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Optimization of the green supply chain management considering uncertainty in consequence of risk (Case Study: Golsam Company)

Abbasali Jafari-Nodoushan[1*], Mohammad Bagher Fakhrzad[2], Hamed Maleki[2]

[1]*Department of Industrial Engineering, Faculty of Engineering, Meybod University, Meybod, Iran*
[2]*Department of Industrial Engineering, Faculty of Engineering, Yazd University, Yazd, Iran*

a.jafari@meybod.ac.ir, mfakhrzad@yazd.ac.ir

Abstract

Regulation changes affect pollutions tax of industry, labor union problems such as insurance and retirement health plan. Although environmental and economic performance is significant, safety and inherent risk are important to the supply chain. The paper proposes a multi-objective optimization model to minimize the inherent risk, carbon emissions, and economic cost. There is uncertainty in the risk consequence of facilities and transportation accidents between facilities, whose distribution function is unknown. Therefore, robust optimization is applied to resolve the uncertainty. The weighted sum utility method also combines some functions having different measurement units. Three functions of risk, carbon emissions, and cost are converted into one. The paper presents a case study to prove the proposed model and discusses constraints for more improvement.

Keywords: Green supply chain management, uncertainty, consequence of risk, robust optimization

1-Introduction

While the surrounding resources are significantly depleting, the contradiction between economic growth and environmental protection has attracted the attention of supply chain management researchers. Innovative and creative management of the sustainable supply chain to minimize the environmental impact that the suppliers impose on customers is called Green Supply Chain Management (GSCM), discussed by many stakeholders (Saffarian et al., 2021). Compared with supply chain management, green supply chain management mainly focuses on the green development strategy. At the same time, it manages the external environmental pressures and internal motivation for innovation (Ebrahimi and Hosseini-Motlagh, 2018). In order to achieve a win-win situation, Green Supply Chain Management seeks ways that not only boost business profits but also generate environmental benefits. In addition, green supply chain management aims to reduce waste by encouraging its transformation into valuable products to reduce the consumption of raw materials and energy and prevent huge waste in the environment. As a specific tool for implementing GSCM, cleaner production aims to reduce the use of toxic substances and waste and reduce the inconsistent impact of the entire supply chain (Mohtashami et al., 2020). Therefore, many materials formerly used in the production of products may be considered dangerous in any phase of the life cycle (from extraction to disposal). The

*Corresponding author
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substance's severity or physical or chemical characteristics may pose a potential risk to human health or the environment. The potential risk management of hazardous materials may significantly impact supply chain operations and may lead to business loss, environmental pollution, and even irreparable injuries. In such a condition, to improve the social performance of the GSCM, the potential risk associated with the supply chain, which includes hazardous materials, should be considered.

Climate change is identified as a critical factor strongly affected by the performance of GSCM, and it may lead to severe uncertainty in terms of public acceptance of various products (Oliveira et al., 2018). For example, customers' preferences may be affected by the information represented on the product label, especially those aware of climate change. Carbon emission management has attracted the attention of many upstream and downstream companies in the supply chain, so they are moving towards a business model of carbon emission reduction. Changes in state laws occur due to the changes in tariffs determined by the Environmental Protection Agency, pollution taxes imposed on industries, issues related to the labor unions in the industry, insurance, and other similar factors (Tian and Sarkis, 2020). But in a state of supply chain management, companies seek profit rather than risk control and reduce carbon emissions due to additional and high costs of such efforts to protect the environment. Therefore, finding out how environmental risk and carbon emissions can be reduced without affecting business sustainability can be a crucial challenge facing the GSCM advocates. The current paper proposes a multi-objective optimization model. It minimizes the environmental risk of the supply chain that derives from the use of hazardous materials, carbon emissions, the risk of government laws, and economic costs. The optimization model is expected to control environmental risk and government regulations and reduce carbon emissions regarding GSCM. It is also expected to inform the stakeholders and promote sustainable development.

Since the 1990s, the optimization of supply chain management has considered environmental issues such as rehabilitation of environmental capital, redesigning supply chain network, green coordination among upstream and downstream companies, and the green initiative that attracted increasing attention.

Rehabilitation of environmental capital encourages waste reduction and promotes reuse and recycling by reverse logistics and reproduction tools. Sheu et al. (2005) proposed a multi-objective linear programming model to maximize the net profit of integrated logistics and reverse logistics of the used products. The results showed that the net profit increased by 21% compared to the current operating performance. In addition, Yang et al. (2009) developed the closed-loop supply chain network, including raw material suppliers, manufacturers, retailers, customers, and recycling centers. The inequality method was used to obtain the optimal recycling ratio of the used products and the conversion rate of recycled products for reusable materials in the supply chain network. An approach similar to the one used by Qiang et al. (2013) addressed the point that customers benefit from lower prices in the market when the recycling rate increases. Kim et al. (2014) developed a model based on the probabilistic model of the return lead time for the items degradation products where the lead time is correlated with the likelihood of delay in returning items to the suppliers. In addition, delayed orders lead to an increase in production and distribution costs. Gholizadeh, H., Fazlollahtabar (2020) considered a closed-loop green supply chain under uncertainty in the melting industry. They used the hybrid method based on a genetic algorithm and robust optimization.

The internal redesign of the supply chain network is mainly based on implementing cleaner production in companies. Shahedi et al. (2021) addressed a new bi-objective mixed-integer linear programming model to design a closed-loop supply chain tire remanufacturing network considering environmental issues under conditions of uncertainty. They used the ϵ-constraint method and Grasshopper Optimization Algorithm (GOA) to solve the problem. Wang et al. (2011) developed a multi-objective model for optimizing environmental investing decisions using mixed-integer programming. They defined the best hierarchy of environmental protection to minimize the economic costs and carbon emissions. A similar study was carried out by Abdallah et al. (2012), where they developed a mixed integer programming model to minimize carbon emissions in the supply chain via green procurement tools. Mallidis et al. (2012) developed a strategic decision-making model to optimize the design of the input and transportation practices. This model showed that the common use of transportation operations has effectively reduced carbon dioxide emissions and specific rains. Considering operational and social costs, Tseng and Hung (2014) proposed a strategic decision-making model that causes carbon emissions. This approach indicates that the social cost rate is dependent upon carbon emissions.

Green coordination among upstream and downstream companies includes green choice and purchase for suppliers. Zhao et al. (2012a) used game theory to select optimal strategies for suppliers in the supply chain to reduce potential risk and carbon emissions. Cost and profit are identified as the main factors influencing the implementation of the chosen strategy. Xie (2015) developed a model for examining how to adjust the level of the saved energy by policymakers who have an impact on energy saving and retailer sales prices. Xie's work showed that the decentralized chain should present a threshold value for energy storage while considering the producer's interest. Wu & Barens (2016) developed a model integrated with ANP and MOP to select the appropriate partner for the development of the green supply chain while considering the four clusters of the ANP network (cost, pollution control, quality, resource consumption) as a benchmark for assessing the economic efficiency of the partners.

Given the green initiative of customers, Liu et al. (2012) focused on the relationship between customers' perceived environmental awareness and the intensity of competition among the members of the green supply chain. A Stackelberg two-stage game model has been used to investigate the interaction between different chain players to determine the other supply chain network structures. In this attempt, retailers and manufacturers in an eco-friendly operation intended to take advantage of double environmental awareness of the customers. Coskun et al. (2016) proposed an ideal planning model for redesigning the supply chain network based on the customers' green expectations. When the green consumers' section expands, retailers are aligned with suppliers to redesign the supply chain to fit customers' expectations. A similar study was carried out by Ghosh et al. (2015), who further confirmed that green customer markets provided better opportunities for supply chain stakeholders to initiate green initiatives. In addition, a common contract from cost type may lead to a greener supply chain network.

Many previous studies have developed optimization models that maximize economic efficiency and profit while having a less environmental impact on supply chain networks. Therefore, many of the materials produced in the supply chain have been considered as hazards degree, although they have been poorly managed. Therefore, while environmental and economic performance is important, the security and potential risks posed by the supply chain are also important (Zhao et al.). Apart from that, many previous studies have barely discussed the integration of environmental risk management and government regulations and reduction in carbon emissions in management performance. This paper addresses the development of the model provided by Zhao et al. and considers the potential risk of hazardous substances, carbon emissions, and total economic costs, including the risk of government laws.

The rest of the paper is organized as follows. Section 2 establishes the model formulation, and section 3 addresses the solution method. The case study is presented in section 4. The computational experiments are performed in section 5. Section 6 will present the conclusions and future research.

2-Model formulation

2-1- Model hypotheses

The proposed supply chain network consists of several raw material suppliers, a key manufacturer, and distribution centers. This proposed network considers the common disposal centers (landfill, burning furnaces, and recycling centers) in a complete life cycle, as shown in figure 1. In order to simplify the supply chain, the authors proposed the following assumptions:

1. The position of raw material suppliers, key manufacturer and distribution centers is presented, and their capacities and transportation routes are identified.
2. The supply chain is assumed to be a single supply chain in which the facilities are not stored as inventory. Regardless of the type of product, one unit of product needs one unit of production capacity.
3. There is no difference between remanufactured products and manufactured products.
4. Suppliers are considered as inputs without involving market competition, product quality dispersion, possible collaboration, etc.

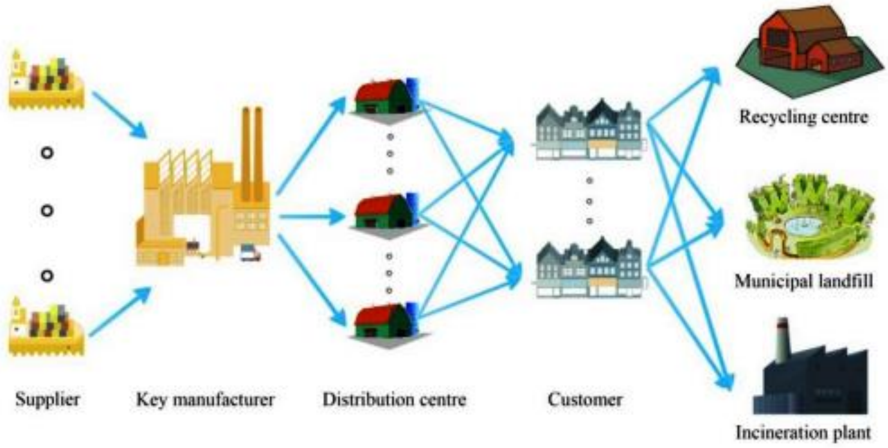

Fig 1. A suggested supply chain network

2-2- Definitions and labeling parameters

In this section, several labeled parameters and definitions are introduced. The corresponding notations of the proposed supply chain network are as follows:

Indices:

s	set of suppliers
k	key manufacturer
d	set of distribution centers
c	set of potential consumers
r	recycling center
i	incineration plant
la	municipal landfill
p	type of risk

Parameters:

dem_k	raw materials demand of key manufacturer k (kg)
dem_c	the demand of consumer c, (kg)
cr_s	cost of purchasing raw materials from supplier s
$c_{ff'}$	unit transportation cost from faculty f to facility f', f and $f' \in \{s,k,d,c,r,i,la\}$
fc_f	fixed cost of operating facility $f \in \{s,d,c,r,i,la\}$
cp_f	processing cost per unit product in the facility $f \in \{s,d,c,r,i,la\}$
ca_f	the capacity of the facility $f \in \{s,d,c,r,i,la\}$
ca_t	capacity of transportation
Inv_m	investment for risk control when the risk level is m
Inv_l	investment for carbon emissions reduction when the emission level is l

$Prob_m$ probability of risk when the level is *m*

$Prob_f$ the probability of risk in facility f

$Prob_{ff'}$ the probability of transportation risk from f to f'

N_{fp} the consequence of the p type of risk in facility f, million Yuan

$N_{ff'p}$ the transportation accident resulted from the p type of risk from f to f', million Yuan

L_{ij} distance between facility f ϵ{s,k,d,c} and f' ϵ {k,d,c,r,i,la}, (km)

EM_l emission factor when the emission level is *l*, kgCO2/kg

EM_f the emission factor of facility f , kgCO2/kg

$EM_{ff'}$ transportation emission factor from f to f', kgCO2/kg

η waste generation rate

ξ incineration ratio of unrecyclable waste

ω landfilling ratio

MP scaling parameter

RL regulation level

μ the recycling rate of the recycling center

g Government reward

Decision variables:

$$x_s = \begin{cases} 1 & if\ supplier\ s\ is\ selected \\ 0 & otherwise \end{cases}$$

$$x_d = \begin{cases} 1 & if\ distribution\ center\ d\ is\ selected \\ 0 & otherwise \end{cases}$$

$$x_r = \begin{cases} 1 & if\ recycling\ center\ r\ is\ operated \\ 0 & otherwise \end{cases}$$

$$x_i = \begin{cases} 1 & if\ incineration\ plant\ i\ is\ operated \\ 0 & otherwise \end{cases}$$

$$x_{la} = \begin{cases} 1 & if\ landfil\ la\ is\ operated \\ 0 & otherwise \end{cases}$$

$$y_m = \begin{cases} 1 & if\ risk\ level\ m\ is\ selected\ when\ taking\ risk\ control\ measures \\ 0 & otherwise \end{cases}$$

$$z_l = \begin{cases} 1 & if\ carbon\ emissions\ level\ l\ is\ selected\ when\ taking\ emissions\ reduction\ measures \\ 0 & otherwise \end{cases}$$

x_{sk} the amount of products flowing from the supplier *s* to the key manufacturer

x_{kd} the amount of products flowing from the key manufacturer to the distribution center d

x_{dc} the amount of products flowing from the distribution center *d* to the customer *c*

x_{cr} the amount of products flowing from the customer *c* to the recycling center *r*

x_{ci} the amount of products flowing from the customer *c* to the incineration plant *i*

x_{cla} the amount of products flowing from the customer *c* to the municipal landfill *la*

2-3- The objective function

As presented below, the optimization model minimizes the potential risk of hazardous materials, including government regulations, carbon emissions, and overall economic cost.

2-3-1- Minimize the potential risk

The potential risk of the supply chain of hazardous materials includes three sets of risks: the risk of incidents, environmental pollution, and capital loss, which is assumed as probable incident multiplied by related probability in the risk scenario. In particular, the risk of accidents, environmental pollution, and capital loss are defined in the form of incidents, air and soil pollution, and economic loss, respectively. The value R_i is the risk of facility i, which is calculated as follows.

$$R_i = Prob_i \sum_{p=1}^{3} N_{ip} + \mathrm{s.d.}Prob_i \sum_{p=1}^{3} N_{ip} \tag{1}$$

The value $Prob_i$ is the likelihood of a failure in facility i, N_{ip} is a p-type event risk, including accidents, loss of capital, and environmental pollution, and s and d are levels of rules and scale parameters.
The transportation risk during the supply chain operation is as follows:

$$R_{ij} = Prob_{ij} \sum_{p=1}^{3} N_{ijp} \tag{2}$$

$$Prob_{ij} = Ar_{ij} L_{ij} Q_{ij} \tag{3}$$

Where $Prob_{ij}$ is the risk probability of the facility i to j, L_{ij} is route length, Q_{ij} is the amount of transported products, and Ar_{ij} is the incident rate of the freight vehicles.

The objective function for minimizing the potential risk is as follows:

$$OBJ1 = \min(R_f + R_t) \tag{4}$$

$$\begin{aligned} R_f = & \sum_s \mathrm{Pr}ob_s x_s \sum_{p=1}^{3} N_{sp} + MP.RL.\sum_m \mathrm{Pr}ob_m \sum_{p=1}^{3} N_{kp} + \sum_l \mathrm{Pr}ob_m y_m \sum_{p=1}^{3} N_{kp} + \sum_d \mathrm{Pr}ob_d x_d \sum_{p=1}^{3} N_{dp} \\ & + \sum_r \mathrm{Pr}ob_r x_r \sum_{p=1}^{3} N_{rp} + \sum_i \mathrm{Pr}ob_i x_i \sum_{p=1}^{3} N_{ip} + \sum_{la} \mathrm{Pr}ob_{la} x_{la} \sum_{p=1}^{3} N_{lap} \end{aligned} \tag{5}$$

$$\begin{aligned} R_t = & \sum_s x_{sk} Ar_{sk} L_{sk} \sum_{p=1}^{3} N_{skp} + \sum_d x_{kd} Ar_{kd} L_{kd} \sum_{p=1}^{3} N_{kdp} + \sum_d \sum_c x_{dc} Ar_{dc} L_{dc} \sum_{p=1}^{3} N_{dcp} \\ & + \sum_c x_{cr} Ar_{cr} L_{cr} \sum_{p=1}^{3} N_{crp} + \sum_c x_{ci} Ar_{ci} L_{ci} \sum_{p=1}^{3} N_{cip} + \sum_c x_{cla} Ar_{cla} L_{cla} \sum_{p=1}^{3} N_{cla} \end{aligned} \tag{6}$$

Where R_f measures the risk for all facilities, from upstream suppliers to the disposal center, while R_t estimates shipping risk based on the flow of products from different nodes.

2-3-2- Minimize the carbon emissions

The life cycle, based on the carbon emission of the supply chain, will be calculated as follows.

$$CE = \sum_i Q_i EM_i \tag{7}$$

Where Q_i is the i[th] activity contributing to carbon emission, for example, manufacturing, dispose, etc. The value of EM_i is emission factor for the i[th] activity. Therefore, the objective function for minimizing carbon emission will be as follows:

$$OBJ2 = \min(CE_f + CE_t) \tag{8}$$

$$CE_f = \sum_s x_{sk} EM_s + \sum_l EM_l z_l dem_k + \sum_d \sum_c x_{dc} EM_c + \sum_c x_{cr} EM_r + \sum_c x_{ci} EM_i + \sum_c x_{cla} EM_{la} \tag{9}$$

$$CE_t = \sum_s x_{sk} EM_{sk} L_{sk} + \sum_d x_{kd} EM_{kd} L_{kd} + \sum_d \sum_c x_{dc} EM_{dc} L_{dc} + \sum_c x_{cr} EM_{cr} L_{cr} + \sum_c x_{ci} EM_{ci} L_{ci} + \sum_c x_{cla} EM_{cla} L_{cla} \tag{10}$$

Where CE_f is the carbon emission for all facilities in the supply chain, and CE_t is the carbon emission resulting from transportation, based on transportation distances.

2-3-3- Minimizing total economic costs

In this study, the overall cost of the supply chain not only includes the cost of manufacturing, transporting, and disposing of wastes but also covers the cost paid to reduce potential risk and carbon emissions, as is shown below:

$$OBJ3 = \min(FC + RC + MC + DC + TC + \sum_m Inv_m y_m + \sum_l Inv_l z_l - g) \tag{11}$$

$$FC = \sum_s fc_s x_s + \sum_d fc_d x_d + fc_r x_r + fc_i x_i + fc_{la} x_{la} \tag{12}$$

$$RC = \sum_s x_{sk} cr_s \tag{13}$$

$$MC = \sum_s x_{sk} cp_s + \sum_d x_{kd} cp_d \tag{14}$$

$$DC = \sum_c x_{cr} cp_r + \sum_c x_{ci} cp_i + \sum_c x_{cla} cp_{la} \tag{15}$$

$$TC = \sum_s x_{sk} c_{sk} L_{sk} + \sum_d x_{kd} c_{kd} L_{kd} + \sum_d \sum_c x_{dc} c_{dc} L_{dc} + \sum_c x_{cr} c_{cr} L_{cr} + \sum_c x_{ci} c_{ci} L_{ci} + \sum_c x_{cla} c_{cla} L_{cla} \tag{16}$$

Where FC is the fixed cost based on facility operation and RC is the cost of purchasing raw materials. Also, MC is defined as the cost of raw material extraction and manufacturing products. DC and TC are the waste disposal costs and the shipping cost, respectively. The investment for risk control and reducing carbon emission is $\sum_m Inv_m y_m$ and $\sum_l Inv_l z_l$, respectively.

2-4- Constraints

Several general constraints which are considered in the optimization model based on decision-making variables, including materials balancing constraints, capacity constraints, and variable decision-making constraints, are proposed as follows:

2-4-1- Mass balance constraints

Constraint 17 assures the raw materials demand for the key manufacturer. Constraints 18 to 20 are defined for products provided by the key manufacturer equal to the demand of potential customers and introduce the products flowing from the key manufacturer, which are equal to the incomes of the distribution centers. The constraints 21 to 23 ensure the mass balance of created and recycled wastes.

$$\sum_s x_{sk} = dem_k \quad \forall k \tag{17}$$

$$\sum_d x_{kd} = \sum_c dem_c \tag{18}$$

$$x_{kd} = \sum_c x_{dc} \quad \forall d \tag{19}$$

$$dem_c = \sum_d x_{dc} \quad \forall c \tag{20}$$

$$x_{cr} = dem_c \times \eta \times \mu \forall c \tag{21}$$

$$x_{ci} = dem_c \times \eta \times (1-\mu) \times \xi \quad \forall c \tag{22}$$

$$x_{cla} = dem_c \times \eta \times (1-\mu) \times \omega \quad \forall c \tag{23}$$

2-4-2- Capacity constraints

The constraints 24 to 27 demonstrate the capacity range in each facility which is less than the designed capacity. Constraint 28 ensures the shipped products which cannot exceed the shipping capacity.

$$x_{sk} \le ca_s x_s \forall s \tag{24}$$

$$\sum_d x_{kd} \le ca_k \tag{25}$$

$$\sum_d x_{dc} \le ca_d x_d \forall d \tag{26}$$

$$\sum_c dem_c \eta \mu \le ca_r x_r \tag{27}$$

$$x_{ff'} \le ca_{ff'} \tag{28}$$

2-4-3- Range constraints

Constraints 29 to 31 define the range of lower production capacity, and constraints 32 and 33 introduce decision variables x_{la}, x_i, x_r, x_d, x_s, which are binary, and $x_{ff'}$ where is not negative. Constraint 34 introduces z_l, y_m, which are binary. Constraint 35 defines μ the recycling rate, which is in the range of [0, 1]. The constraints 36 and 37 indicate government reward constraints.

$$x_s \le x_{sk} \quad \forall s \tag{29}$$

$$x_d \le \sum_c x_{dc} \quad \forall d \tag{30}$$

$$x_r \le \sum_c dem_c \eta \mu \tag{31}$$

$$x_s, x_d, x_r, x_i, x_{la} \in \{0,1\} \tag{32}$$

$$x_{ff'} \ge 0 \tag{33}$$

$$y_m, z_l \in \{0,1\}, m \in \{1,...,a\}, l \in \{1,...,b\}, a, b \in Z \tag{34}$$

$\mu \in [0,1]$ (35)

$g \leq \sum Inv_m y_m$ (36)

$g \geq 0$ (37)

3- Solution method

3-1- A robust optimization approach

This paper relies heavily on robust optimization tools developed by Bertsimas and Sim (2004) for the linear programming problem. Given the data uncertainty, the following problem is considered.

$$\min\ c'x : Ax \leq b,\ \ l \leq x \leq u \tag{38}$$

It is assumed that there is uncertainty in matrix A:

$$Let\ A = \{A \in R^{m\times n} | a_{ij} \in [\bar{a}_{ij} - \hat{a}_{ij}, \bar{a}_{ij} + \hat{a}_{ij}]\ \forall i,j\} \tag{39}$$

The robust problem will be formulated as follows.

$$\begin{aligned} &\min c'x \\ &s.t.\ \ Ax \leq b,\ \ \forall A \in A \\ &l \leq x \leq u \end{aligned} \tag{40}$$

Theorem 1 (Bertsimas and Sim): The uncertain linear programming problem has a linear and robust counterpart:

$$\begin{aligned} &\min c'x \\ &s.t.\ \sum_j \bar{a}_{ij}x_j + z_i\Gamma_i + \sum_{j:(i,j)\epsilon J} p_{ij} \leq b_i\ \ ,\forall i \\ &z_i + p_{ij} \geq \hat{a}_{ij}y_j\ \ \ ,\forall (i,j) \in J \\ &-y_j \leq x_j \leq y_j \\ &l_j \leq x_j \leq u_j \\ &p_{ij} \geq 0,\ z_i \geq 0\ , y_j \geq 0 \end{aligned} \tag{41}$$

Γ is a parameter that controls the degree of conservatism. Therefore, the robust counterpart of the same class is a nominal problem, that is, a linear programming problem. This approach has an excellent feature since standard optimization packages can easily solve linear programming problems. In addition, if some variables are limited to integers in the original problem (40), the robust counterpart (41) retains the same properties, so that the robust counterpart of a mixed integer programming problem is an integer programming problem.

As discussed earlier in the research, the proposed model and cost-cutting and carbon-emission reduction seek to reduce supply chain risks. We know that in the real world, the factors creating and exacerbating the risks are diverse, and the number of these factors is huge, which justifies uncertainty about the risks of the supply chain. In this model, the event risk parameter and the amount of transportation events resulting from risk are uncertain where are presented as follows.

Uncertain parameters:

$\bar{N}_{sp}$ The certain part of the p-type risk event in facility s

$\bar{N}_{kp}$ The certain part of the p-type risk event in facility k

$\overline{N}_{dp}$ The certain part of the p-type risk event in facility c

$\overline{N}_{rp}$ The certain part of the p-type risk event in facility r

$\overline{N}_{ip}$ The certain part of the p-type risk event in facility i

$\overline{N}_{lap}$ The certain part of the p-type risk event in the facility *la*

$\overline{N}_{skp}$ The certain part of the transportation event from s to k resulted from a p-type risk.

$\overline{N}_{kdp}$ The certain part of the transportation event from k to d resulted from a p-type risk.

$\overline{N}_{dcp}$ The certain part of the transportation event from d to c resulted from a p-type risk.

$\overline{N}_{crp}$ The certain part of the transportation event from c to r resulted from a p-type risk.

$\overline{N}_{cip}$ The certain part of the transportation event from c to *i* resulted from a p-type risk.

$\overline{N}_{clap}$ The certain part of the transportation event from c to la resulted from a p-type risk.

$\widehat{N}_{sp}$ The uncertain part of a p-type risk event in facility s

$\widehat{N}_{kp}$ The uncertain part of a p-type risk event in facility k

$\widehat{N}_{dp}$ The uncertain part of a p-type risk event in facility d

$\widehat{N}_{rp}$ The uncertain part of a p-type risk event in facility r

$\widehat{N}_{ip}$ The uncertain part of a p-type risk event in facility i

$\widehat{N}_{lap}$ The uncertain part of a p-type risk event in facility la

$\widehat{N}_{skp}$ The uncertain part of the certain part of the transportation event from s to k resulted from p-type risk.

$\widehat{N}_{kdp}$ The uncertain part of the certain part of the transportation event from k to d resulted from p-type risk.

$\widehat{N}_{dcp}$ The uncertain part of the certain part of the transportation event from d to c resulted from p-type risk.

$\widehat{N}_{crp}$ The uncertain part of the certain part of the transportation event from c to r resulted from p-type risk.

$\widehat{N}_{cip}$ The uncertain part of the certain part of transportation event from c to i resulted from p-type risk.

$\widehat{N}_{clap}$ The uncertain part of the certain part of transportation event from c to la resulted from p-type risk.

Uncertain decision variables:

p_{sp}^{1} Variable related to uncertainty in $\widehat{Nsp}_{sp}$

p_{kp}^{2} Variable related to uncertainty in $\widehat{Nkp}_{kp}$

p_{dp}^{3} Variable related to uncertainty in $\widehat{Ndp}_{dp}$

p_{rp}^{4} Variable related to uncertainty in $\widehat{Nrp}_{rp}$

p_{ip}^{5} Variable related to uncertainty in $\widehat{Nkp}_{ip}$

p_{lap}^{6} Variable related to uncertainty in $\widehat{Ndp}_{lap}$

p_{skp}^{7} Variable related to uncertainty in $\widehat{Nskp}_{skp}$

p_{kdp}^{8} Variable related to uncertainty in $\widehat{Nkdp}_{kdp}$

p_{dcp}^{9} Variable related to uncertainty in $\widehat{Ndcp}_{dcp}$

p_{crp}^{10} Variable related to uncertainty in $\widehat{Ncrp}_{crp}$

p_{cip}^{11} Variable related to uncertainty in $\widehat{Ncip}_{cip}$

p_{clap}^{12} Variable related to uncertainty in $\widehat{Nclap}_{clap}$

Z The variable related to uncertainty in the objective function (with the same number of the expressions including uncertainty)

As stated above, the first objective function was formulated as follows.

$$
\begin{aligned}
MinOBJ1 = & \sum_{s} Prob_{s} \sum_{p=1}^{3} N_{sp} + s.d.\sum_{m} Prob_{m} \sum_{p=1}^{3} N_{kp} + \sum_{m} Prob_{m} y_{m} \sum_{p=1}^{3} N_{kp} + \sum_{d} Prob_{d} \sum_{p=1}^{3} N_{dp} \\
& + \sum_{c} Prob_{c} \sum_{p=1}^{3} N_{cp} + Prob_{r} \sum_{p=1}^{3} N_{rp} + Prob_{i} \sum_{p=1}^{3} N_{ip} + Prob_{la} \sum_{p=1}^{3} N_{lap} \\
& + \sum_{s} x_{sk} Ar_{sk} L_{sk} \sum_{p=1}^{3} N_{skp} + \sum_{d} x_{kd} Ar_{kd} L_{kd} \sum_{p=1}^{3} N_{kdp} + \sum_{d}\sum_{c} x_{dc} Ar_{dc} L_{dc} \sum_{p=1}^{3} N_{dcp} \\
& + \sum_{c} x_{cr} Ar_{cr} L_{cr} \sum_{p=1}^{3} N_{crp} + \sum_{c} x_{ci} Ar_{ci} L_{ci} \sum_{p=1}^{3} N_{cip} + \sum_{c} x_{cla} Ar_{cla} L_{cla} \sum_{p=1}^{3} N_{clap}
\end{aligned}
\tag{42}
$$

In order to affirm the objective function, at first, the objective function was turned into a constraint; then, according to the Bertsimas and Sim model, the following objective functions and constraints will obtain.

$$
MinOBJ1 = f \tag{43}
$$

Subject to

$$
\begin{aligned}
& \sum_{s} \mathrm{Pr}ob_{s}\, \mathrm{x}_{s} \sum_{p=1}^{3} \overline{N}_{sp} + s.d.\sum_{m} \mathrm{Pr}ob_{m} y_{m} \sum_{p=1}^{3} \overline{N}_{kp} + \sum_{m} \mathrm{Pr}ob_{m} y_{m} \sum_{p=1}^{3} \overline{N}_{kp} + \sum_{d} \mathrm{Pr}ob_{d}\, \mathrm{x}_{d} \sum_{p=1}^{3} \overline{N}_{dp} \\
& + \sum_{r} \mathrm{Pr}ob_{r} x_{r} \sum_{p=1}^{3} \overline{N}_{rp} + \sum_{i} \mathrm{Pr}ob_{i} x_{i} \sum_{p=1}^{3} \overline{N}_{ip} + \sum_{la} \mathrm{Pr}ob_{la} x_{la} \sum_{p=1}^{3} \overline{N}_{lap} + \sum_{s} x_{sk} Ar_{sk} L_{sk} \sum_{p=1}^{3} \overline{N}_{skp} \\
& + \sum_{d} x_{kd} Ar_{kd} L_{kd} \sum_{p=1}^{3} \overline{N}_{kdp} + \sum_{d}\sum_{c} x_{dc} Ar_{dc} L_{dc} \sum_{p=1}^{3} \overline{N}_{dcp} + \sum_{c} x_{cr} Ar_{cr} L_{cr} \sum_{p=1}^{3} \overline{N}_{crp} + \sum_{c}\sum_{i} x_{ci} Ar_{ci} L_{ci} \sum_{p=1}^{3} \overline{N}_{cip} \\
& + \sum_{c}\sum_{la} x_{cla} Ar_{cla} L_{cla} \sum_{p=1}^{3} \overline{N}_{clap} + \Gamma.z + \sum_{k}\sum_{p} p_{kp}^{1} + \sum_{k}\sum_{p} p_{kp}^{2} + \sum_{d}\sum_{p} p_{dp}^{3} + \sum_{r}\sum_{p} p_{rp}^{4} \\
& + \sum_{i}\sum_{p} p_{ip}^{5} + \sum_{la}\sum_{p} p_{lap}^{6} + \sum_{s}\sum_{k}\sum_{p} p_{skp}^{7} + \sum_{k}\sum_{d}\sum_{p} p_{kdp}^{8} + \sum_{d}\sum_{c}\sum_{p} p_{dcp}^{9} + \sum_{c}\sum_{r}\sum_{p} p_{crp}^{10} \\
& + \sum_{c}\sum_{i}\sum_{p} p_{cip}^{11} + \sum_{c}\sum_{la}\sum_{p} p_{clap}^{12} \le f
\end{aligned}
\tag{44}
$$

$$p_{sp}^{1} + z \geq \widehat{N}_{sp} \times x_s \qquad \forall s, p \tag{45}$$
$$p_{kp}^{2} + z \geq \widehat{N}_{kp} \times y_m \qquad \forall k, p, m \tag{46}$$
$$p_{dp}^{3} + z \geq \widehat{N}_{dp} \times x_d \qquad \forall d, p \tag{47}$$
$$p_{rp}^{4} + z \geq \widehat{N}_{rp} \times x_r \qquad \forall r, p \tag{48}$$
$$p_{ip}^{5} + z \geq \widehat{N}_{ip} \times x_i \qquad \forall i, p \tag{49}$$
$$p_{lap}^{6} + z \geq \widehat{N}_{lap} \times x_{la} \qquad \forall la, p \tag{50}$$
$$p_{skp}^{7} + z \geq \widehat{N}_{skp} \times x_{skp} \qquad \forall s, k, p \tag{51}$$
$$p_{kdp}^{8} + z \geq \widehat{N}_{kdp} \times x_{kdp} \qquad \forall k, d, p \tag{52}$$
$$p_{dcp}^{9} + z \geq \widehat{N}_{dcp} \times x_{dcp} \qquad \forall d, c, p \tag{53}$$
$$p_{crp}^{10} + z \geq \widehat{N}_{crp} \times x_{crp} \qquad \forall c, r, p \tag{54}$$
$$p_{cip}^{11} + z \geq \widehat{N}_{cip} \times x_{cip} \qquad \forall c, i, p \tag{55}$$
$$p_{clap}^{12} + z \geq \widehat{N}_{clap} \times x_{clap} \qquad \forall c, la, p \tag{56}$$
$$f, z, p_{sp}^{1}, p_{kp}^{2}, p_{dp}^{3}, p_{rp}^{4}, p_{ip}^{5}, p_{lap}^{6}, p_{skp}^{7}, p_{kdp}^{8}, p_{dcp}^{9}, p_{crp}^{10}, p_{cip}^{11}, p_{clap}^{12} \geq 0 \tag{57}$$

The objective function was rewritten as the objective function (43), and the constraints (44) to (57) were added to the model. So, the uncertain model was transformed into a definite model; however, the model is still a multi-objective model and needs a technique to achieve an optimal model response.

3-2- The weighted sum utility method

In order to combine several functions with different units, the weighted sum utility method is used, and the three functions of cost, carbon dioxide emissions, and risk, with different units, are converted into a function. Before using the weighted sum utility method, the setting parameters, criteria parameters, and counter response variables need to be introduced.

Setting parameters:

WT_{OBJ1}: The weight of cost-utility
WT_{OBJ2}: The weight of carbon dioxide emission utility
WT_{OBJ3}: The weight of risk-utility

Criteria parameters:

$OBJ1_{min}$: Minimum value derived from cost minimization function
$OBJ2_{min}$: Minimum value derived from carbon dioxide emission minimization function
$OBJ3_{min}$: Minimum value derived from risk minimization function

Response variables:

$OBJ1$: The real amount of the cost minimization function
$OBJ2$: The real amount of the carbon dioxide emission minimization function
$OBJ3$: The real amount of the risk minimization function
UT_{OBJ1}: Utility of the cost minimization function
UT_{OBJ2}: Utility of the carbon dioxide emission minimization function
UT_{OBJ3}: Utility of the risk minimization function
UT: Utility of the hybrid function

According to the above definition, the model is presented as follows.

$$MinUT = WT_{OBJ1}UT_{OBJ1} + WT_{OBJ2}UT_{OBJ2} + WT_{OBJ3}UT_{OBJ3} \tag{58}$$

$$UT_{OBJ1} = \frac{OBJ1 - OBJ1_{min}}{OBJ1_{max} - OBJ1_{min}} \tag{59}$$

$$UT_{OBJ2} = \frac{OBJ2 - OBJ2_{min}}{OBJ2_{max} - OBJ2_{min}} \tag{60}$$

$$UT_{OBJ3} = \frac{OBJ3 - OBJ3_{min}}{OBJ3_{max} - OBJ3_{min}} \tag{61}$$

Equation (58) is the objective function of the weighted sum utility method, and its aim is to minimize the weighing of each target function. The weight of each utility function shows the relative importance of that objective function and is determined by decision-makers. The sum of the weights of the three functions is one. Equations (59), (60), and (61) show the calculation method for each one of the utility functions. In Equation (59), $OBJ1_{max}$ minus $OBJ1_{min}$ shows the highest amount of theoretical difference between the lowest and the highest cost, which can be used to calculate cost-utility. Also *OBJ1* minus $OBJ1_{min}$ represents the deviation between the actual value and the minimum accessible value. Equations (60) and (61) also act in the same way for the carbon emission function and the risk function. Therefore, the utility functions become unitless and can directly be added to each other under different weights.

4- Case study

Golsam company in Gorgan is one of the largest companies producing pesticides and chemical fertilizer in the country that thanks to its continuous efforts to improve the position of the country's GDP, has received the title “Premier industrial unit of the country” from the Ministry of Industries and Mines of Iran in 2007 and 2014. The company, with over half a century of experience and activity in the field of production, import, and distribution of agricultural chemicals, annually manufactures between 15% and 20% of the country's pesticides with tested raw materials from internationally recognized sources and according to FAO production standards and supplies the consumers with the highest quality.

Golsam tries to produce its pesticides under the license of major European and Japanese manufacturers such as Syngenta, Switzerland, ISK, Japan, Sumitomo, and Nippon soda, Japan, so that it will always be one of the top companies to produce and distribute pesticide in the country. The fertilizers produced by the company are also manufactured with European raw materials, and the formulations recommended by Italian and Dutch companies with the best quality, similar to the fertilizers produced by the world-class companies. Golsam Company is one of the top importers of the seeds in the country and imports and distributes the various types of vegetable seeds from the most reputable international companies such as Sinjenta (SG), Heuser, US Agriseeds, and so on. In addition, the company has the production of its own seeds, which are known under the general title “Samin Bazr”.

Eight provinces, including Isfahan, Yazd, Khorasan Razavi, Semnan, Fars, Zanjan, Kerman and Sistan and Baluchestan, are able to supply the raw materials of these pesticides and chemical fertilizers, but it is not possible to supply all provinces. Items such as transportation costs, different purchasing costs for each ton of the required raw materials, the amount of gas emitted from the transportation system due to long journeys and the commute times constraint the supplier's selection.

It is important to note that at each stage of production if the manufactured pesticide or fertilizer is not based on international standards or its expiration date has passed, it will be conveyed to the recycling site. At the recycling site, the components of the pesticides or fertilizers will be analyzed by experts of toxicology and laboratory experts, and that portion of the raw material which are usable will be reused, but the unusable portion of it will be burnt to produce energy or will be buried. To determine how much should be burnt and how much should be buried is raised as a rate in the current study, although the study aims not to determine this rate. The main purpose of the research is to determine the number and location of the recycling centers, the pesticide burying sites, and the distribution centers from candidate provinces. The candidate provinces of the recycling centers are the five provinces of Golestan, Mazandaran, Lorestan, Isfahan and Semnan. The pesticide burying sites were selected from five North and South Khorasan, Semnan, East Azarbaijan, and Markazi provinces. The distribution centers were also selected from Mazandaran, Gilan, Khuzestan, Kerman, Khorasan Razavi, Hamedan, Fars and Isfahan provinces. The places of burning unrecoverable pesticides are Semnan, Yazd and Golestan provinces, which are constant locations. Because of the high volume of unrecoverable pesticides, the facilities of all three burning sites are used. It should be noted that each one of these three centers has a limited capacity. The case study selected for the current study is Golsam Gorgan Company. The goal is to design a green supply chain, considering the risk of the chain and covering all customers in potential provinces. The potential provinces are Golestan, Mazandaran, Gilan, Khuzestan, Fars, Khorasan Razavi, South Khorasan, Isfahan, Ilam and East Azarbaijan. The descriptions related to the locations of the supply chain components are shown schematically in figure 2.

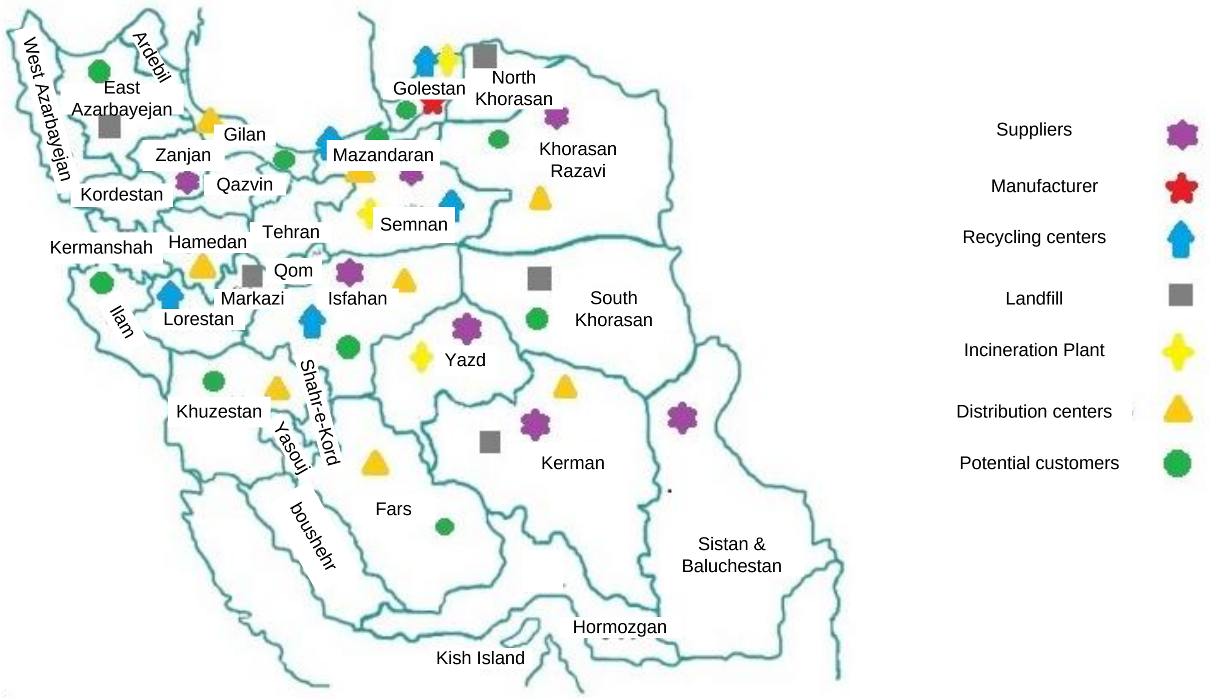

Fig 2. The supply chain components in order to design supply chain

We also know that the risk obtains from multiplying risk probability by the probable event. The acceptable risk level is used to measure risk probability. To understand the level of risk, the principle of "risk acceptance utility" should provide a model for determining an acceptable level. Risk is divided into three levels: intolerable, tolerable and acceptable, as shown in figure 3. Similar to the HSE Handbook, each member's maximum risk (i.e. the event rate per facility in the supply chain) should be tolerated and set as 1×10^{4} per year. For transportation, the rate of tolerable events will be set as 2.4×10^{-4} (incident rate) and 1.61×10^{-5} (the number of common incidents). The risk event is mainly divided into accidents, environmental pollution, and losing properties.

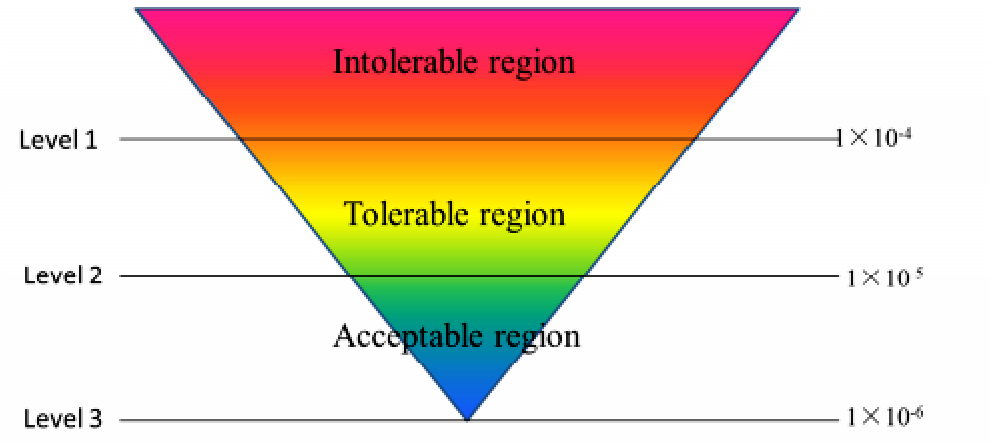

Fig 3. Risk tolerance framework

5- Computational experiments

Part of the important information is presented in tables 1 through 4, used to solve the model. The proposed model is uncertain that in the previous section and using the developed model by Bertsimas and Sim turned to a definite and solvable state. The demand of potential provinces (tons per year) is presented in table 1.

Table 1. Demand of potential provinces (Tons per year)

Potential province	Golestan	Mazandaran	Gilan	East Azarbayejan	Khouzestan	Ilam	Isfahan	Fars	Khorasan Razavi	South Khorasan
Demand	17000	25000	18000	13000	15000	9000	14000	15000	18000	8000

Table 2 presents the likelihood of risk for the supplier, recycling center, landfill, incineration plant, and distribution center.

Table 2. The likelihood of risk in the facility

Supplier	Isfahan	Yazd	Khorasan Razavi	Semnan	Fars	Zanjan	Kerman	Sistan & Baluchestan
Probability	0.1	0.13	0.17	0.1	0.05	0.1	0.17	0.18
Recycling center	Golestan	Mazandaran	Lorestan	Isfahan	Semnan	-	-	-
Probability	0.2	0.25	0.15	0.4	0.1	-	-	-
Landfill	North Khorasan	South Khorasan	East Azarbayejan	Semnan	Markazi	-	-	-
Probability	0.2	0.1	0.3	0.25	0.25	-	-	-
Incineration Plant	Golestan	Yazd	Semnan	-	-	-	-	-
Probability	0.3	0.45	0.25	-	-	-	-	-
Distribution center	Mazandaran	Gilan	Khorasan Razavi	Khuzestan	Kerman	Hamedan	Isfahan	Fars
Probability	0.07	0.08	0.15	0.12	0.18	0.1	0.15	0.15

The consequence of the p type of risk in facility f for the supplier, recycling center, landfill, incineration plant, and distribution center is presented in table 3.

Table 3. The consequence of the p type of risk in facility f, (a million Toman per year)

Supplier	Isfahan	Yazd	Khorasan Razavi	Semnan	Fars	Zanjan	Kerman	Sistan & Baluchestan
Accidents	(3.3,7.7)	(2.93,6.85)	(2.88,6.71)	(4.35,10.15)	(2.61,6.09)	(3.71,8.65)	(2.7,6.3)	(3.76,8.76)
Environmental pollution	(2.61,6.09)	(2.1,4.9)	(3.06,7.14)	(2.7,6.3)	(2,4.66)	(3.28,7.64)	(2.35,5.49)	(2.1,4.9)
losing properties	(3.9,9.1)	(4.13,9.65)	(3.15,7.35)	(4.8,11.2)	(3.67,8.55)	(5.21,12.04)	(4.5,10.5)	(4.06,9.48)
Recycling center	Golestan	Mazandaran	Lorestan	Isfahan	Semnan	-	-	-
Accidents	(1.26,2.94)	(1.14,2.66)	(1.32,3.08)	(1.92,4.48)	(1.14,2.66)	-	-	-
Environmental pollution	(1.5,3.5)	(1.17,2.73)	(1.23,2.87)	(1.98,4.62)	(1.74,4.06)	-	-	-
losing properties	(1.92,4.48)	(1.35,3.15)	(2.1,4.9)	(2.34,5.46)	(2.1,4.9)	-	-	-
Landfill	North Khorasan	South Khorasan	East Azarbayejan	Kerman	Markazi	-	-	-
Accidents	(1.5,3.5)	(3.3,7.7)	(2.94,6.86)	(1.74,4.06)	(1.86,4.34)	-	-	-
Environmental pollution	(2.1,4.9)	(3.9,9.1)	(2.22,5.18)	(3.12,7.28)	(2.76,6.44)	-	-	-
losing properties	(2.7,6.3)	(4.5,10.5)	(4.86,11.34)	(4.44,10.36)	(3.78,8.82)	-	-	-
Incineration Plant	Golestan	Yazd	Semnan	-	-	-	-	-
Accidents	(2.1,4.9)	(2.7,6.3)	(3.3,7.7)	-	-	-	-	-
Environmental pollution	(2.34,5.46)	(2.34,5.46)	(3.6,8.4)	-	-	-	-	-
losing properties	(2.4,5.6)	(2.7,6.3)	(3.3,7.7)	-	-	-	-	-
Distribution center	Mazandaran	Gilan	Khorasan Razavi	Khuzestan	Kerman	Hamedan	Isfahan	Fars
Accidents	(2.52,5.88)	(2.34,5.46)	(3.54,8.26)	(2.54,5.92)	(1.62,3.78)	(1.39,3.25)	(3.05,7.13)	(2.55,5.95)
Environmental pollution	(2.34,5.46)	(2.88,6.72)	(3.6,8.4)	(1.98,4.62)	(2.64,6.16)	(2.33,5.45)	(2.46,5.74)	(2.82,6.58)
losing properties	(3.96,9.24)	(4.35,10.15)	(5.7,13.3)	(3.84,8.96)	(3.06,7.14)	(3.13,7.29)	(3.78,8.82)	(3.12,7.28)

Table 4 presents the emission factor for the Recycling center, Landfill and Incineration Plant.

Table 4. Emission factor (in a million cubic meters per year)

Recycling center	Golestan	Mazandaran	Lorestan	Isfahan	Semnan
emission factor	12	13.5	15	17	10
Landfill	North Khorasan	South Khorasan	East Azarbayejan	Semnan	Markazi
emission factor	1	1.5	2	1.5	1.1
Incineration Plant	Golestan	Yazd	Semnan	-	-
emission factor	50	60	70	-	-

According to the data related to the case study and coding the presented model in the GOM software version 24.7.3, we embark on solving the model. The results of the above model are presented in figure 4. Isfahan, Yazd, Semnan and Zanjan provinces were selected as suppliers in this solution. Distributors are Mazandaran, Gilan, Khorasan Razavi and Khuzestan provinces.

North Khorasan, South Khorasan and Kerman provinces were selected as burial centers and Golestan, Mazandaran and Semnan provinces were considered as the recycling centers. Also, burning centers are Golestan and Semnan provinces.

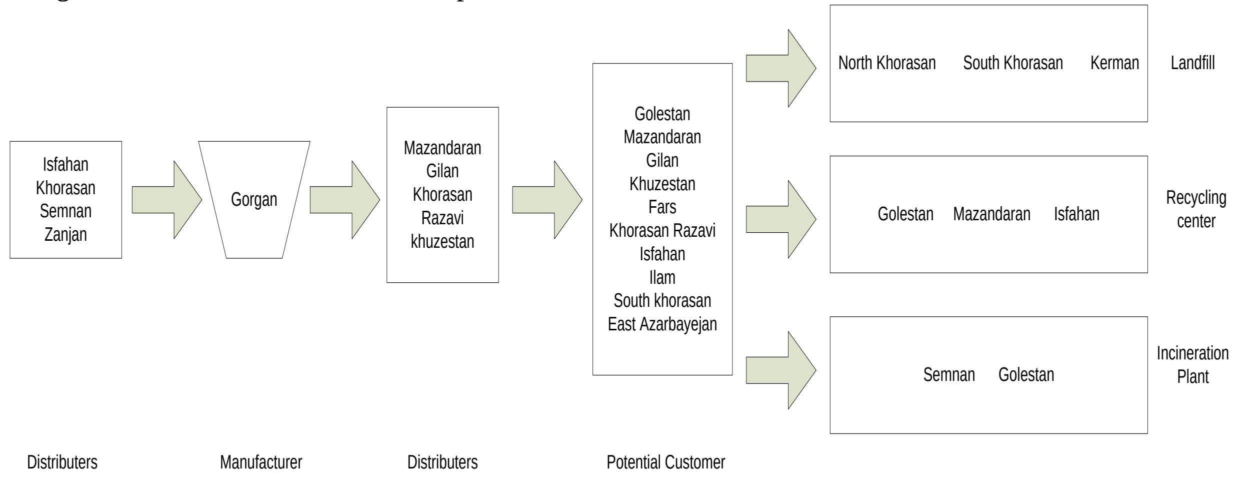

Fig 4. Selected provinces by the solved model

According to the solution of the study, supply chain risk, released carbon dioxide and the costs decreased to a minimum amount. Also, the locations were evaluated and selected based on these three criteria. The uncertainty used in the proposed model, which has been involved in risk events, has brought the model closer to reality. This will have a significant effect on the more correct decision-making by the managers.

7-Conclusions

The present study proposes a multi-objective optimization model to provide insight into green supply chain management. Although this model minimizes the potential risk of handling hazardous materials, such risk is generally related to carbon emissions and economic costs. The best strategy for controlling risk and reducing carbon emissions is expected to be determined through optimization, which facilitates insightful management performance and helps improve green supply chain management. However, there are several constraints in the proposed model. First, to simplify the model's structure, the supply chain network is assumed to be a single-stage product supply chain. Second, the risk defined in the study focuses on the immediate risk of the sudden incidents, which are not considered long-term ones. Risk reduction and carbon emissions may have long-term impacts on the economic performance of the supply chain network, which should be investigated. Further studies are focused on improving the model, including taking into account the impact of stored inventory and delayed orders on the optimization of the supply chain network. This study is mostly implemented using a dynamic system approach and considers the cumulative effect of potential risk and the long-term effect of reducing risk and carbon emissions on economic costs, so different stakeholders apply GSCM performance.

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