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Designing a closed loop supply chain network for engine oil in an uncertain environment: A case study in Behran Oil Company

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Abstract

The increase in demand for petroleum derivatives such as engine oil has contributed to not only the rapid and adequate response to them, but also attracting many managers and researchers to control their adverse environmental impacts. In this regard, this study unveils an optimization model to develop a closed loop supply chain network for engine oil in an uncertain environment. In the concerned model, in addition to addressing supply chain costs, adverse environmental effects are also minimized. To solve the proposed multi-objective model and acquire Pareto optimal solutions, the goal programming approach is deployed. The demand and amount of recyclable materials are considered to be imbued with uncertainty, which a robust optimization approach is devised to capture it. Likewise, new methods are taken into account to recycle engine oil, being capable of supporting both economic and environmental benefits. Lastly, a case study is utilized to evaluate and validate the presented model, through which outstanding management results are derived.

Keywords: Closed loop supply chain, environmental effects, uncertainty, robust optimization, goal programming

1-Introduction

Nowadays, in the global competitive market, manufacturing high quality products in accordance with customers' requirements is one of the most fundamental principles of durability and stability of companies. Meanwhile, the demand for various products is increasing every day, putting a lot of pressure on manufacturers and suppliers of raw materials (Ebrahimi, 2018). Among the manufacturers, the greatest impact is on the manufacturers and suppliers of petrochemical and petroleum products. In this manner, companies are forced to increase production volume to meet customer needs. One of the advantages of such situation is flexibility in sales. On the other side, price fluctuations in the supply of raw materials and other items contribute to the complexity of management and control (Husain, Assavapokee, & Khumawala, 2006). Among petrochemical products, car engine oil is of great importance owing to the increase in the number of cars manufactured. The production of engine oil may be hampered by problems such as expensive raw material, which may interfere with customer demand (Salem, Salem, & Babaei, 2015). Accordingly, it is incumbent upon to manage the engine oil supply chain. In view of the complexity of supply chain management, its various aspects are examined in this study.

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In general, there are two main categories of supply chain management. The first is direct supply chain management, which aims to improve system performance in responding appropriately the demand. The second is reverse supply chain management, which includes economic strategy, government guidelines, and environmental considerations (Amin & Zhang, 2013). Similarly, by integrating direct supply chain management and reverse supply chain management, closed loop supply chain management is introduced. Closed loop supply chain management is presented for recyclable products such as car batteries, paper and syringes (Paydar, Babaveisi, & Safaei, 2017). As mentioned earlier, the demand for engine oil is increasing, which is followed by the rapid increase in the amount of used (burned) engine oil. Increasing the amount of used engine oil is associated with the increase of the emission of dangerous environmental pollutants, which threatens the health of the environment, water and even humans (Botas, Moreno, Espada, Serrano, & Dufour, 2017; Rincón, Cañizares, & García, 2005, 2007; Salem et al., 2015).

Given the problems caused by the increase in used engine oil, it is apparent that the collection, transportation and recycling of used engine oil should be done within the framework of environmental considerations. Used engine oil has a high value because it has the ability to be converted to energy or raw materials to regenerate engine oil. Thus, closed loop supply chain management in engine oil manufacturing process is of great importance. In this supply chain, used engine oil is collected from engine oil demand centers and sent to recycling centers. Used engine oil is refined and recycled by various methods in oil recycling centers. One of the most basic methods of recycling used engine oil is solvent (Rincón et al., 2007). The use of ethane is another method of recycling used engine oil, in which the extraction of unnecessary materials is reduced and the quality of the refined base oil will increase (Rincón et al., 2005). In accordance with studies on used engine oil recycling methods, the greatest focus is on the feasibility of the proposed method or the effects of the factors involved in the recycling of used engine oil. The proposed method presented in this study for recycling used engine oil, in addition to having the high ratio of converting used engine oil to base oil, environmental considerations are also taken into account. In this method, a proportion of recycled engine oil that is non-recyclable can also be converted into a secondary product and sent to the market.

In closed loop supply chain network for used engine oil, the parameters of demand for engine oil and the amount of engine oil collected from the demand centers are in uncertain conditions (Paydar et al., 2017). The uncertainty of some parameters can put the model in a critical situation or impose a high cost on the model by affecting the activation or non-activation of the equipment (Pishvaee, Rabbani, & Torabi, 2011). Uncertainty is divided into two main groups based on the research by Dehghani, Jabalameli, Jabbarzadeh, & Pishvaee (2018). The first group is dedicated to the uncertainty resulting from crises, and the second group is pertaining to the uncertainty caused by the inherent changes in parameters, called business uncertainty. To deal with business uncertainty, two methods are commonly used: stochastic programming and robust planning. In accordance with the models examined, the stochastic programming model is the best suggestion for optimizing the model with this type of uncertainty. But it has some drawbacks. The first drawback of this approach is that the access to the probability distribution of uncertain parameters may be impossible. The second is that in real-world problems with large dimensions, it imposes too many complexities on the model. For this reason, a robust optimization approach is exploited to address this type of uncertainty. A robust optimization approach is a conservative approach to achieve solutions that does not increase the complexity of the model (Yu & Li, 2000; Yuan, Li, & Huang, 2016).

According to previous studies, the control and collection of used engine oil is of great importance and the need for closed loop supply chain management of engine oil is well felt. In this study, taking into account the new methods used in the field of engine oil recycling, an attempt has been made to consider economic and environmental goals simultaneously. In the concerned model, the parameters of demand and used engine oil, which are returned from the demand centers, are considered to be imbued with uncertainty. In order to solve the multi-objective model and obtain optimal Pareto answers, the goal programming approach is devised. Eventually, the model validation is measured with the aid of data from Behran Oil Company.

According the above-mentioned discussion, the important innovations obtained from the literature are introduced as follows:

- Incorporating new recycling methods into the proposed model for recycling used engine oil.
- Given some parameters of the proposed model are hemmed in by uncertainty, a robust optimization approach is devised to deal with this uncertainty.
- Utilizing real data of Behran Oil Company to evince the efficiency and credibility of the proposed model.

The structure of the presented article is as follows. In the next section, the methodology used in the proposed model is examined. In section 3, statement of the problem and the optimization model will be provided. The method used to deal with uncertainty will be elucidated in section 4. In section 5, the goal programming method for solving the multi-objective model is given. Section 6 includes a case study and its results, and finally, section 7 will present the results of this research and future suggestions.

2-Methodology

As shown in figure 1, the methodology applied to solve the model comprises of four-stages. In the first stage, due to the significance of the issue and the existing complexities in the petrochemical industry, an attempt is made to develop a closed-loop supply chain model to deal with the existing problems. Owing to the variety of objectives in the proposed model, we are faced with a multi-objective model. Accordingly, in the second stage, a goal programming method is employed to solve the multi-objective problem. In the introduced model, some parameters are hemmed in by uncertainties. Therefore, in the third stage, a robust optimization method is exploited to deal with model uncertainty. Eventually, in the last phase, the validation of the proposed model is examined according to the real data of Behran Oil Company.

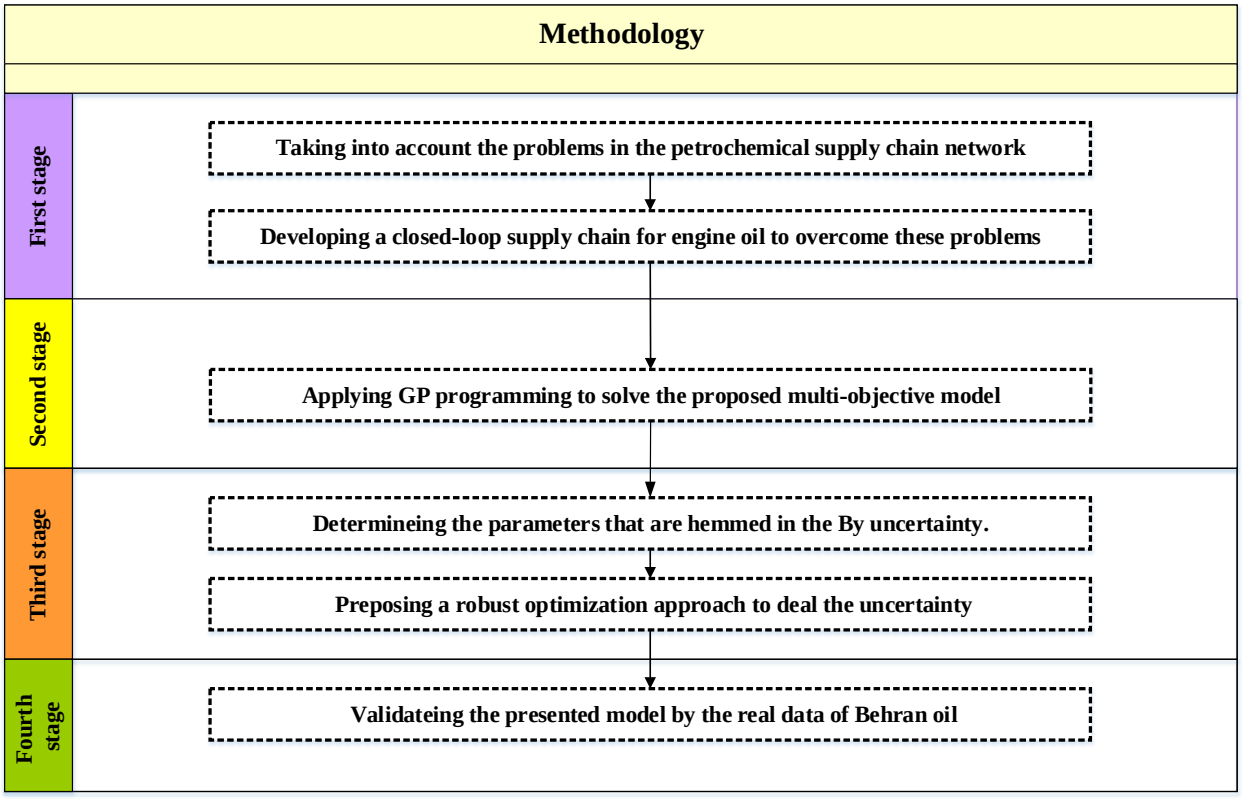

Fig 1. Methodology

3-Problem description

Inspired by the case study, in this section, the descriptions of the closed loop supply chain are examined. Figure 1 shows this supply chain under review. As can be seen, the closed loop supply chain network includes suppliers, manufacturers, the main product demand market, the recycling center, the disposal center, and the secondary product demand market.

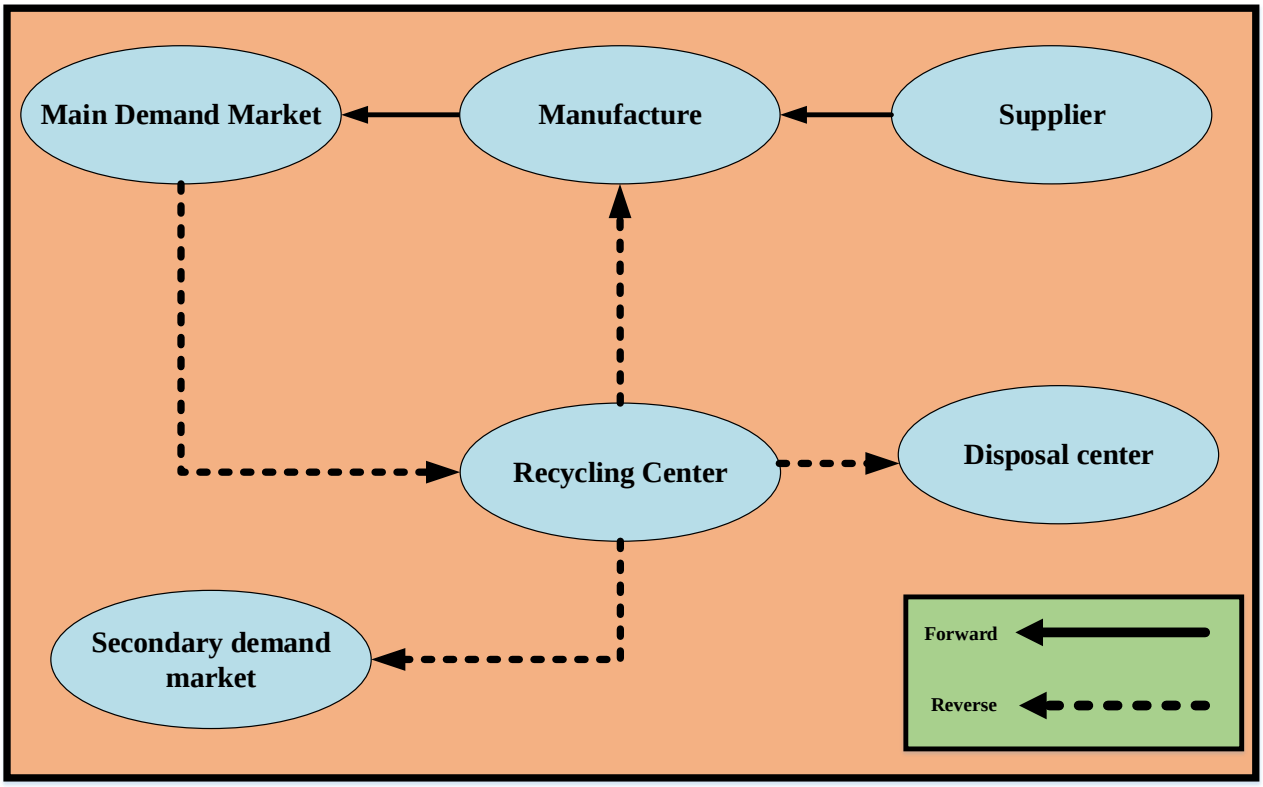

Fig 2. Supply chain network structure.

According to figure 2, in this network, raw materials are sent from suppliers to production centers. The product is then sent to the main product demand centers. At the end of the useful life of the products in the demand centers, the products used are collected from the demand centers and sent to the recycling centers. It should be noted that the most important decisions about the model are made in introduced recycling centers. Due to the fact that the main product in the proposed model is car engine oil, so various technologies are used in recycling centers to recycle engine oil. In this research, two types of traditional and modern technology have been considered for recycling engine oil. The traditional technology, introduced by Rincón et al. (2007), engine oil is purified and refined by solvents. In this method, a percentage of the used engine oil is refined and a percentage of it that cannot be recycled is sent to the disposal centers for disposal. On the other hand, there is one of the new recycling methods called KTI exclusive, which is used to recycle engine oil. This model, despite the high cost of activation, is able to return a significant percentage of engine oil to the production cycle and a percentage that cannot be recycled turns into bitumen. The recycled materials obtained from this method have a standard quality and the conversion performance of the returned engine oil to the raw materials in this method is approximately 82% (Hamawand, Yusaf, & Rafat, 2013).

The following assumptions are considered in this study:

- Each of the suppliers, manufacturers, and recycling centers has limited capacities.
- Proposed model is considered as single period.
- Recycling capacity of each presented recycling method is limited.
-

3-1-Mathematical model

This section introduces indexes, parameters and variables used in the proposed model and then the model is presented.

3-1-1-Sets

I	Set of manufacturers of main products	$I = 1, 2, ..., i$
J	Set of variation of products	$J = 1, 2, ..., j$
P	Set of main products demand points	$P = 1, 2, ..., p$
R	Set of suggested locations to establish recycling centers	$R = 1, 2, ..., r$
L	Set of suggested locations to establish disposal centers	$L = 1, 2, ..., l$
M	Set of variation of proposed recycling methods	$M = 1, 2, ..., m$
N	Set of variation of proposed disposal methods	$N = 1, 2, ..., n$

3-1-2-Parameters

CP_j	Manufacturing cost of main product *j*
CPP_r	Manufacturing cost of secondary product in recycling center *r*
SC_m	Recycling cost of main products returned to recycling centers using recycling technology *m*
$CTPM$	Transportation cost of main products from manufacturers to demand markets
$CTMC$	Transportation cost of returned goods from demand markets to recycling centers
$CTCP$	Transportation cost of main products returned from recycling centers to manufacturers
$CTCD$	Transportation cost of main products returned from recycling centers to disposal centers
$CTDC$	Transportation cost of secondary product from recycling centers to demand market of secondary product
$DBPM_{ip}$	Distance between manufacturer *i* and demand market *p*
$DBMC_{pr}$	Distance between demand market *p* and recycling center *r*
$DBCP_{ri}$	Distance between recycling center *r* and manufacturer *i*
$DBCD_{rl}$	Distance between recycling center *r* and disposal *l*
$DBPD_r$	Distance between recycling center *r* and secondary product market demand
FP_i	Fixed cost of manufacturer establishment in suggested location *i*
FR_r	Fixed cost of recycling center establishment in suggested location *r*
FD_l	Fixed cost of disposal center establishment in suggested location *l*

$CDRP_{ln}$	The cost of burying each liter of non-recyclable returned goods in the disposal center *l* using the disposal method *n*
PCE	The selling price per liter of the main recyclable returned products to the manufacturers
CIS_{Upper}	Maximum purchase price per liter of the main recyclable returned products to the manufacturers
CIS_{Lower}	The minimum purchase price per liter of the main recyclable returned products to the manufacturers
PIS	Selling price per Kg of secondary product manufactured in recycling centers
CS	The amount of savings in sending recycled raw materials from recycling centers to manufacturers
ψ_m	The least ratio of recyclability of the main returned products in recycling centers using recycling technology *m*
RBP_{pj}	The amount of main returned products *j* from demand markets *p*
CAR_r	The capacity of recycling center *r* for the whole main returned products
CAD_l	The capacity of burying in disposal center *l* for unrecyclable main returned products
$CAMP_{ij}$	Manufacturing capacity of manufacturer *i* for main product *j*
λ_{pj}	Shortage cost of main product *j* in demand market *p*
$FCTR_m$	Fixed cost of creating recycling technology *m*
$FCTD_n$	Fixed cost of creating disposal technology *n*
D_{pj}	Demand amount of main product *j* in demand market *l*
RPR_{rm}	The amount of pollution resulting from the recycling of each liter of recyclable goods using the recycling method *m* in the recycling center *r*
RPD_{ln}	The amount of emissions from the disposal of each liter of non-recyclable returned goods using the disposal method *n* at the disposal center *l*
PRT	The amount of emissions from the transportation of each liter of main products
$PRST$	The amount of emissions from the transportation of each liter of secondary products
$Balance$	The ratio of balance between supply and demand of the main product

3-1-3-Decision variables

X_{ijp}	The amount of dispatching the main product (in liters) *j* from the manufacturer of *i* to the demand market *p*
V_{pr}	Total amount of main product (in liters) returned from market demand *p* to recycling centers *r*
Y_{rl}	Total amount of non-recyclable returned main products (in liters) for transfer from recycling centers *r* to disposal centers *l*
U_{ri}	Total amount of dispatching recyclable main products from the recycling center *r* to the manufacturer *i*
SL_{pj}	The shortage of the main product *j* in the demand market *p*
CIS	The purchase price per liter of the main products returned from the demand markets
Z_i	Equal to one if the manufacturer is established at the proposed location *i* and otherwise equal to zero
W_r	Equal to one if the recycling center is established at the proposed location *r* and otherwise equal to zero

O_l	Equal to one if the disposal center is established at the proposed location *l* and otherwise equal to zero
ASP_r	The amount of secondary product manufactured in the recycling center *r*
Q_{rm}	Equal to one if recycling technology *m* is used in the new recycling center *r*, and otherwise equal to zero
$T_{\ln}$	Equal to one if the burying technology *n* is used at the disposal center *l* and otherwise equal to zero

3-1-4-Objective functions

$$
\begin{aligned}
Min\ Z_1^{eco} &= \sum_i FP_i Z_i + \sum_r FR_r W_r + \sum_l FD_l O_l + \sum_m FCTR_m Q_{rm} + \sum_n FCTD_n Q_{\ln} + \\
&\sum_i \sum_j \sum_p CP_j X_{ijp} + CTPM \sum_i \sum_j \sum_p DBPM_{ip} X_{ijp} + CTMC \sum_p \sum_r DBMC_{pr} V_{pr} + \\
&CTCP \sum_r \sum_i DBCP_{ri} U_{ri} + CTCD \sum_r \sum_l DBCD_{rl} Y_{rl} + DBPD \sum_r DBPD_r ASP_r + \\
&\sum_r CPP_r ASP_r + \sum_p \sum_r \sum_u SC_u V_{pr} + \sum_l \sum_n CDRP_{\ln} T_{\ln} + \sum_p \sum_j \lambda_{pj} SL_{pj} - PIS \sum_r ASP_r \\
&-CS \sum_r \sum_i U_{ir}
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
Min\ Z_2^{env} &= PRT \sum_i \sum_j \sum_p DBPM_{ip} X_{ijp} + PRT \sum_p \sum_r DBMC_{pr} V_{pr} + \\
&PRT \sum_r \sum_i DBCP_{ri} U_{ri} + PRT \sum_r \sum_l DBCD_{rl} Y_{rl} + PRST \sum_r DBPD_r ASP_r + \\
&\sum_r \sum_l Y_{rl} RPD_{rl} + \sum_p \sum_r RPR_{pr} V_{pr}
\end{aligned}
\tag{2}
$$

Objective function1 (Z_1^{eco}) minimizes total cost of supply chain. These costs include manufacturing centers establishment cost, recycling centers establishment cost considering introduced technologies, disposal centers establishment cost considering introduced technologies, final product manufacturing cost, transport cost between different centers of network, shortage cost if any shortage happens, recycling cost for goods returned from demand markets and the amount of secondary products manufactured in recycling centers and the amount of savings in returned goods recycling in recycling centers which are considered negative in cost objective function.

Objective function2 (Z_2^{env}) shows the minimization of emission. The pollution includes pollution caused by recycling of goods returned to recycling centers, goods transportation between different centers of network, destructing non-recyclable goods and manufacturing secondary product in recycling centers that are considered in objective function.

3-1-5-Constraints

$$\sum_{i} X_{ijp} + SL_{pj} \geq D_{pj} \qquad \forall p, j \qquad (3)$$

$$\sum_{j}\sum_{p} X_{ijp} \leq \sum_{j} CAMP_{ij} Z_{i} \qquad \forall i \qquad (4)$$

$$\sum_{p} V_{pr} \leq CAR_{r} W_{r} \qquad \forall r \qquad (5)$$

$$\sum_{r} Y_{rl} \leq CAD_{l} O_{l} \qquad \forall l \qquad (6)$$

$$\sum_{r} V_{pr} \leq \sum_{i}\sum_{j} X_{ijp} \qquad \forall p \qquad (7)$$

$$\sum_{r} V_{pr} \geq \sum_{j} RBP_{pj} \qquad \forall p \qquad (8)$$

$$\sum_{p} \psi_{m} V_{pr} \geq \sum_{i} U_{ri} \qquad \forall i \qquad (9)$$

$$\sum_{p} V_{pr} = \sum_{i} U_{ri} + \sum_{l} Y_{rl} + ASP_{r} \qquad \forall r \qquad (10)$$

$$CIS_{Lower} \leq CIS \leq CIS_{Upper} \qquad (11)$$

$$\frac{\left(\sum_{p}\sum_{j} RBP_{pj} - \sum_{r}\sum_{i} U_{ri}\right)}{\sum_{p}\sum_{j} RBP_{pj}} = \frac{(PCE - CIS)}{PCE} \qquad (12)$$

$$\sum_{m} Q_{rm} = W_{r} \qquad \forall r \qquad (13)$$

$$\sum_{n} T_{\ln} = O_{l} \qquad \forall l \qquad (14)$$

$$\sum_{r} U_{ri} \leq \sum_{p} \sum_{j} X_{ijp} \qquad \forall i \qquad (15)$$

$$\frac{\sum_{i} X_{ijp}}{D_{pj}} \geq Balance \qquad \forall p, j \qquad (16)$$

$$X_{ijp}, V_{pr}, Y_{rl}, U_{ri}, SL_{pj}, CIS, ASP_{r} \geq 0 \qquad (17)$$

$$Z_{i}, W_{r}, O_{l}, Q_{rm}, T_{\ln} \in \{0,1\} \qquad (18)$$

Constraint 3 relates to the relationships between demand and the manufacturing volume of the main products. Constraints 4, 5 and 6 are considered due to the limited capacity of the manufacturers of the main product, recycling centers and disposal centers. Constraint 7 shows that going flow is greater than the return flow. Constraint 8 refers to the fact that all returned goods are collected in a combined form in recycling centers due to their inseparability. Constraint 9 refers to the maximum amount of returned goods according to the technology used in recycling centers that are converted into raw materials. Constraint 10 states that the amount of returned goods from the demand markets will be recycled and returned to the production centers, or they are non-recyclable and disposed, or they will be converted to secondary product in recycling centers.

Constraint 11 points to the fact that the purchase price of returned goods from the demand markets will vary within a permitted range. Constraint 12 describes the price elasticity of demand. The price elasticity of demand is intended to assess changes in manufacturing volume relative to price changes. Ideally, this value is set to zero. Constraints 13 and 14 indicate that each of the active recycle and disposal centers is required to implement one of the technologies introduced. Constraint 15, like constraint 7, indicates that the going flow rate must be greater than the return flow. Constraint 16 is intended to include customer satisfaction in the stated model. In such a way that, according to this constraint, the supply-demand ratio is determined. It means that if this ratio is considered to be 0.5, for example, at least half of the demand for each demand center must be met. Constraints 17 and 18 specify the type of variables.

4-Robust optimization method

Many optimization methods have been implemented based on the certainty of the model parameters, which is impossible in real world. In fact, much of the information about model parameters is in uncertain condition due to the randomness or error in measurement (Li, Ding, & Floudas, 2011). One of the problems with the uncertainty of the parameters is that it has a great effect on solving the optimization problem and may even lead to sub-optimization (Ben-Tal, A., El Ghaoui, L., & Nemirovski, 2004). For this purpose, a robust optimization approach is used to deal with uncertainty. One of the first approaches to robust optimization is provided by Soyster (1973), that offers the most conservative approach. Although this method guarantees the efficiency of the model in facing all possible states, it is important to obtain an approach that interacts between the robustness of the model and its performance (Soyster, 1973). In order to achieve this purpose, the approach of robust optimization of Bertsimas and Sim is presented. This approach is based on considering the uncertainty budget in order to control the degree of conservativism of the proposed solution (Bertsimas & Sim, 2004). It is notable that this method of robust optimization is based on a hybrid distance and creation a multi-dimensional uncertainty set (Li et al.,

2011). In this section, we will describe the robust optimization approach provided by Bertsimas and Sim (2004).

$$\max_{x \in X} c^{'} x$$
$$s.t:$$
$$A\,x \le b \tag{19}$$

Given relation 19, *c* is the vector of the coefficients related to the objective function, *x* is the vector of the decision variables, *A* is the matrix of the left coefficients, and *b* is the vector of the parameters of the right. In this model, it is assumed that each element in matrix *A* has uncertainty. Therefore, without losing the generalities, we will only focus on the constraints of the mathematical model, which is in uncertainty, as follows:

$$\sum_j \tilde{a}_{ij} x_j \le b_i \tag{20}$$

In equation (20), the coefficient $\tilde{a}_{ij}$ represents an uncertain parameter. In the Bertsimas and Sim model, it is assumed that each of the parameters in the uncertain conditions is formulated as follows (Bertsimas & Sim, 2004):

$$\tilde{a}_{ij} = \bar{a}_{ij} + \xi_{ij} \hat{a}_{ij} \tag{21}$$

In relation 20, $\overline{a_{ij}}$ shows the nominal value of an uncertain parameter, ξ_{ij} is a symmetrical and independent variable in the range of $[-1,+1]$. $\hat{a}_{ij}$ shows the maximum tolerance for the uncertain parameter $\tilde{a}_{ij}$. In the proposed method, an uncertainty budget, shown by Γ_i parameter, is defined to adjust the level of conservatism in the ith constraint. The parameter Γ_i is in the range $[0,|j|]$, as J_i is a set of parameters in column *i* that has uncertainty (Gregory, Darby-Dowman, & Mitra, 2011):

The approach of robust optimization is defined based on the set of uncertainty in relation 22:

$$U = \left\{ \xi \mid \sum_{\forall j \in J_i} |\xi_{ij}| \le \Gamma_i ; |\xi_{ij}| \le 1 \;\; \forall j \in J_i \right\} \tag{22}$$

Considering the above mentioned conditions, the robust counterpart Bertsimas and Sim is stated as below:

$$\begin{aligned} &\sum_j \bar{a}_{ij} x_j + z_i \Gamma_i + \sum_{j \in J_i} p_{ij} \le b_i \\ &z_i + p_{ij} \ge \hat{a}_{ij} |x_j| \quad \forall j \in J_i \\ &z_i \ge 0 \\ &p_{ij} \ge 0 \quad \forall j \in J_i \end{aligned} \tag{23}$$

5-Goal programming

The goal programming approach is one of the most important models offered for solving multi-objective models. In linear programming models, it is common to set a goal for the model. For this purpose, goal programming can be introduced as a developed mode of linear programming model in which different ideals of objective functions are tried to be considered. In the goal programming method, each of the objective functions is considered as a constraint of the model. The values on the side of each constraint indicate the ideal of the objective function, and the difference between the objective functions and the desired ideals is indicated by a deviation variable, which aims to minimize the amount of deviation (Dauer & Krueger, 1977). In this case, it is obvious that there will be a conflict between the objective functions, which is solved by weighting or prioritizing the target functions (Zografos & Davis, 1989). Another advantage of the goal programming approach is that it does not need to replace the target functions with a single value in order to evaluate the different scenarios. In addition, the goal programming method will require the least amount of decision-making information to solve the model (Cohon, 2004).

In order to introduce the goal programming approach, consider the following multi-objective model:

$$\begin{aligned} &Min\left(F_1(x), F_2(x), ..., F_n(x)\right) \\ &X \in S \end{aligned} \tag{24}$$

Each objective function is determined as $F_1(x), F_2(x), ..., F_n(x)$ and X vector is related to decision variables of the model. S shows the feasibility of the problem (Dauer & Krueger, 1977).

In the following, each of the objective functions is appended to the constraints of the main model in the form of a new constraint:

$$\begin{aligned} &F_1(x) - d_1^+ = b_1 \\ &F_2(x) - d_2^+ = b_2 \\ &. \\ &. \\ &. \\ &F_n(x) - d_n^+ = b_n \\ &X \in S \end{aligned} \tag{25}$$

In a way that b_1 is the ideal value of first objective function, b_2 is the ideal value of second objective function and b_n shows the ideal value of nth objective function. $(d_1, d_2, ..., d_n)$ also represent objective functions deviation variables of ideals (Zografos & Davis, 1989).

Finally, the ideal objective function is introduced as below:

$$MinimizeF = P_1 d_1^+ + P_2 d_2^+ + ... + P_n d_n^+ \tag{26}$$

According to relation (26), F represents the value of ideal objective function, P_1 is the weight of first objective function, P_2 is the weight of second objective function and P_n represents the weight of nth objective function.

6-Case study

Behran Oil Company is one of the most reputable companies in the Iran market, which operates in the petroleum and petrochemical products industry. This company started its activities since 1964 under the ESSO brand, which produced ESSO oil in Iran, and since 1966, it continued its work under the name of Oil Production and Refining Company. Behran Oil Company established its first refinery in 1968, with a production capacity of 30,000 tons of engine oil per year. In 1984, the company continued its activities under the new name of Tehran Oil Refining. Finally, in 1991, the company's name was changed to Behran Oil Company. This company succeeded to produce antifreeze in 1992. One of the most durable products of this company is high quality paraffin wax produced by sweating method, which was produced for the first time in the country in 1993. At present, the company has the capacity to produce 400,000 tons of various products, the most important of which are engine oil, industrial oil, grease and antifreeze.

Two types of engine oil are considered in this study to implement a case study. First is mineral engine oil that is commonly used in older cars, and the second type is synthetic engine oil, which is used in newer cars.

6-1-Case study evaluating and implementing

The model is solved by *GAMS* software (Intel(R) core(TM) i7 6500 U CPU @ 2.50 GHz) and the results are discussed in different situations:

6-1-1-The effect of objective functions weights on ideals deviation

As mentioned earlier, the goal programming method has been used to solve the multi-objective model. In this section, according to the weight allocated to the amount of deviations of the objective functions of the desired ideals, the value of the ideal objective function is calculated and the results of the solution are presented in Figure 2. It is to note that the weight of the deviation function of the economic objective function from its ideal value is shown by w_1 and the weight of the deviation function of the environmental objective function from its ideal value is shown by w_2.

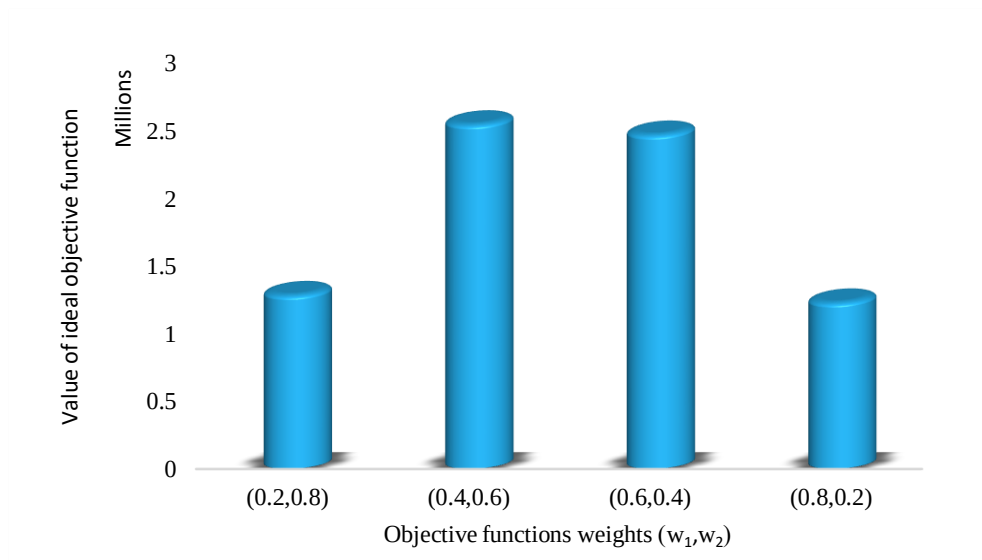

Fig 3. The effects of objective functions weights on ideals deviations.

According to figure 3, it is clear that by increasing the weight of the economic objective function up to the value of 0.4, the value of the ideal objective function will increase, and then the value of the ideal objective function follows the downward trend. One of the highlights of figure 3 is that the values of the ideal function for the starting and ending points are almost close to each other. This means that the value of the ideal objective function approaches its optimal value when the weight difference allocated to the deviation of two objective functions is significant. On the other hand, when the weights are close to each other, the value of the ideal objective function will increase significantly.

6-1-2- The effect of uncertainty budget parameter on the value of economic objective function

As noted in section 3, the approach used to deal with uncertainty is the approach to Bertsimas and Sim (2004). One of the effective parameters in this method is the uncertainty budget parameter. In this section, the effect of this parameter on the value of the economic objective function is discussed. In order to investigate the effects of this parameter on the value of the economic function at this stage, the value of this parameter is changed from 0.1 to 2 and the value of the economic objective function for each of the values allocated to the uncertainty budget parameter has been calculated and the results are shown in figure 4.

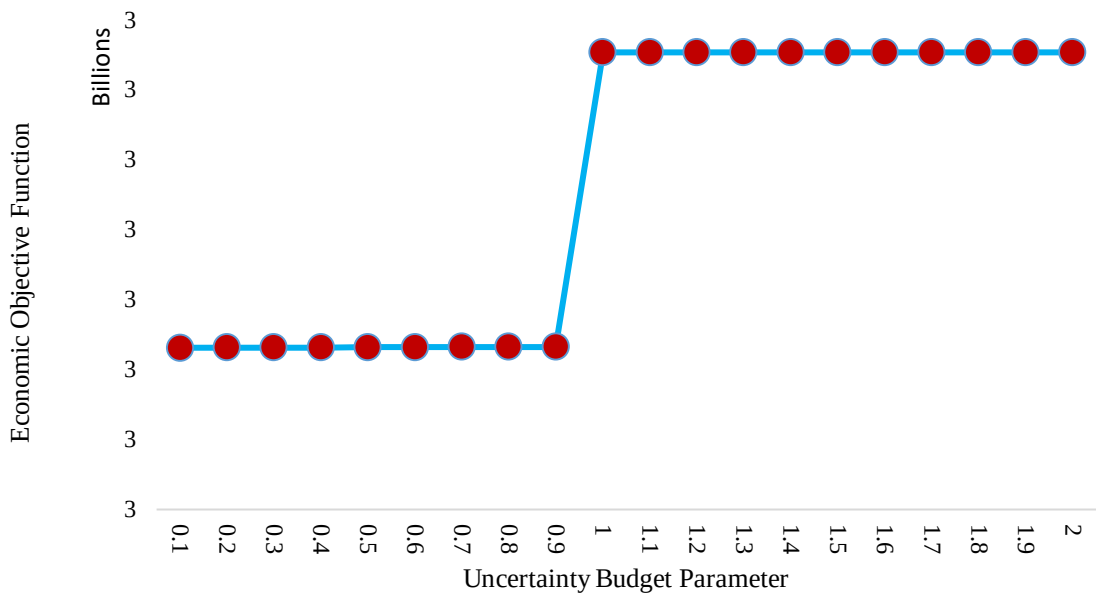

Fig 4. The effect of uncertainty budget parameter on the value of economic objective function

According to figure 3, the increase in the uncertainty budget parameter leads to an increase in the value of the economic objective function, and this increase is not noticeable as long as the uncertainty budget parameter value is less than 1, but when the value of the uncertainty budget parameter increases to 1, the value of the economic objective function suddenly increases significantly, and finally, for values greater than 1 up to the value of 2, the amount of increase in the value of the economic objective function is not significant.

6-1-3-The effect of the balance ratio between supply and demand in the model

Another effective parameter in the proposed model is the balance ratio between supply and demand. Using this parameter, a balance is created in the supply of products through all demand centers. Obviously, if the objective is to meet all the requirements, this parameter will take the value of 1. In this

section, the effects of the balance ratio between supply and demand on the value of the economic objective function and the environmental objective function are examined and the results are presented in figure 5.

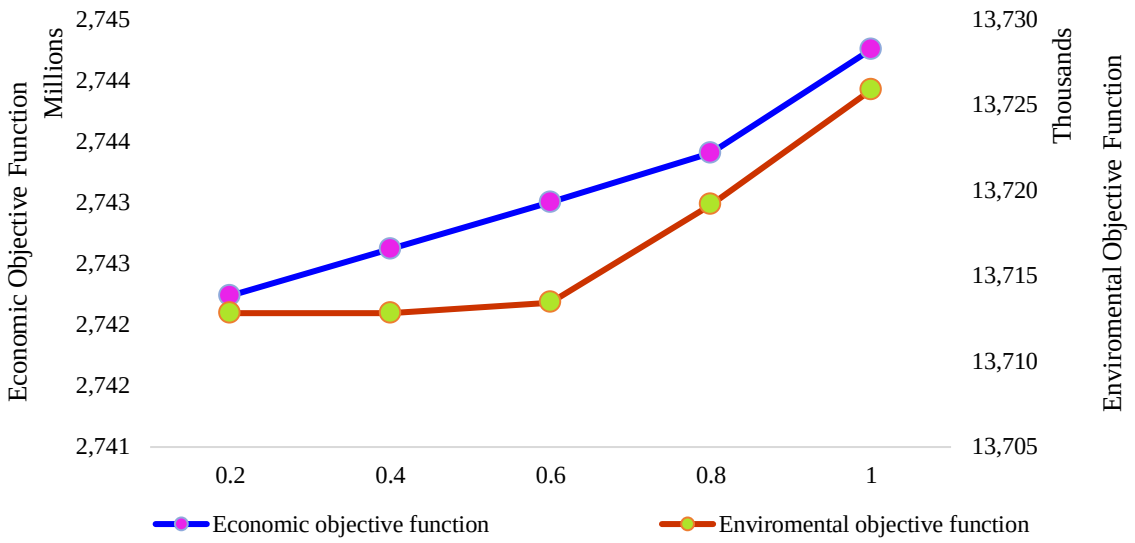

Fig 5. The effect of balance ratio between supply and demand on economic and environmental objective functions

According to figure 5, it is clear that increasing the parameter of balance between supply and demand leads to a simultaneous increase in the value of the economic and environmental objective functions. It is noteworthy that by covering the demand of the demand centers up to 40%, the amount of increase in the value of the environmental objective function is such that the changes are not noticeable. In other words, as long as the goal is to meet 40% of the demand, there will not be much change in the environmental function. But when the goal is to meet more than 50 percent of the demand, the value of the environmental objective function suddenly increases dramatically.

But the effect of the balance ratio between supply and demand on the value of the economic objective function seems slightly different. Increasing the balance ratio between supply and demand, leads to an increase in the value of the economic objective function. However, the changes in the value of the objective economic function have the same slope.

Therefore, the significant result that can be obtained from this section is that in order to create justice in responding customer demand as well as full response to all demands, we must pay more and the spread of adverse environmental pollutants will be increased.

7-Conclusion

Automotive engine oil is one of the main derivatives of petroleum, which the increase in its demand causes many problems such as environmental pollutants. In a bid to address the above-mentioned problems, this study deals with the design of a closed loop supply chain network for engine oil in an uncertain environment. One of the main advantages of this research compared to other studies published in this field is applying new methods of recycling used engine oil in terms of their performance. As such, this research aims at taking into account customer satisfaction in the form of matching demand response.

In the concerned model, besides to addressing supply chain costs, adverse environmental effects are also minimized. In order to solve the proposed multi-objective model, the goal programming approach is exploited. The parameters of demand and returned goods from demand centers are also considered to be imbued with uncertainty that a robust optimization method is utilized to capture it.

In order to evaluate the proposed robust model, real data of Behran Oil Company is utilized, via which prominent results are achieved. For example, the results corroborate that to better meet the demand and also create a balance between them, the amount of the economic and environmental objective function will increase. As such, the results endorse that increasing the uncertainty budget parameter eventuates in an increase in the value of the economic objective function. This increase continues until this parameter rises to a value of 2. Additionally, for values greater than 2, no changes in the value of the economic objective function are observed.

In an effort to ameliorate the model presented in this article, the following suggestions can be recommended:

- Taking into account the decisions related to routing and transportation in the proposed model.
- Addressing hazard uncertainty in recycling centers and providing resilience approaches to deal with it.
- Considering all triple lines of sustainability (i.e., economic, environmental and social aspects) simultaneously.

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