Resistive Economics
International Journal

The Open Access Journal of Resistive Economics (OAJRE)/
Volume 3, Number 1, 2015 Published Online January 01
E-ISSN: 2345-4954 http://oajre.ir

Original Article

Pages: 11-25

A Robust Optimization Model Based on The Green Supply Chain Network Design under Uncertainty of Future Economic Conditions

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Received: 2014/07/15 Revised: 2014/10/29 Accepted: 2014/12/10

ABSTRACT: In this paper, a robust programming model for forward and reverse green (environmental) supply chain network design is established under uncertainty of future economic conditions. Initially, a deterministic mixed integer programming model is provided, and then the robust model based on using a scenario-based approach (two-step) is developed. The network design problem, including assumptions such as: multi-product, multi-echelon and single-period. Considering a situation of instability of the economic situation, the uncertainty has been considered in a different way from previous papers. The unstable economic conditions affect the demand and prices of raw materials and fuel; as a result, demand and total costs of production and transportation parameters in the problem are uncertain. The Proposed model is also considers the release rate of greenhouse gas production and transportation systems in the chain and tries to reduce it by providing an objective function at a time. Besides, Manufacturing and distribution centers work in a dual-purpose manner; its advantages are saving money and reducing pollution resulted from shared transport equipment's and infrastructure.

KEYWORDS: Green Supply Chain, Network Design Problem, Environmental Impacts, Demand Uncertainty, Uncertainty of Cost, Robust Programming.

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1. INTRODUCTION

The strong competition in today's markets and the rapid changing of customers' preferences, together with the quick development of technology and globalization, have obliged organizations to work as members of a supply chain(SC) instead of operating as individual enterprises. The success of an SC depends on the synthesis and coordination of its all entities to shape an efficient network structure; an impressive network leads to cost-effective functions throughout the chain and helps it to react quickly in response to customers' needs. Lin and Wang (2011) define SC network design as a unified configuration of supply, manufacturing and demand side sub-systems. According to Simchi-Levi and Kaminsky (2004), SC network design is the most fundamental decision of SC management, which impresses all other decisions concerning an SC and has the widest effect on the chain's return on investment and its overall efficiency. SC network design deals with strategic decisions of the chain, such as the number, location and capacity of entities in each echelon of the chain.SC network design mainly deals with stra- tegic decisions that are usually long-term. Considering changes over time also has an important role in making suitable strategic decisions.

Tang (2006) considers two types of risks: (a) operational risks which are inherent uncertainties such as uncertain cus- tomer demands, uncertain supply, and uncertain costs, and (b) disruption risks which are major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, or economic crises such as currency fluctuations or strikes. There are many examples of disruption in real- world SC problems. During the recent mortal earthquake of Japan in 2011, the Toyota Motor Company had to lay off manufacture at its twelve assembly plants, leading to a production loss of 140,000 vehicles. The main cause of this problem was disruption of its chain's manufacturing subsystem. In addition to the impairment of production facilities and facto- ries throughout Japan, many Japanese companies had problems with the supply of required materials, fuel and power.

2. LITERATURE REVIEW

In a research, a probabilistic model for a two-stage multi-product multi-echelon supply chain network design under uncertainty of demand was presented (Tsiakis, 2001). The problem of designing the production - distribution system which includes three levels (i.e. factories-distribution centers and customer locations) is also examined in another study (Gofin, 2005) . An integrated plan for production and distribution the computer services and food service that are manufacture to order industries, in another article was developed. The service level is measured by the delivery time to customer and shipping cost are two important aspects for decision-making in these industries. The multi-criteria objective function balances between the shipping cost and the delivery time (Chen, 2005).

Gutierrez (1996) designed a robust model for a supply chain that are appropriate for a number of scenarios and for the others searches the solution that are close the optimum. MirHassani (2000) presented two modeling approach and solution techniques to solve the problem under uncertainty. The "wait and see" model employs scenario analysis that a decision-maker decides to open factories and distribution centers or close and adjust plant capacities. In this paper the Benders decomposition method is used to solve the model. Leung (2007) considered a robust optimization model for a multi-site production planning problem under different economic growth scenarios that every scenario has different probability. The works that has been done in designing green supply chain have been divided into four categories:

1. Green planning and producing (Luh, 2010), (Chu, 2009), (Brien, 1999)

2.Green distribution and transportation (Neto,2008) ,(Li,2008) ,(Ramadhin,2009), ,(Lakovou,2010)

3. Green warehousing (Emmet, 2010), (McKinnon, 2010)

4. Reverse Logistic (Hu, 2002), (Fleischmann, 1997)

Neto et al (2008) established a multi-objective function that balances between reducing costs and environmental impact. They also decreased the environmental impact (global warming, air toxins, chemicals and acids, nitrogen and solid waste). Ramudhin (2009) developed a comprehensive framework for a sustainable supply chain network design (eco) that is a multi-objective mixed integer linear programming model to select suppliers and contractors. Pishvaeee (2012) designed a two-objective model for the supply chain of syringe manufacturing plant and its reverse logistics with regarding to the environmental impact.

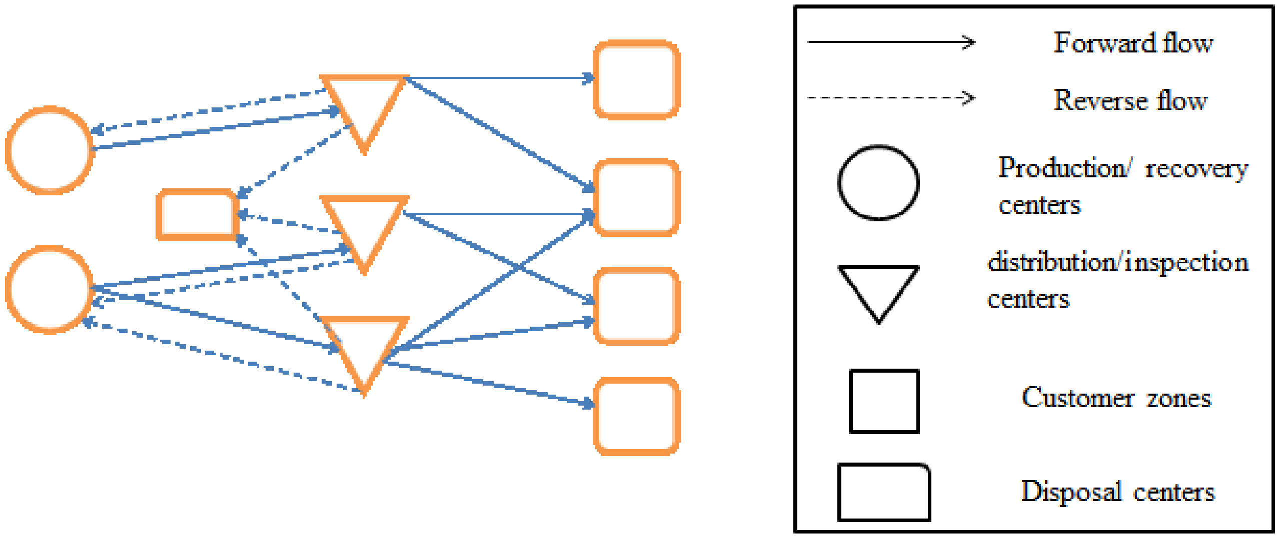
In the mentioned articles a model that also considers the environmental impact uncertainty and uncertainty of economic conditions of society, is not observed. That's why in this article these two issues are intended together. The problem is defined in section 3. The green deterministic mathematical model is presented in section 4. In section 5 the model is made robust and section 6 concludes this paper and presents directions for further research.

3. PROBLEM DESCRIPTION

The supply chain network that considered in this paper is a multi-product, multi echelon and single period logistic network including production, distribution, customer, inspection, recovery and disposal centers. A model for multi-product SC network design in markets under stochastic demands and with a disruption probability for manufacturers. Each customer of this chain orders its goods early before the beginning of each period, which is called its lead time. DCs receive orders of a customer and integrate them and pass them to the manufacturers with limited capacity. Produced goods of manufacturers are delivered to customers through DCs. DCs first inspect the products those products that are recyclable or restorable will be transferred to the manufacturers and the healthy products are packaged and labeled and delivered to the customers and the rest are transferred to disposal centers. There are some manufacturers with specific costs and reliability characteristics which can be selected to use as the facilities of the first echelon. The DCs and customers of this chain will be located in a number of pre-determined candidate locations. In this problem, we are to determine the optimal network structure of this chain in a manner which minimizes its whole costs and environmental impacts.

the total cost of the chain is the sum of the current investment costs to open the production/recovery and the inspection/distribution and production costs, processing costs, transportation costs and penalty costs for non-utilized capacities. At the environmental function, the total environmental impacts of production and processing at different stages and the impacts due to transportation should be minimized. Various decisions, namely the number, location, and capacity of entities in each tier and material/product flow throughout the network are made. Demand is considered as a specific distribution function because the real demand is uncertain. The uncertainty that related to costs should be interpreted by different scenarios in the solving phase. In this model, production and distribution centers are considered as hybrid places. The production center is also used as a place for recovering some recoverable products. The distribution centers are also used as inspection centers. The advantages of it include both cost savings and pollution reduction as results of sharing material handling equipment and infrastructures. (Pishvaee, 2009).

Figure 1. Sample Figure



4. Mathematic Model

This problem can be formulated as a mixed integer programming model. The following notation is used in the formulation of the ILN model.

Sets

P Set of products

I set of potential production/recovery center locations

J Set of potential hybrid inspection/distribution center locations

K Fixed location of customer zones

M Fixed locations for disposal

Parameters

d_{kp} Demand of customer zone k of product p

$s1_p$ Average disposal fraction of product p

$s2_p$ Average fraction of product p sent to recovery center i

f_i Fixed cost of opening production/recovery center i

g_j Fixed cost of opening inspection/distribution center j

c_{ijp} Shipping cost per unit of product p from production/recovery center i to hybrid

Inspection/distribution center j

a_{jkp} Shipping cost per unit of product p from hybrid inspection/distribution center j

To customer zone k

e_{jip} Shipping cost per unit of product p from hybrid inspection/distribution center j

To production/recovery center i

p_{jmp} Shipping cost per unit of product p from hybrid inspection/distribution center j

To disposal center m

p_{ip} Manufacturing/recovery cost per unit of product p at production /recovery center i

q_{jp} Processing cost per unit of product p at hybrid inspection/distribution center j

η_{mp} Disposal cost per unit of product p at disposal center m

Γip Penalty cost per unit of non utilized capacity at p

βjp Penalty cost per unit of non utilized capacity at hybrid inspection/distribution center j

αmp Penalty cost per unit of non utilized capacity at disposal center m

cw_{ip} Capacity of production for product p for production/recovery center i

cy_{jp} Capacity of handling product p in forward flow at hybrid inspection/distribution center j

cz_{mp} Capacity of handling scrapped product p at disposal center m

cwr_{ip} Capacity of recovery for product p for production/recovery center i

Green (environmental) Parameters

ei_{p}^{pro} : Environmental impact per production of one unit product

ei_{ijp}^{pd} : Environmental impact of shipping one unit of product from i to j

ei_{jkp}^{dc} : Environmental impact of shipping one unit of product from j to k

ei_{jip}^{ip}: Environmental impact of shipping one unit of product from j to i

ei_{jmp}^{id} : Environmental impact of shipping one unit of product from j to m

ei_{jp}^{in} : Environmental impact of inspecting one unit of product in inspection center j

ei_{ip}^{re} : Environmental impact of recovering one unit of product in recovery center i

ei_{mp}^{di} : Environmental impact of disposaling one unit of product in disposal center i

Variables

x_{ijp} Quantity of product p shipped from production/recovery center i to hybrid

Inspection/distribution center j

u_{jkp} Quantity of product p shipped from hybrid inspection/distribution center j

To customer zone k

v_{jip} Quantity of recoverable product p shipped from hybrid inspection/distribution center j

To production/recovery center i

T_{jmp} Quantity of scrapped product p shipped from hybrid inspection/distribution center j to

Disposal center m

w_i Binary variable indicates open or close for production center i

y_j Binary variable indicates open or close for distribution center j

The shipping costs between facilities are calculated by multiplying the transportation cost of one unit of product per unit of distance (e.g. one kilometer) by the corresponding shipping distance.

$$\text{Min } Z_1 = \sum_i f_i w_i + \sum_j g_{jy_j} + \sum_{i,j,p} (p_{ip} + c_{ijp}) x_{ijp} + \sum_{j,k,p} (q_{jp} + a_{jkp}) u_{jkp} + \sum_{i,j,p} (p_{ip} + e_{jip}) v_{jip} + \sum_{j,m,p} (\eta_{mp} + p_{jmp}) T_{jmp} + \sum_{m,p} \alpha_{mp} \left(cz_{mp} - \sum_j T_{jmp} \right) + \sum_{i,p} \tau_{ip} \left[\left(w_i cw_{ip} - \sum_j x_{ijp} \right) + \left(w_i cwr_{ip} - \sum_j v_{jip} \right) \right] + \sum_{j,p} \beta_{jp} \left(y_j cy_{jp} - \sum_k u_{jkp} \right) \quad (1)$$

$$Min\ Z_2 = \sum_{i,j,p}\left(ei_{ijp}^{pd} + ei_{p}^{pro}\right)x_{ijp} + \sum_{i,k,p}\left(ei_{jkp}^{dc} + ei_{jp}^{in}\right)u_{jkp} + \sum_{i,i,p}\left(ei_{jip}^{ip} + ei_{ip}^{re}\right)\imath + \sum_{j,m,p}\left(ei_{jmp}^{id} + ei_{mp}^{di}\right)T_{jmp} \quad (2)$$

$$\sum_{j} u_{jkp} \geq d_{kp} \quad \forall k \in K\ , \quad \forall p \in P \quad (3)$$

$$\sum_{i} x_{ijp} - \sum_{i,m}\left(v_{jip} + T_{jmp}\right) = \sum_{k} u_{jkp} \quad \forall j \in J\ , \quad \forall p \in P \quad (4)$$

$$\sum_{k} u_{jkp} - (1 - s1_p - s2_p)\sum_{i} x_{ijp} = 0 \quad \forall j \in J\ , \quad \forall p \in P \quad (5)$$

$$\sum_{m} T_{jmp} - s1_{\,p}\sum_{i} x_{ijp} = 0 \quad \forall j \in J\ , \quad \forall p \in P \quad (6)$$

$$\sum_{i} v_{jip} - s2_{\,p}\sum_{i} x_{ijp} = 0 \quad \forall j \in J\ , \quad \forall p \in P \quad (7)$$

$$\sum_{j} v_{jip} - \sum_{j} x_{ijp} \leq 0 \quad \forall i \in I\ , \quad \forall p \in P \quad (8)$$

$$\sum_{j} x_{ijp} \leq cw_{ip}w_i \quad \forall i \in I\ , \quad \forall p \in P \quad (9)$$

$$\sum_{i} x_{ijp} \leq cy_{jp} y_j \quad \forall j \in J \ , \quad \forall p \in P \tag{10}$$

$$\sum_{j} v_{jip} \leq cwr_{ip} w_i \quad \forall i \in I \ , \quad \forall p \in P \tag{11}$$

$$\sum_{j} T_{jmp} \leq cz_{mp} \quad \forall m \in M \ , \quad \forall p \in P \tag{12}$$

$$y_j, w_i \in \{0,1\} \ , \ \forall j \in J, \quad \forall i \in I \tag{13}$$

$$x_{ijp}, \ u_{jkp}, \ v_{jip}, \ T_{jmp} \geq 0 \ , \ \forall i \in I, \ \forall j \in J, \ \forall k \in K, \ \forall m \in M, \ \forall p \in P \tag{14}$$

Objective function (1) minimizes the total costs including fixed opening costs, transportation costs, processing costs and penalty costs for non utilized capacities. Objective function (2) minimizes the network environmental impacts of different supply chain network configurations including production, distribution, inspection, disposal and transportation. The Eco-indicator 99 method is used to estimate the total environmental impact of every stage. For doing this work, the life cycle should be defined. In this problem the life cycle stages include: (1) production (pro), (2) transportation from production centers to distribution centers (pd), (3) inspection (in), (4) transportation from distribution centers to customers (dc), (5) transportation from distribution centers to recovery centers (ip), (6) transportation from distribution centers to disposal centers (id), (7) recovery processing (re), (8) disposal processing (di).(Ministry of Housing)

Constraints (3) ensure that the demands of all customers are satisfied. Constraints (4)–(8) assure the flow balance at production/recovery and hybrid distribution–inspection centers in forward and reverse flows. Constraints (9)–(12) are capacity constraints on facilities. Finally, Constraints (13) and (14) enforce the binary and non-negativity restrictions on corresponding decision variables. In the past decade fluctuations in the prices of fuel and raw materials has created problems for manufacturers and it is expected that these uncertain conditions of the prices continue with the new economic conditions, leading to uncertainty in demand. Following this conditions for having a robust supply chain network against these fluctuations, a robust optimization model based on deterministic model will be presented in the next section.

4-ROBUST OPTIMIZATION MODEL

To develop the former model, the compact form of the proposed model can be stated as follows:

Min FY + cx

s.t. Ax ≥ d

$\mathrm{N}x = 0$

$\mathrm{M}x \leq 0$

$\mathrm{B}x \geq \mathrm{C}Y$

$Y \in \{0,1\}, x \in R$

The above vectors f, c, and d correspond to fixed opening costs, transportation, processing and penalty costs, demands and returns, respectively. The matrices A, B, C, M and N are coefficient matrices of the constraints. Also all binary decision variables are included into vector y and all the continuous decision variables are included into vector x.In this model we assume that the parameters of the demand and cost of production and shipping costs have uncertain nature. To model the problem under uncertainty, a scenario-based approach (two-step) is used in this article. Let Ω be the set of all possible scenarios that can happen in the future and θ a particular scenario. For a particular scenario the compact model can be stated as follows:

Min $fy + c_\theta x$

s.t. $\mathrm{A}x \geq d_\theta$

$\mathrm{N}_\theta x = 0$

$\mathrm{M}x \leq 0$

$\mathrm{B}x \geq \mathrm{C}y$

$Y \in \{0,1\}, x \in R$

If $\pi\theta$ denotes the probability of scenario θ then because θ is a finite number (number of scenarios) the expected value function becomes a summation on θ and the uncertain model for compact form can be formulated as follows:

Min $fy + \sum_\theta \pi_\theta c_\theta x_\theta$

s.t. $\mathrm{A}x_\theta \geq d_\theta$

$\mathrm{N}_\theta x_\theta = 0$

$\mathrm{M}x_\theta \leq 0$

$\mathrm{B}x_\theta \geq \mathrm{C}y$

$Y \in \{0,1\}, x_\theta \in R$

In this model, a series of decisions are Independent of the occurrence of scenarios and are determined before happening the scenarios. They are known as "Here and now" decisions and must decide about them now. The second stage decisions are dependent of the occurrence of scenarios and are determined after happening the scenarios. They are known as "Wait and see" decisions. For example, strategic decisions in supply chain network design, are costly and time-consuming decisions that cannot be changed by the occurrence of various scenarios and must be determined before they occur; But tactical decisions, such as the flow of goods between facilities has ability to change with changing the scenarios and can be changed after they occur. Therefore, supply chain network should be robust in such a way doesn't lead to excessive costs and infeasibility against all scenarios. The probability of scenarios is (πθ) and the amount of dependent parameters is determined based on past data (historical). In this model, indices, parameters and variables are as previously defined, but some of the parameters and variables that need correcting again, they are as follows:

Sets

Ω Set of potential scenarios $\theta \in \Omega$

Parameters

$d_{kp\theta}$ Demand of customer zone k of product p for scenario θ

$c_{ijp\theta}$ Shipping cost per unit of product p from production/recovery center i to hybrid Inspection/distribution center j for scenario θ

$a_{jkp\theta}$ Shipping cost per unit of product p from hybrid inspection/distribution center j to customer zone k for scenario θ

$e_{jip\theta}$ Shipping cost per unit of product p from hybrid inspection/distribution center j To production/recovery center i for scenario θ

$p_{jmp\theta}$ Shipping cost per unit of product p from hybrid inspection/distribution center j To disposal center m for scenario θ

$p_{ip\theta}$ Manufacturing/recovery cost per unit of product p at production /recovery center I for Scenario θ

π_{θ} Probability of scenario θ

Variables

$x_{ijp\theta}$ Quantity of product p shipped from production/recovery center i to hybrid Inspection/distribution center j in scenario θ

$u_{jkp\theta}$ Quantity of product p shipped from hybrid inspection/distribution center j

To customer zone k in scenario θ

$v_{jip\theta}$ Quantity of recoverable product p shipped from hybrid inspection/distribution center j

To production/recovery center in scenario θ

$T_{jmp\theta}$ Quantity of scrapped product p shipped from hybrid inspection/distribution center j to

Disposal center m in scenario θ

The Robust Model:

$$\begin{aligned}\text{Min } Z_1 &= \sum_i f_i w_i + \sum_j g_{jy_j} \\ &+ \sum_{i,j,p,\theta} \pi_\theta \left(p_{ip\theta} + c_{ijp\theta}\right) x_{ijp\theta} + \sum_{i,k,p,\theta} \pi_\theta \left(q_{jp} + a_{jkp\theta}\right) u_{jkp\theta} \\ &+ \sum_{i,j,p,\theta} \pi_\theta \left(p_{ip\theta} + e_{jip\theta}\right) v_{jip\theta} \\ &+ \sum_{j,m,p,\theta} \pi_\theta \left(\eta_{mp} + p_{jmp\theta}\right) T_{jmp\theta} + \sum_{m,p,\theta} \pi_\theta \alpha_{mp} \left(cz_{mp} - \sum_j T_{jmp\theta}\right) \\ &+ \sum_{i,p,\theta} \pi_\theta \tau_{ip} \left[\left(w_{ip} cw_{ip} - \sum_j x_{ijp\theta}\right) + \left(w_{ip} cwr_{ip} - \sum_j v_{jip\theta}\right)\right] \\ &+ \sum_{j,p,\theta} \pi_\theta \beta_{jp} \left(y_{jp} cy_{jp} - \sum_k u_{jkp\theta}\right)\end{aligned} \quad (1)$$

$$\begin{aligned}Min\ Z_2 &= \sum_{i,j,p,\theta} \pi_\theta\left(ei_{ijp}^{pd} + ei_p^{pro}\right) x_{ijp\theta} + \sum_{i,k,p,\theta} \pi_\theta\left(ei_{jkp}^{dc} + ei_{jp}^{in}\right) u_{jkp\theta} \\ &+ \sum_{i,i,p,\theta} \pi_\theta\left(ei_{jip}^{ip} + ei_{ip}^{re}\right) v_{jip\theta} + \sum_{j,m,p,\theta} \pi_\theta\left(ei_{jmp}^{id} + ei_{mp}^{di}\right) T_{jmp\theta}\end{aligned} \quad (2)$$

$$\sum_j u_{jkp\theta} \geq d_{kp\theta} \quad \forall k \in K, \quad \forall p \in P, \quad \theta \in \Omega \quad (3)$$

$$\sum_i x_{ijp\theta} - \sum_{i,m}\left(v_{jip\theta} + T_{jmp\theta}\right) = \sum_k u_{jkp\theta} \quad \forall j \in J, \quad \forall p \in P, \quad \theta \in \Omega \quad (4)$$

$$\sum_k u_{jkp\theta} - (1 - s1_p - s2_p) \sum_i x_{ijp\theta} = 0 \quad \forall j \in J, \quad \forall p \in P, \quad \theta \in \Omega \quad (5)$$

$$\sum_{m} T_{jmp\theta} - s1_{p} \sum_{i} x_{ijp\theta} = 0 \quad \forall j \in J\ , \quad \forall p \in P\ , \quad \theta \in \Omega \tag{6}$$

$$\sum_{i} v_{jip\theta} - s2_{p} \sum_{i} x_{ijp\theta} = 0 \quad \forall j \in J\ , \quad \forall p \in P\ , \theta \in \Omega \tag{7}$$

$$\sum_{j} v_{jip\theta} - \sum_{j} x_{ijp\theta} \leq 0 \quad \forall i \in I\ , \quad \forall p \in P\ , \ \theta \in \Omega \tag{8}$$

$$\sum_{j} x_{ijp\theta} \leq cw_{ip} w_{i} \quad \forall i \in I\ , \quad \forall p \in P\ , \ \theta \in \Omega \tag{9}$$

$$\sum_{i} x_{ijp\theta} \leq cy_{jp} y_{j} \quad \forall j \in J\ , \quad \forall p \in P\ , \ \theta \in \Omega \tag{10}$$

$$\sum_{j} v_{jip\theta} \leq cwr_{ip} w_{i} \quad \forall i \in I\ , \quad \forall p \in P\ , \ \theta \in \Omega \tag{11}$$

$$\sum_{j} T_{jmp\theta} \leq cz_{mp} \quad \forall m \in M\ , \ \forall p \in P\ , \ \theta \in \Omega \tag{12}$$

$$\sum_{j} T_{jmp\theta} \leq cz_{mp} \quad \forall m \in M\ , \ \forall p \in P\ , \ \theta \in \Omega \tag{13}$$

$$y_j, w_i \in \{0,1\}\ , \ \forall j \in J, \ \ \forall i \in I \tag{14}$$

$$x_{ijp\theta},\ u_{jkp\theta},\ v_{jip\theta},\ T_{jmp\theta} \geq 0\ , \ \forall i \in I,\ \forall j \in J,\ \forall k \in K,\ \forall m \in M,\ \forall p \in P\ , \ \theta \in \Omega \tag{15}$$

It is worth noting that the solution of the robust model is not the optimal solution for each scenario, due to the model is solved for all scenarios while in a mathematical model for each scenario, the obtained answer only considers the constraints of the same scenario and actually becomes a deterministic model. The defined Scenarios for robust model should represent the true picture of the future up to the model have a good performance in front of their occurrence. In real-world the different approaches are used to generate scenarios and determine the probability of occurrence of them that illustrate the importance of scenarios. the assumptions used to generate the scenarios should be consistent, plausible and important up to all appropriate factors in making scenarios be considered.(Birge,1997)

5-CONCLUSIONS

Environmental issues have become a critical topic in recent years. The design of the environmental supply chain is a very significant and complex decision that forms in a dynamic and uncertain environment. To cope with this issue, this paper proposes a multi-objective robust mathematical programming model with the uncertainty of future economic conditions. Despite the past research works, this model integrates the design of both forward and reverse supply chains besides considering the environmental impacts in the whole supply chain. Many possible future research directions are that the model can be formulated as a multi-period supply chain. Also the other techniques for making robust can be used such as Mulvey method. To make the model green can also add the multiple constraints such as maximum allowable contamination in the manufacturing sector and the maximum allowable contamination in the transport sector. Considering the social aspects in supply chain optimization models are also interesting topics for researchers.

ACKNOWLEDGMENTS

None.

ETHICAL CONSIDERATION

Authenticity of the texts, honesty and fidelity has been observed.

AUTHOR CONTRIBUTIONS

Planning and writing of the manuscript was done by the authors.

CONFLICT OF INTEREST

Author/s confirmed no conflict of interest.

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