Journal of Industrial and Systems Engineering
Vol. 13, No. 4, pp. 307-327
Autumn (November) 2021

Designing a market basket to mitigate supply risks

Hamed Maleki[1], Hasan Khademi Zare[1*], Mohammad Bagher Fakhrzad[1], Hasan Hosseini Nasab[1]

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

h.maleki@stu.yazd.ac.ir, hkhademiz@yazd.ac.ir, mfakhrzad@yazd.ac.ir, hhn@yazd.ac.ir

Abstract

Volatility in competitive businesses has increased the uncertainty and ambiguity of decision-makings. Uncertainties are known as risks in the literature reviews. The present study developed the model proposed by Kirilmaz and Erol to mitigate risks and ambiguity in decision makings in the green supply chain. An initial multi-objective procurement plan was developed using a robust planning model considering costs, purchase discounts, carbon emissions and uncertainty as the first priority. The paper applies a scenario-based approach to consider an uncertain customer demand in different scenarios. The scenario-based model ensured that regret whereas scenarios are not probability. Moving toward the green supply chain decreases the costs that exert negative and devastating effects on the environment. As the second priority, risk was ultimately incorporated into this plan. A hypothetical data-set was examined and a cost analysis performed to evaluate the quality of the obtained solutions and the performance of the proposed model.

Keywords: Supply chain risk management, robust optimization, uncertainty, multi-objective model

1- Introduction

Lower costs, commercial treaties, new markets, developing communication and internet opportunities are some of the advantages of globalization. However, cultural diversities, standardization difficulties, political instabilities and extended distances make supply chains more vulnerable to risks. Companies must accept some degree of risk and apply risk mitigation strategies to gain a competitive advantage and make profit. However, most companies invested little time or resources for mitigating supply chain risks (Jianlin 2011). Although the number of academic studies on supply chain risk management has increased since the year 2000, use of quantitative models remained insufficient. Kirilmaz et al. (2017) proposed a linear programming model having shortcomings for real world situations to mitigate risk.

Both the terms uncertainty and risk may include sources, events and impacts, and they can be used to indicate concepts and/or objects (Saminian-Darash and Rabinow 2015). Therefore, sometimes the term uncertainty is confused with risk (Sanchez-Rodrigues Vasco et al. 2008). In addition, the uncertainty and risk are terms that in practice are often used interchangeably (Peck, 2006). Lee (2002) illustrated on narrower aspects of supply chain uncertainty that there are two types of uncertainties – supply and demand uncertainty. In recent years, the supply chain of some industries has paid a lot of attention to the available natural and non-renewable resources, and green supply has become a very useful activity for industries.

---

*Corresponding author

In addition to minimizing the conventional costs of the green supply chain such as purchase order cost, directors of the green supply chain seek to minimize social costs to fulfill the social responsibility of the organization and improve its productivity and therefore create value, satisfy customer needs and gain the approval of new parts of the market and ultimately help the organization achieve competitive advantage.

Today, directors of the green supply chain in leading companies strive to earn profit through achieving environmental satisfaction and improving the environmental performance throughout the supply chain as a strategic asset. They therefore base their goals on three main issues, i.e. green design (product), green production (process) and product recycling (Kaplan 1996). The materials were transported to the manufacturers by plane, train, ship and truck. Transportation is mainly fossil fuel based and produce pollution. The novelty of this article therefore lies in decreasing the pollution generated through the production process.

The product life cycle used to include processes encompassing the design phase and consumption (Chen 2009). According to the modern environmental management, resource consumption and detrimental environmental effects are minimized by incorporating processes such as procurement, design, manufacture, utilization, recovery and reuse into a closed loop of material flow (Folan 2005). Organizations are therefore required to ensure the environmental performance of the supply chain by applying environmental management to their product lifecycle. Given that different risks associated with all the products and activities of the green supply chain can disrupt its activities, managing the risk and reducing its complexity is crucial for green supply chains. This study was therefore conducted to assess the risk of green supply chains by developing a model.

On the one hand, the cost of raw materials and components constitutes a major portion of the total cost of products in many industries. Purchase of materials therefore accounts for 70% of production costs (Ghodsypour et al., 1998). On the other hand, applying discount is a common incentive policy in different industries. The logistics department can therefore play a key role in the efficiency and effectiveness of an organization by significantly reducing its costs and enhancing its profitability and flexibility (Ghodsypour et al., 2001). Discounts are all-unit or incremental in type (Fatemi Qomi 2004). All-unit discounts are uniformly applied to all the purchased commodities, whereas incremental discounts are granted for only the items purchased beyond a threshold (Sadeghi Moghadam 2017). Amornpetchkul (2017) found the manufacturer's utility to be higher under the incremental than all-unit discount given the higher profitability of the incremental discount to the retailer. A multi-objective programming procedure is proposed considering incremental discount in this paper in light of these views. The main aim of the procedure is to take precaution against risky suppliers in case of uncertain demand and to achieve competitive advantage by reducing carbon emissions, while Kirilmaz and Erol's model just included the purchase cost and cost of transportation from suppliers to manufacturers and ignored the discount awarded to purchases that meet a minimum quantity.

2- Literature review

Despite the prosperity, welfare and advancement brought about by the industrialization of communities, it has negatively affected the environment, human health and resources and caused ecological mismatch and occupational accidents. These effects constitute an obstacle to development of countries (Angappa 2015). Modern management approaches and specific techniques recommended for the effective management of organizations include risk management, which is used to enhance effectiveness (Shahbandarzadeh et al., 2017). The risk assessment stage helps evaluate and prioritize the identified risks according to their probability to occur and associated consequences if they materialize, enabling the decision-maker to distinguish those risks that require greater attention (Pishvaee et al., 2021). Aboutorab et al. (2021) surveyed the domain-independent risk identification techniques proposed between 1980 and 2020.

Effective mathematical tools have gained popularity in terms of effective analysis of supply chain risk management. The numerous studies conducted on supply chain risk management are more qualitative than quantitative and model-based. The stage entitled risk treatment explores leading optimization approaches for handling uncertainty, along with strategies for reducing the vulnerability of the supply chain (Pishvaee et al., 2021).

For instance, Arntzen et al. (1995) developed an integer programming model to identify optimal relationships with supplier, design optimal supply networks and optimally allocate supplier orders. Tang and Tomlin (2008) proposed a model for estimating the number of suppliers considering supply costs. As a risk reduction approach, they recommended placing orders to a limited number of suppliers to reduce the risk of supply costs. Tomlin (2006) solved the problem of supplier selection in the face of supply disruption using random optimization. Comparing a reliable but costly supplier with an unreliable but inexpensive one, they found the supplier efficiency and the nature of the disruptions to play key roles in selecting a supplier.

Gutierrez et al. (1996) used a robust approach to find near-optimal solutions to different scenarios of a supply chain design problem. Stephen et al. (2007) developed a robust optimization model for production planning at different production sites with uncertain data. Pan and Nagi (2010) proposed a robust model for the integrated optimization of the logistics and production costs of a supply chain based on the members of the supply chain and under uncertain demand and agile manufacturing.

Figure 1 shows the general concept and benefits of robust planning in a supply chain, suggesting that certain methods produce optimal solutions by considering certain values for variables, whereas robust methods generate near-optimal solutions, which are more costly and more reliable (Landeghem 2002).

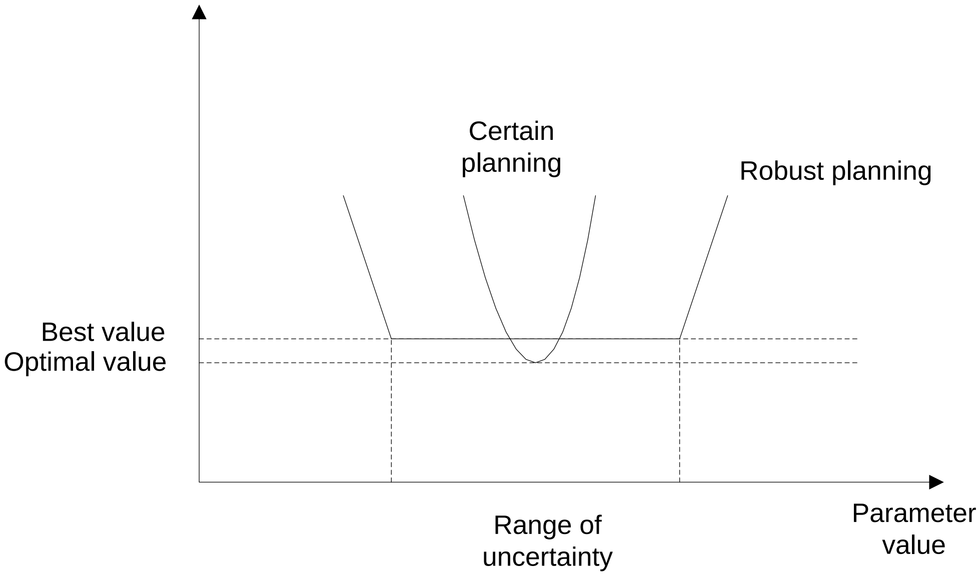

Fig 1. Effect of robust planning on the total cost of a supply chain (Landeghem 2002)

Kirilmaz et al. (2017) proposed a method for risk reduction using linear programming. An initial procurement plan developed by applying cost constraints, i.e. purchase and transportation costs, was modified using risk constraints. The present article used robust planning based on the model proposed by Kirilmaz and Erol to reduce risk and eliminate ambiguity in decision making.

Exacerbation of environmental pollution due to greenhouse gas emissions in recent years has been a cause for concern among consumers and the authorities of many businesses and government agencies. Governments have therefore enacted new environmental regulations to control the emission of different greenhouse gases, including carbon dioxide and sulfur dioxide. Environmentally-friendly policies were also proposed in literature to address these concerns and reduce the pollution and its adverse effects (Tseng et al., 2019).

Zahraee et al. (2020) showed that the highest greenhouse gas emissions were associated with train transportation mode while it was lowest with truck. To achieve this goal, they used the data of three empty fruit bunches suppliers in Malaysia as a case study. Transportation is done by truck in the paper. A model developed by Shahbandarzadeh et al. (2017) showed major risks in green supply chains to include governmental risk, production risk, recycle risk, supply risk and demand risk. The supply risk highlighted in this article was associated with inability to meet orders, unavailability of green materials and quality of supplier green materials.

According to Shahbandarzadeh et al. (2017), both operation and plan of a supply chain are influenced by risk and uncertainty. Demand uncertainty influences supply chain integration’s effect on firm performance (Hendijani and Saeidi Saei, 2020). Robust and stochastic methods are often used for optimization under uncertainty (Snyder and Daskin, 2006). The uncertainty in supply can be due to long lead times, loss, damage or theft in transit (Surti et al., 2013).

According to a multi-objective decision-making model proposed by Tseng et al., recycling was included in the optimization process and manufacturing cost was minimized by integrating forward logistics with reverse logistics and considering a trade-off between emissions and costs. The production strategy they ultimately proposed was based on the most economical and environmental-friendly approach. Purchasers could also lower their cost as per the comprehensive truckload discount policy through raising the number of full truckload product orders.

The objectives of a novel method proposed by Nahavandi and Sadeghi Rad (2018) for a multi-product, multi-period, multi-echelon and capacitated closed-loop green logistic network included minimizing the cost and pollution and maximizing customer satisfaction. Suppliers are selected in a real-world supply chain based on the unit price of items and the discount offered by suppliers based on the purchase level. This model therefore integrated the supply risk and supplier selection with the allocation problem on the basis of the quantity discount.

3- Mathematical models

Mathematical problems can be modeled by ignoring certain real-world constraints. Parameters are predetermined with certainty in most of mathematical models. The model comprises 3 steps. In the first step, the model is introduced in certain conditions. A multi-objective optimization includes cost and carbon emissions objective functions.

Supply chain uncertainty is becoming increasingly popular in business management. However, few studies have provided a depth discussion on the uncertainty so far (Wang 2018). Demand uncertainty is one of problem in supply chains. The second step considers the uncertain conditions. Due to the nature of uncertainty, uncertainty is not able to be forecasted or expected beforehand.

Optimization under uncertainty is generally performed using either stochastic planning or robust optimization. According to stochastic planning, uncertain parameters are controlled using probability distribution functions to minimize the expected cost as the objective function. Moreover, robust optimization addresses uncertainty by estimating random parameters using discrete or continuous scenarios. In contrast to stochastic models, the robust models proposed can be solved in polynomial time, theoretically yielding quality solutions (Maggioni et al., 2014). The computation burden of stochastic models has also been experimentally shown to be heavier than that of robust models for a large number of scenarios. The model in robust conditions is presented in the third step.

Fundamental mathematical models in robust optimization include the regret model and the variability model (Baohua and Shiwei, 2009). According to the regret model, the regret value of a scenario refers to the relative or absolute difference between the objective function value associated with a feasible solution and its optimal value.

Given demand uncertainty as fluctuations in manufacturers demand, the regret model is used for the sake of model robustness in the paper. Variable demand in different months of the year results in recession, stability or boom in customer demand in different months. The paper studies an uncertain customer demand and investigated demand parameters in different scenarios. Despite the simplicity of the study method and its application to real-world modeling, the model limitations cannot be ignored. The main limitations of scenario-based optimization are associated with the method of creating and probability of a scenario. This study considered a 100% probability for all the scenarios to avoid disruptions.

3-1- Mathematical model under certain conditions

The problem was mathematically modeled as a directed complete bipartite graph considering cost and carbon emissions as the first and second objective functions, respectively, vector V_1 for the suppliers and V_2 for the manufactures. Arcs $A=V_1*V_2$ represent the material flow between the suppliers and manufactures. In the first step of the proposed approach, a multi-objective initial optimization was performed using a robust planning model considering cost constraints, purchase cost discounts, carbon emissions and demand uncertainty as the first priority.

As discussed earlier, the model was solved as a multi-objective optimization problem by defining the second objective function. In addition to the conventional minimization of transportation and purchase costs, environmental problems were also defined as the second objective function in the model (Farhang Moghhaddam et al., 2013).

Despite the certainty of the purchase cost as the decision function (amount of purchase), the proposed model was nonlinear in nature. In the second step, the plan was modified by adding risk constraints as the second priority. The difference in the risk between the suppliers was determined to replace a supplier receiving an order based on the minimum cost with a more reliable supplier with a lower risk.

3-1-1- Definition of parameters

i : Supplier
j : Manufacturer
p_i : Per unit cost of purchasing from supplier *i*
y_{ij} : Quantity of materials transported from supplier *i* to manufacturer *j*
T_{ij} : Per unit cost of transportation from supplier *i* to manufacturer *j*
c_i : Capacity of supplier *i*
D_j : Demand of manufacturer *j*

$$s_i : \begin{cases} \text{Supplier } i \text{ selected} & 1 \\ \text{Supplier } i \text{ not selected} & 0 \end{cases}$$

EM_{ij} : Carbon emission from supplier *i* to manufacturer *j*
L_{ij} : Distance between supplier *i* and manufacturer *j*
Q_{Ti} : The amount of material transported from supplier *i*
k : All suppliers with a lower risk than that of supplier *i*
c_{Ri} : Remaining capacity of supplier *i*
N_{ij} : Difference in the normalized risk between supplier *i* and manufacturer *j*
x_{ij} : The amount of material transported from supplier *i* to manufacturer *j*
q_l : Lower limit for purchase quantity at price *l*

In the first step of the proposed method, an initial plan was developed through the robust multi-objective planning considering cost constraints as the first priority.

$$MinCost = \sum_{i \in v_1} p_i \sum_{j \in v_2} y_{ij} + \sum_{i \in v_1} \sum_{j \in v_2} T_{ij} y_{ij} \tag{1}$$

Equation (1) is the sum of purchase and transportation costs (Kirilmaz and Erol, 2017). The purchase cost is certain though a function of the decision (purchase amount). Equation (2) shows per unit purchase cost based on the amount of purchase as determined by the supplier.

$$P_i = \left\{ \begin{array}{ll} p_{i1} & q_1 \le y_{ij} < q_2 \\ p_{i2} & q_2 \le y_{ij} < q_3 \\ \dots & \dots \\ p_{in} & q_n \le y_{ij} \end{array} \right\} \tag{2}$$

In which $p_{i1} > p_{i2} > \dots > p_{in}$ and $q_1 < q_2 < \dots < q_n$ (Taleizadeh et al., 2015).

Equation (3) represents the objective function of carbon emission (Zhao et al., 2017), inequality (4) the capacity constraint of the supplier, inequality (5) the constraint on the factory demand, inequality (6) the constraint on the variable decision, inequality (7) the constraint on the decision variable of the quantity of transported materials and constraint (8) the decision variable of selecting or not selecting *i*, $(\forall i \in V_1, j \in V_2)$.

$$MinPollution = \sum_{i \in v_1} \sum_{j \in v_2} y_{ij} EM_{ij} L_{ij} \tag{3}$$

$$\sum_{j \in v_2} y_{ij} \le c_i s_i \tag{4}$$

$$\sum_{i \in v_1} y_{ij} \ge D_j \tag{5}$$

$$s_i \le \sum_{j \in v_2} y_{ij} \tag{6}$$

$$y_{ij} \ge 0 \;\; (i \in v_1, j \in v_2) \tag{7}$$

$$s_i \in \{0,1\} \;\; (i \in v_1) \tag{8}$$

In the second step, the plan was revised by adding risk constraints as the second priority.
Equation (9) represents the material transported from a high-risk to a low-risk supplier (Kırılmaz and Erol, 2017).

$$MaxZ = \sum_{ij} N_{ij} x_{ij} \tag{9}$$

The objective is to maximize the product flow from a risky supplier to a relatively less risky supplier. So the parameters of the decision variables in the objective function are the positive differences between the normalized risk values of suppliers. The objective function value does not represent any quantity but since the objective function is maximization, it satisfies the condition of transfer from a risky supplier to a less risky supplier.
Equation (10) shows the constraint on the material transportation capacity.

$$\sum_{j}^{J} x_{ij} \le Q_{Ti} \, (\forall i, i \ne j) \tag{10}$$

Constraint (11) ensures that the difference between the input and output of point *i* does not exceed the remaining capacity of the supplier.

$$\sum_{k}^{K} x_{ki} - \sum_{j}^{J} x_{ij} \le c_{Ri} \tag{11}$$

3-2- Mathematical model under uncertainty

This section presents the mathematical model in uncertain conditions. The set of the scenarios is shown by *O*.

3-2-1- Definition of parameters

The modified parameters in the uncertain model are as follows:

O : Set of existing scenarios

y_{ij}^{O} : The amount of materials transported from supplier *i* to manufacturer *j* in scenario *O*

D_j^{O} : Demand of manufacturer *j* in scenario *O*

p_i^O : Per unit cost of purchasing from supplier *i* in scenario *O*

$$s_i^O : \begin{cases} \text{Selecting supplier } i \text{ in scenario } O & 1 \\ \text{Otherwise} & 0 \end{cases}$$

$$MinCost = \sum_{i \in v_1} p_i^O \sum_{j \in v_2} y_{ij}^O + \sum_{i \in v_1} \sum_{j \in v_2} T_{ij} y_{ij}^O \tag{12}$$

$$MinPollution = \sum_{i \in v_1} \sum_{j \in v_2} y_{ij}^O EM_{ij} L_{ij} \tag{13}$$

$$\sum_{j \in v_2} y_{ij}^O \leq c_i s_i^O \tag{14}$$

$$\sum_{i \in v_1} y_{ij}^O \geq D_j^O \tag{15}$$

$$s_i^O \leq \sum_{j \in v_2} y_{ij}^O \tag{16}$$

$$y_{ij}^O \geq 0 \tag{17}$$

$$s_i^O \in \{0,1\} \tag{18}$$

Equations (12)-(18) are equivalent to equations (1)-(8) for an existing scenario. In every scenario, solving the mathematical model generated $C_1^*$and C_2^* as optimal values of the first and second objectives functions, respectively. The next section presents the mathematical model in robust conditions.

3-3-Mathematical model in robust conditions

Some problems seek to determine a regret limit for all the existing scenarios. For each scenario, its optimal value is considered, it means C_1^*andC_2^*, and the value of each objective function under *A* is called the robust value. The left side of equation (19) shows the relative regret value of every scenario. The mathematical model of the problem is as follows.

$$\frac{C_1(\mathrm{X}) - C_1^*}{C_1^*} \leq A \tag{19}$$

$$MinCost = \sum_{i \in v_1} p_i^O \sum_{j \in v_2} y_{ij}^O + \sum_{i \in v_1} \sum_{j \in v_2} T_{ij} y_{ij}^O \tag{20}$$

$$MinPollution = \sum_{i \in v_1} \sum_{j \in v_2} y_{ij}^O EM_{ij} L_{ij} \tag{21}$$

$$\sum_{i \in v_1} p_i^O \sum_{j \in v_2} y_{ij}^O + \sum_{i \in v_1} \sum_{j \in v_2} T_{ij} y_{ij}^O \leq (1+A) C_1^* \tag{22}$$

$$\sum_{i \in v_1} \sum_{j \in v_2} y_{ij}^O EM_{ij} L_{ij} \leq (1+A) C_2^* \tag{23}$$

$$\sum_{j \in v_2} y_{ij}^O \leq c_i s_i^O \tag{24}$$

$$\sum_{i \in v_1} y_{ij}^O \geq D_j^O \tag{25}$$

$$s_i^O \le \sum_{j\in v_2} y_{ij}^O \tag{26}$$

$$y_{ij}^O \ge 0 \tag{27}$$

$$s_i^O \in \{0,1\} \tag{28}$$

C_1^* and C_2^* obtained from solving the model in different scenarios were inserted into equations (22) and (23). Equations (14)-(18) of the previous model were repeated for this model. The following multi-objective optimization problem was solved by assigning w_i as a weight to every objective function.

$$MinZ = \sum_i w_i z_i \tag{29}$$

$$g_i(x) \ge 0 \tag{30}$$

4- Numerical examples and model validation

This study proposed a single-commodity, single-period capacitated model with a single-echelon chain of suppliers and manufacturers in the same and/or different geographical regions as per figure 2.

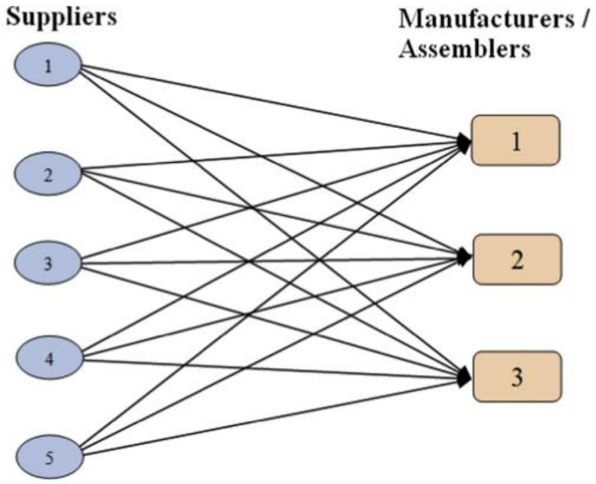

Fig 2. Supply chain network (Kirilmaz and Erol, 2017)

Table 1 presents the capacity and per unit cost of purchasing a commodity from the individual suppliers and the cost of transporting commodities between the individual suppliers and manufacturers. Table 2 presents the distance in *kilometer* between the individual suppliers and manufacturers and the risk of the suppliers. Table 3 presents the demand of the individual manufacturers and Table 4 carbon emission according to *Euro 4* as the emission standard enforced in developing countries. In this example, the cost objective function was given a weight twice as high as that of the pollution objective function.

Table 1. Purchase information of suppliers

Manufacturer **Supplier**	**Transportation cost (*$*)**			**Capacity (part unit)**	**Amount of Purchase**	**Per unit cost of purchase (*$*)**
	1	**2**	**3**			
1	8.5	13	13	47000	≤40000	100
					>40000	90
2	8.5	13	14	92000	≤40000	100
					>40000	95
3	7	10	7	49000	≤40000	90
					>40000	85
4	10	11	5.5	95000	≤40000	90
					>40000	70
5	8	8	9	44000	≤40000	100
					>40000	85

Table 2. Risk information of suppliers

Manufacturer **Supplier**	**Distance value (*km*)**			**Risk value (Risk Priority Number)**
	1	**2**	**3**	
1	100	150	150	50
2	100	150	160	32
3	80	120	80	66
4	120	130	50	56
5	90	90	95	60

Table 3. Demand of manufacturers (part unit)

Scenario **Manufacturer**	**1**	**2**	**3**
1	49000	80000	60000
2	60000	50000	80000
3	95000	30000	45000

Table 4. Carbon emission (IKCO, 2013)

Emission standard	**Emission level (*g/km*)**	**Implementation year in the EU**	**Implementation year in developing countries**
Euro 4	1.5	2005	2012

Table 5 presents the solution obtained from simulating the study model in GAMS 24.9.2 using a 2.16-GHz processor and a 2-GB RAM. BONMIN and SCIP are used for solving the model. BONMIN is an open-source solver for mixed-integer nonlinear programming (MINLPs), implementing branch-and-bound, branch-and-cut, and outer approximation algorithms. SCIP is a framework for Constraint Integer Programming oriented towards the needs of Mathematical Programming experts who want to have total control of the solution process and access detailed information down to the guts of the solver. SCIP can also be used as a pure MIP or MINLP solver or as a framework for branch-cut-and-price (GAMS Software, 2020). The same results are given by both BONMIN and SCIP. Table 6 presents the results obtained from investigating at different *A* values, suggesting the same values for the objective functions.

Table 5. Optimal solution

Manufacturer / **Supplier**	**1**	**2**	**3**	**Total**
1	7890	0	0	7890
2	8110	0	0	8110
3	40000	4000	5000	49000
4	0	36000	40000	76000
5	4000	40000	0	44000
Total	60000	80000	45000	185000
Minimum Total cost (*$*)	**9.057608×10^9**			

This procurement plan was developed disregarding the risk constraint. The initial supply values obtained for the individual suppliers based on cost and carbon emission constraints were modified based on the risk constraint. Table 6 presents the results of solving the sample problem at different *A* values, suggesting no changes in the objective function values with increases in *A*. The fourth column also provides the solution time.

In order to analyze the proposed procedure, a comparison was made with Kirilmaz and Erol's approach. For this purpose, the carbon emission objective function was removed from the model and the demand is considered certain. The total cost is 20,361,500 $ in Kirilmaz and Erol's approach, while the proposed procedure indicates total cost of 20,168,000 $ from table 6. In fact that the purchase cost is considered without a discount, so it was expected such a result would be achieved.

Table 6. Information of each objective function in terms of different values of *A*

A	**Value of the first objective function (*$*)**	**Value of the second objective function (*$*)**	**Simulation time (second)**
0.5	2.016800×10^7	2.448000×10^7	0.842
1	2.016800×10^7	2.448000×10^7	1.171
10	2.016800×10^7	2.448000×10^7	0.858
1000	2.016800×10^7	2.448000×10^7	1.170
∞	2.016800×10^7	2.448000×10^7	1.140

According to table 7, suppliers 2 and 3 were respectively the most reliable and the most unreliable, and the materials should be transported from a high-risk supplier to a low-risk supplier. Moreover, the risk value of the most reliable supplier was therefore subtracted from that of the other suppliers, suggesting the impossibility of transporting the materials from supplier 2 to the other suppliers. It was therefore considered the basic value, and the differences in the risk values of other suppliers remained constant. These risk values were ultimately normalized.

Table 7. Values of the normalized risk criteria

Supplier	**Risk value (Risk Priority Number)**	**Relative risk value based on a low-risk supplier**	**Normalized value**
1	50	18	0.173
2	32	0	0
3	66	34	0.327
4	56	24	0.231
5	60	28	0.269
Total		104	1

Figure 3 shows the material flow network based on the supplier risk criteria. Tables 8-9 presents the parameters used in the model.

Table 8. Parameters used in the model (part unit)

Supplier	**Procurement plan based on minimum cost**	**Normalized risk value**	**Number of transported materials**	**Quantity of remaining materials**	**Remaining capacity**
1	7890	0.173	1365	6525	39110
2	8110	0	0	8110	83890
3	49000	0.327	16023	32977	0
4	76000	0.231	17556	58444	19000
5	44000	0.269	11836	32164	0

Table 9. Difference in the normalized risk value between the suppliers

N_{12}	N_{42}	N_{52}	N_{32}	N_{41}	N_{51}	N_{31}	N_{54}	N_{34}	N_{35}
0.173	0.231	0.269	0.327	0.058	0.096	0.154	0.038	0.096	0.058

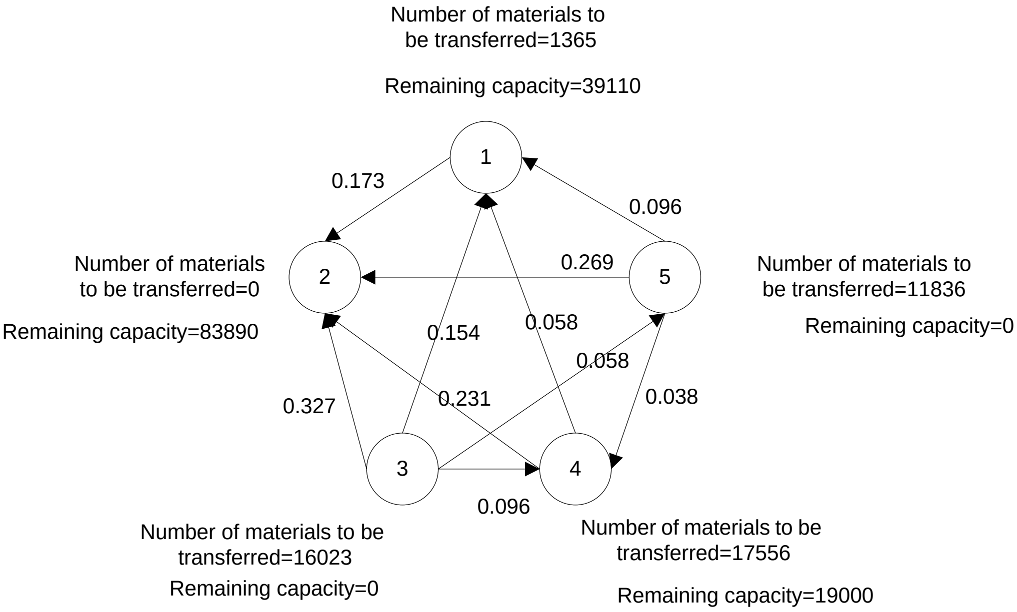

Fig 3. Material flow network based on supplier risk values (Kirilmaz and Erol, 2017)

$$\begin{aligned} MaxZ &= 0.173X_{12} + 0.231X_{42} + 0.269X_{52} + 0.327X_{32} + 0.058X_{41} \\ &+0.096X_{51} + 0.154X_{31} + 0.038X_{54} + 0.096X_{34} + 0.058X_{35} \end{aligned} \tag{31}$$

$$X_{31} + X_{41} + X_{51} - X_{12} \leq 39110 \tag{32}$$

$$X_{12} \leq 1365 \tag{33}$$

$$X_{12} + X_{32} + X_{42} + X_{52} \leq 83890 \tag{34}$$

$$X_{31} + X_{32} + X_{34} + X_{35} \leq 16023 \tag{35}$$

$$X_{34} + X_{54} - X_{41} - X_{42} \leq 19000 \tag{36}$$

$$X_{41} + X_{42} \leq 17556 \tag{37}$$

$$X_{51} + X_{52} + X_{54} \leq 11836 \tag{38}$$

$$X_{35} - X_{51} - X_{52} - X_{54} \leq 0 \tag{39}$$

$$X_{ij} \geq 0 \tag{40}$$

Equations (32), (34), (36) and (39) show the capacity constraints and equations (33), (35), (37) and (38) the constraints on the transported materials. Table 10 presents the results of solving the model in GAMS 24.9.2 and table 11 shows the modified procurement plan. A comparison between the two column of initial and modified procurement planning shows that purchases from risky suppliers are decreased, while purchases from less risky suppliers are increased.

Table 10. The optimal solution

Variable	X_{35}	X_{54}	X_{34}	X_{52}	X_{42}	X_{32}	X_{51}	X_{41}	X_{31}	X_{12}
Value	0	0	0	11836	17556	16023	0	0	0	1365
Z	12715									

Table 11. The initial and modified procurement plan

Supplier	Procurement planning based on cost and carbon emission	Risk value	Procurement planning based on risk, cost and carbon emission
1	7890	50	6525
2	8110	32	54890
3	49000	66	32977
4	76000	56	58444
5	44000	60	32164
Total (part)	185000	-	185000

5- Model validation

Although five suppliers were more than enough for single-commodity suppliers in real-world (Kirlimaz and Erol, 2017), the proposed model was tested and validated ten times using random data as per table 12.

Table 12. Random samples for validating the model (part unit)

Random sample	Initial and modified procurement plan	Supplier				
		1	2	3	4	5
1	Procurement plan based on minimizing carbon emission, cost	0	0	6000	5000	8000
	Procurement plan based on minimizing carbon emission, cost and risk	4100	0	4800	4500	5600
2	Procurement plan based on minimizing carbon emission, cost	1180	820	5000	6000	10000
	Procurement plan based on minimizing carbon emission, cost and risk	6339	529	4079	6000	6053
3	Procurement plan based on minimizing carbon emission, cost	644	356	5000	6000	9000
	Procurement plan based on minimizing carbon emission, cost and risk	379	305	3214	5464	11638
4	Procurement plan based on minimizing carbon emission, cost	0	0	5000	5000	11000
	Procurement plan based on minimizing carbon emission, cost and risk	0	3515	5000	3299	9186
5	Procurement plan based on minimizing carbon emission, cost	8000	2000	5000	5000	1000
	Procurement plan based on minimizing carbon emission, cost and risk	8000	1385	5000	6000	615

Table 12. Continued

Random sample	Initial and modified procurement plan	Supplier				
		1	2	3	4	5
6	Procurement plan based on minimizing carbon emission, cost	6000	4000	6000	5000	0
	Procurement plan based on minimizing carbon emission, cost and risk	4337	6904	3759	6000	0
7	Procurement plan based on minimizing carbon emission, cost	3500	5000	3500	6000	3000
	Procurement plan based on minimizing carbon emission, cost and risk	2039	4223	2379	5359	7000
8	Procurement plan based on minimizing carbon emission, cost	0	4000	8000	8000	4000
	Procurement plan based on minimizing carbon emission, cost and risk	0	3200	5333	7467	8000
9	Procurement plan based on minimizing carbon emission, cost	0	0	5000	6000	10000
	Procurement plan based on minimizing carbon emission, cost and risk	5788	0	4647	4800	5765
10	Procurement plan based on minimizing carbon emission, cost	0	4000	5000	4000	8000
	Procurement plan based on minimizing carbon emission, cost and risk	0	7000	3580	2364	8056

Applying supply chain risk management may not be economically justified from a managerial perspective unless its benefits are elucidated in advance. Given the higher event-related costs than probabilistic costs in terms of performing supply chain risk management (Kirilmaz and Erol, 2017), a balance should be struck between these two costs. A cost analysis was therefore conducted on the 10 datasets and the results were presented in table 13, suggesting an increase of 0.732% in the costs and 3.51% in carbon emission as a result of incorporating the risk into the procurement plan, while the weight of the first objective function is twice as high as that of the second objective function. The data also showed an increase of 0.39%-1.06% in the costs and 0.77%-6.25% in carbon emission at a 95% confidence interval. Analyzing 827 events in 10 years showed a 33%-40% reduction in the stock price of organizations facing risks (Hendricks and Singhal, 2005), which justifies ignoring the cost imposed by the model. The use of new emission standard fuel such as *Euro 5* and *Euro 6* can reduce carbon emission. By means of this approach which reduces the risk and carbon emissions, companies can decrease the vulnerability of their Supply chains and gain competitive advantage.

Table 13. Results of the statistical cost analysis (percentage unit)

Random sample	**Increase in the purchase cost**	**Increase in the transportation cost**	**Increase in the total cost**	**Increase in emission levels**
1	0.95%	3.37%	1.11%	5.03%
2	0.42%	7.29%	0.96%	7.9%
3	1.17%	-1.16%	0.98%	0.34%
4	0.85%	-1.85%	0.66%	12.92%
5	-0.5%	-0.89%	-0.53%	-2.56%
6	0.62%	-6.80%	0.11%	-0.06%
7	0.88%	1.93%	0.95%	2.59%
8	1.43%	-2.44%	1.10%	1.23%
9	0.78%	0.42%	0.75%	3.86%
10	1.52%	-2.01%	1.23%	3.90%
Mean	0.812%	-0.21%	0.732%	3.51%
Standard deviation	0.572%	3.80%	0.545%	4.42%
Variance	0.328%	14.42%	0.297%	19.57%
Confidence interval	0.45%≤μ≤1.16%	2.56%≤μ≤2.14%	0.39%≤μ≤1.06%	0.77%≤μ≤6.25%

6-Conclusion and recommendations

Lower costs, commercial treaties, new markets, developing communication and internet opportunities are some of the ad vantages of globalization. However, cultural diversities, standardization difficulties, political instabilities and extended distances make supply chains more vulnerable to risks. Effective mathematical tools have gained popularity in terms of effective analysis of supply chain risk management. The numerous studies conducted on supply chain risk management are more qualitative than quantitative and model-based. One of the studies is presented by Kirilmaz and Erol. Evaluating the model proposed by Kirilmaz and Erol in an electromotor industry showed its shortcomings. First of all, their model is including failure to include discounts, which was resolved by incorporating incremental discounts into the proposed procedure. The second one is depending on the market demand, manufacturers' demand varies from time to time, and the contract can be modified to change the demand. This study analyzed the risk of decision making using robust planning. Ignoring the costs of reducing carbon emissions was third limitation of the model proposed by Kirilmaz and Erol so the costs were considered in the paper.

This procedure is unique in that risk is quantified and included in the model not in terms of cost but as a value and it proposes a transfer of product strategy. This transfer plan is made before the order and suppliers receive the final product order prepared according to the risk criteria, carbon emission, uncertain demand and the cost including discount.

The proposed model was validated using random data. According to the obtained results of the study, considering the weight of the first objective function to be twice as high as that of the second objective function yielded a mean cost increase of 0.39%-1.06% and a mean carbon emission increase of 0.77%-6.25% at a 95% confidence interval. This paper developed the Kırılmaz and Erol’s model to reflect real world situations. While interviews with the electro motor’s production administrator, production planning manager and engineers indicated that the procedure has yet to be implemented in the company, a preliminary study conducted and based on the proposed procedure suggests that the efficiency of the company’s supply chain can be improved greatly.

It is recommended that further studies be conducted using other robust methods to solve models under uncertainty. Other risks of supply chains can also be incorporated into the model using clustering. The procedure can be extended to multi-period, multi-commodity and multi-echelon supply chains in further studies. The present research used a linearization method rather than mixed-integer nonlinear programming to solve the nonlinear multi-objective model in GAMS.

References

Aboutorab, H., Hussain, O.K., Saberi, M., Hussain, F.K., Chang, E., (2021). A survey on the suitability of risk identification techniques in the current networked environment, *Journal of Network and Computer Applications*, 178

Amornpetchkul, T., (2017). Threshold discounts comparison: All-unit or incremental, *Journal of Revenue and Pricing Management*, 16, 265-294.

Angappa Gunasekaran, (2015). Green supply chain management enablers: Mixed methods research. Sustainable production and consumption, *Sustainable Production and Consumption*, 4, 72-88.

Arntzen, B., Brown, G., Harrison, T., Trafton, L., (1995).”Global supply chain management at digital equipment corporation, *Interfaces*, 25, 69–93.

Baohua, W., and Shiwei, H.E., (2009). Robust optimization model and algorithm for logistics center location and allocation under uncertain environment, *Journal of Transportation Systems Engineering & Information Technology*, 9(2), 69-74.

Chen, J., (2009). Performance Evaluation of Green Supply Chain Based on Entropy Weight Grey System Model, *6th International Conference on Service Systems and Service Management*, 474-478.

Farhang Moghhaddam, B., and Pishvaei Mirsaman, (2013). Robust Optimization Approach to Capacitated SAHLP and MAHLP Models, www.resathesis.ir.

Fatemi Qomi, S.M., (2004). Planning and controlling inventory, *International Publishing Company*, Iran.

Folan, P., and Jim Browne, (2005). A review of performance measurement: towards performance management, *Computers in Industry*, 56, 663– 680.

GAMS Software GmbH, (2020). www.gams.com

Ghodsypour, S.H., and O’Brien, C., (1998). A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, *International Journal of Production Economics*. 56–57, 199–212.

Ghodsypour, S.H., and O’Brien, C., (2001). The total cost of logistics in supplier selection, under conditions of multiple souring, multiple criteria and capacity constraint, *International Journal of Production Economics*, 73.

Gutierrez, G., Kouvelis, P., and Kurawala, A., (1996). A robustness approach to uncapacitated network design problems, *European Journal of Operational Research*, 94, 362–76.

Hendricks, K.B., and Singhal, V.R., (2005). An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm, *Production & Operations Management*, 14(1), 35–52.

Hendijani, R., Saeidi Saei, R., (2020). Supply chain integration and firm performance: the moderating role of demand uncertainty, *Cogent Business & Management*, 7(1), 1-21.

IKCO. (2013). Introduction to Euro Pollution Standards, http://www.ikido.org, Iran Khodro Investment Development Company.

Jianlin Y., (2011). The Risk Management of Supply Chain. In: Proceedings of the International Conference on Management and Service Science (MASS), Wuhan, China, 1–4.

Kaplan, R.S., (1996). Devising Balanced Scorecard as Strategic management System, Harvard Business Review, 10-17.

Kırılmaz, O., and Erol, S., (2017). A proactive approach to supply chain risk management: Shifting orders among suppliers to mitigate the supply side risks, *Journal of Purchasing & Supply Management*, 23, 54–65.

Lee, H.L., (2002). Aligning supply chain strategies with product uncertainties, *California Management Review*, 44(3), 105-119.

Maggioni, F., Potra, F., and Bertocchi, M., (2014). Stochastic versus Robust Optimization for a Transprtation Problem, www.optimization-online.org.

Pan, F., and Nagi, R., (2010). Robust supply chain design under uncertain demand in agile manufacturing, *Computers & Operations Research*, 37, 668-683.

Peck, H., (2006), Reconciling supply chain vulnerability, risk and supply chain management, *International Journal of Logistics Research and Applications*, 9(2), 127-142.

Pishvaee, M.S., Mohseni, S., Bairamzadeh, S., (2021). Uncertainties in biofuel supply chain, *Biomass to Biofuel Supply Chain Design and Planning under Uncertainty, Concepts and Quantitative Methods*, 65-93.

Rad, R.S., and Nahavandi, N., (2018). A novel multi-objective optimization model for integrated problem of green closed loop supply chain network design and quantity discount, *Journal of Cleaner Production*, 196, 1549-1565.

Sadegi Moghadam, S., Hajiaghaei-Keshteli, M., and Mahmood Janlou, M., (2019). Designing a model and providing a solution for the fixed cost transportation problem considering Discount Constraint, *Journal of Transportation Engineering*, 10(3), 635-655.

Saminian-Darash, L., Rabinow, P., (2015), Modes of Uncertainty: Anthropological Cases, *the University of Chicago Press*, Chicago, IL.

Sanchez-Rodrigues, V., Stantchev, D., Potter, A., Naim, M., Whiteing, A., (2008), Establishing a transport operation focused uncertainty model for the supply chain, *International Journal of Physical Distribution & Logistics Management*, 38(5), 388-411.

Shahbandarzadeh, H., and Kabgani, M.H., (2017). Quantitative Analysis of Risks in Green Supply Chain Management Using Mathematical Modeling, *Journal of Business Research*, 82, 1-32.

Snyder, L., and Daskin, M., (2006). Stochastic p-robust location problems, *IIE Transactions*, 38, 971–985.

Stephen, C.H., Leung Sally, O.S., Tsang, W.L., Ng, Y.W., (2007). A robust optimization model for multi-site production planning problem in an uncertain environment, *European Journal of Operational Research*, 181, 224–238.

Surti, C., Hassini, E., and Abad, P., (2013). PRICING AND INVENTORY DECISIONS WITH UNCERTAIN SUPPLY AND STOCHASTIC DEMAND, *Asia-Pacific Journal of Operational Research*, 30(6), 1-25.

Taleizadeh, A., Stojkovska, I., and Pentico, D.W., (2015). An Economic Order Quantity Model with Partial Backordering and Incremental Discount, *Computers & Industrial Engineering*, 82, 21-32.

Tang, C., and Tomlin, B., (2008). The power of flexibility form itigating supply chain risks, *International Journal of Production Economics*, 116, 12–27.

Tomlin, B., (2006).On the value of mitigation and contingency strategies for managing supply chain disruption risks, *Management Science*, 52(5), 639–657.

Tseng, S.H., Wee, H.M., and Song, P.S., (2019). Optimal green supply-chain model design considering full truckload, *Kybernetes*, 48(9), 2150-2174.

Van Landeghem, H., and Vanmaele, H., (2002). Robust planning: a new paradigm for demand chain planning, *Journal of Operations Management*, 20.

Wang, M., (2018). Impacts of supply chain uncertainty and risk on the logistics performance, *Asia Pacific Journal of Marketing and Logistics*, Vol. 30 Issue: 3, pp.689-704

Zahraee, S.M., Golroudbary, S.R., Shiwakoti, N., Stasinpoulos, P., Kraslawski, A., (2020). Transportation system analysis of empty fruit bunches biomass supply chain based on delivery cost and greenhouse gas emission, *Procedia Manufacturing*, 51, 1717-1722.

Zhao, R., Liu, Y., Zhang, N., Huang, T., (2017). An Optimization Model for Green Supply Chain Management by Using a Big Data Analytic Approach, *Journal of Cleaner Production*, 142(2), 1085-1097.

Appendix A– GAMS Code

```
sets
i suppliers /supplier1*supplier5/
j Manufactures /manufacture1*manufacture3/
s /1,2,3/
m /1,2/
t /1,2,3/;

parameters
a(i) capacity of supplier i in cases
/supplier1 47000, supplier2 92000, supplier3 49000, supplier4 95000, supplier5 44000/

d(j) demand
/manufacture1    0
 manufacture2    0
 manufacture3    0/;

table l(i,j) length route
            manufacture1      manufacture2          manufacture3
supplier1       100               150                   150
supplier2       100               150                   160
supplier3       80               120                   80
supplier4       120               130                   50
supplier5       90               90                   95;


table p(i,m) purchasing cost with discount
                    1       2
supplier1      100      90
supplier2      100      95
supplier3      90       85
supplier4      90       70
supplier5      100      85;

table b(j,s) demand at manufacture j in cases
                            1           2        3
 manufacture1  49000   80000     60000
 manufacture2  60000   50000     80000
 manufacture3  95000   30000     45000;

table u(j,t) demand at manufacture j in cases
                1       2         3
 manufacture1  49000   80000     60000
 manufacture2  60000   50000     80000
 manufacture3  95000   30000     45000;



table c(i,j) transport cost
            manufacture1      manufacture2          manufacture3
supplier1       8.5               13                   13
supplier2       8.5               13                   14
supplier3       7               10                   7
supplier4       10               11                   5.5
```

```
supplier5       8                  8                      9;

parameters
zl(s) extera
/1  0
 2  0
 3  0/;

 parameters
wl(t) extera
/1  0
 2  0
 3  0/;

scalar risk/1000/;
scalar Em/1.5/;
scalar co/40000/;

variables   y(i,j)   shipment quantities in cases
            z        total transportation costs
            w         polution rate
            g        final objective;
positive variable y;
binary variable o;
binary variable x;

equations
cost         define objective function 1
supply(i)    observe supply limit at supplier i
demand(j)    satisfy demand at manufcature j
decision(i)  decision constraint
regret(s)    regret constraint
regret1(t)    regret constraint
polution     define objective function 2
multiobject  define multiobjective function
weight
pmin(i,j,m)
pmax(i,j,m);

cost..         z=e=sum((i,j,m),c(i,j)*y(i,j)+p(i,m)*y(i,j)*x(m));
polution..     w=e=sum((i,j),l(i,j)*y(i,j)*Em);
multiobject..  g=e=(2/3)*(z/sum((i,j,m),c(i,j)+p(i,m)*x(m)))+(1/3)*(w/Em*sum((i,j),l(i,j)));
supply(i)..    sum(j,y(i,j))=l=a(i)*o(i);
demand(j)..    sum(i,y(i,j))=g=d(j);
decision(i)..  sum(j,y(i,j))=g=o(i);
regret(s)..    (z-zl(s))/(zl(s))=l=risk;
regret1(t)..    (w-wl(t))/(wl(t))=l=risk;
pmin(i,j,m)..   y(i,j)=l=x("1")*(co);
pmax(i,j,m)..   y(i,j)=g=x("2")*(co+eps);
weight..        sum(m,x(m))=e=1;

option threads=0;
option MINLP=bonmin;

model robustl
```

```
/cost,supply,demand,decision,weight,pmin,pmax/;
loop(s,
d(j)=b(j,s);
solve robustl using MINLP minimizing z;
zl(s)=z.l;
display zl;
);

model robust2
/polution,supply,demand,decision/;
loop(t,
d(j)=u(j,t);
solve robust2 using MIP minimizing w;
wl(t)=w.l;
display wl;
);

model robust/all/;
solve robust using MINLP minimizing g;
parameter time;
time=robustl.resusd+robust2.resusd+robust.resusd;
display y.l,z.l,w.l,g.l,time;
```