows the maximum and minimum value for each objective function in the case of solving individually (without the presence of two other objectives). Also, Table 8 indicates the values of epsilon and objective function in each breakpoint by EC for sample 3.

Furthermore, sample 3 is also solved by the proposed NSGA II and the obtained Pareto solutions are demonstrated in Table 7. According to Table

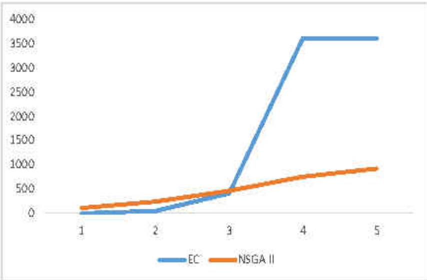

Figure 10: Solution time for NSGA II and EC (second)

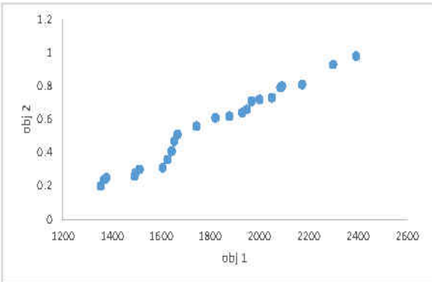

Figure 11: Obtained Pareto front for sample 5 by NSGA II (the first and second objectives)

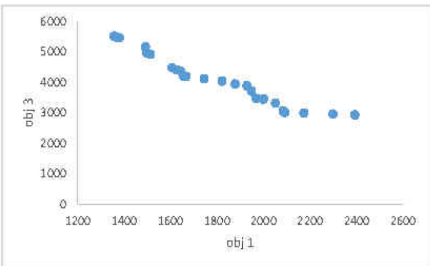

Figure 12: Obtained Pareto front for sample 5 by NSGA II (the first and third objectives)

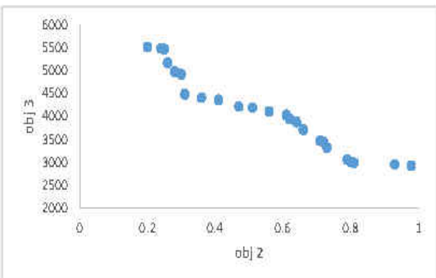

Figure 13: Obtained Pareto front for sample 5 by NSGA II (the second and third objectives)

9, NSGA II managed to find 9 Pareto solutions for sample 3. In Figures 3 to 5, the obtained Pareto solutions by EC and NSGA II for sample 3 (as an example of small size) are depicted. Figure 3 shows the Pareto front for the first and second objectives. With regards to the nature of the first objective function (cost) and second objective function (customers' satisfaction); it is clear that spending more cost has brought more satisfaction for customers. Figure 4 investigates the relation of the first and second objective. Due to Figure 4, by increasing the costs, the amount of destructive impact on the environment has reduced, which indicates the proper performance of the proposed model. In addition, in Figure 5, it is evident that by reducing the destructive environmental impact, customers' satisfaction level increases simultaneously.

On the other hand, according to Figures 3 to 5, obviously, the proposed Paretofront by NSGA II is largely close to the Pareto front derived from the exact EC approach. But for more accurate validation of the proposed algorithm and to identify the strength of NSGA II to find the Pareto optimal solutions, some indicators are utilized. Therefore, Mean Ideal Distance (MID), Space Metrics (SM) and Diversity Metrics (DM) are calculated [23] and by the use of Sum of Average Weighted (SAW) criteria the performance of NSGA II is examined. These values are calculated for the Pareto fronts of the two algorithms in all five samples are presented in Tables 10 to 14.

Regarding Tables 10 to 14, NSGA II algorithm performance is very close to the Epsilon constraints method in the small dimension (samples 1 through 3). In other words, it can provide near-optimal solutions in the absence of the exact method or its inefficiency. For instance, after sample 4 one, the EC method is not able to solve the samples in the time limitation of 3600 second. Thus, according to the suitable performance of NSGA II, it will be used for solving large size samples.

Figures 6 to 8 shows the values of MID, SM and DM for the both approaches. These Figures also emphasize the high efficiency of NSGA II, as it can be seen that its performance is largely close to the EC in the charts. Finally, Figure 9 shows the final and comprehensive comparison of these two methods by comparing the value of SAW of the approaches.

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Table 15 shows the runtime for solving the samples by each of two methods.

According to table 15, with the increase of the problem dimensions, the exact solution time has increased significantly such that after sample 3 on, EC is not capable of solving the samples in 3600 seconds time limitation. This is while the NSGA II can solve the samples in much shorter time. As a result, NSGA II has a proper efficiency in a suitable time. This can be followed in Figure 10.

All in all, due to the high performance of the proposed NSGA II, large samples of this study is solved by this algorithm. As an instance, optimal Pareto front for sample 5 is presented in Figures 11 to 13, which is obtained by means of NSGA II approach.

5 Conclusion

In this research, a multi-level supply chain was extended which includes production/recycle centers, distribution/inspection centers, customers and waste centers. To consider the environmental issues in the problem, green programming was studied in the problem to minimize the environmental impact of the supposed supply chain on the circumstance. To do so, a life-cycle based approach was applied, namely Eco-indicator 99. The presented model was initially non-linear which was turned into the linear model by means of operation research techniques. Moreover, due to the complexity of the proposed model and difficulties of solving the problem with exact methods, a NSGA II was designed. According to the results, the proposed NSGAII is a reliable method to find efficient Pareto frontiers in a reasonable and much shorter time. For further studies, some suggestions can be made and followed:
- Separating distribution and inspection centers as well as production and recycle centers, each of these facilities can exist in the model individually and by different features - Different modes of transportation can be considered. - Different prices can be specified for producing the finished product from raw materials and recyclable materials. - Some other critical objectives such as supply chain reliability and delays in deliveries can be added to the problem. - The problem can be studied in the form of multi-periodic way. - To improve the solution quality of NSGA II, heuristic methods can be presented for generating initial population of the algorithm

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