World Applied Sciences Journal 8 (5): 596-607, 2010
ISSN 1818-4952

Applying Interactive Multi-Objective Decision Making Method in Design of a Sustainable Recovery Network to Include Different Stakeholders' Preferences

Farzad Dehghanian, Saeed Mansour and Reza Zanjirani Farahani

Department of Industrial Engineering, Amirkabir University of Technology,
424 Hafez Ave., Tehran 15916-34311, Iran

Abstract: In a Sustainable development different stakeholders are involved in decision making. Stakeholders belong to economical, environmental and social dimension of sustainable development. In order to incorporate different stakeholders in the process of decision making, this paper applies an interactive multi-objective decision making method in designing of the sustainable recovery network of scrap tires. At first, multiple objectives of recovery network design are presented regard to three dimensions of sustainable development. A reservation level driven Tchebycheff procedure, that is an interactive method based on reference points, is utilized to solve the multi-objective mixed integer programming model of scrap tire recovery network design. A team of decision makers specify the final most preferred Pareto-optimal solution for network design. Finally, some results deriving from the application of the proposed procedure are presented.

Key words: Interactive multi-objective decision making · Sustainable development · Recovery network · Reference points · Scrap tires

INTRODUCTION

Sustainable development was articulated by the Brundtland Commission as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". Moving toward sustainable development needs to meet the objectives in three mentioned areas in such a way that:

- Maintain a high and stable level of economical growth and employment.
- Effective protection of the environment.
- Provide social progress which recognizes the needs of every one.

Sustainable development must consider economic, environmental and social considerations, simultaneously. These issues relates to disciplines as diverse as ecology, economics and sociology in developing a sustainable development perspective [1].

With respect to growing importance of sustainability, considerations have been given to the convergence of supply chains and sustainability. Concentration on supply chains leads us to wider adoption and development of sustainability, since the supply chain considers the product from initial processing of raw materials to delivery to the customer [2] and also management of end-of-life (EOL) product.

Applying a sustainable production usually involve a wide range of stakeholders, many of whom are not directly involved with the organization. So dealing with sustainable development could bring out significant difficulties to the decision makers (DMs) [3]. This could be emphasized in multi-stakeholder nature of supply chain management. Since sustainable development involves interactions amongst environmental, economical and social parameters, it could be much more complex [4]. Different stakeholders will look upon the sustainability issues from a different perspective. Freeman [5] has identified two groups of stakeholders that are primary and secondary stakeholders. Primary stakeholders are those that have a direct interest in the organization (e.g. customers, shareholders, employees, suppliers and regulators). Secondary stakeholders are those that have not direct relation with the organization but can affect, or are affected by the organization (e.g. academic institutions, NGOs, neighbors and social activists). One of the main challenges is to find a balance between

Corresponding Author: Farzad Dehghanian, Department of Industrial Engineering, Amirkabir University of Technology, 424 Hafez Ave., Tehran 15916-34311, Iran Tel: +98 21 64542766

the different stakeholders' preferences in 3 aspects of sustainable development.

Traditionally, cost has been the most important factor in supply chain management decisions. Recently, with the growing importance of sustainability, environmental and social impact, are going to play key roles in this area [6]. In fact, in sustainable development context, supply chain operations should be optimized in multi-objective approach. These objectives are maximizing economical and social benefits and at the same time minimization of negative environmental impacts. As mentioned above, these objectives relates to different stakeholders' preferences that are involved in any given supply chain. To incorporate DM's preferences in solution methodology, interactive methods can be seen as a suitable methodology to deal with multi-objective decision making (MODM) problems. Interactive methods include the decision processes where the DM is continuously asked to express her/his own preferences. Among interactive approaches, methods using reference points have been popular because of their straightforward nature. A reference point consists of desirable values for each objective function [7].

This paper applies the reference point methodology within an iterative procedure to model a multi-objective decision process for designing sustainable recovery network of end-of-life (EOL) products. The network configuration specifies physical location of facilities and transportation route among them. In a previous contribution [8] the authors have introduced a multi-objective model for recovery network of scrap tires that considers economical, social and environmental objectives simultaneously. The paper applied the multi-objective genetic algorithm to find the Pareto-optimal solutions. This paper presents a multi-objective approach that explicitly considers the interaction of the decision model with the DMs to reach a compromise solution.

The rest of the paper is organized as follows. The next section, presents the different stakeholders of a typical supply chain with their preferences relating to the three aspects of sustainable development. In the third section, a brief review of the interactive methods is provided and the reference point method is also presented in detail. Then a multi-objective mixed integer programming model is offered for recovery network of scrap tires in the next section and the selected interactive method is applied to solve the problem. In the final section some conclusions are drawn.

Stakeholders in Sustainable Supply Chain Management: Sustainability extends the concept of supply chain management to look at optimizing operations from a broader perspective. In this perspective, the entire production system and post-production should be considered [2]. Looking to the supply chain management in broader perspective, forces the supply chains to deal with various stakeholders. Similar to the three pillars of the sustainable development, stakeholders may be classified in economical, environmental and social sections.

Henriques and Sadorsky [9] classified environmental stakeholder into four groups: (1) regulatory stakeholders, which can highly influence the regulation and standard setting (2) organizational stakeholders that are directly connected to an organization with direct financial impact on the company (3) community groups, environmental organizations and other potential lobbies who can organize public opinion in favor of or against a firm's environmental policies and (4) the media, which have the ability to influence society's perception of a firm.

Social responsibility of the organizations is defined as ‘‘the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large" [10]. This definition shows that the field of social responsibility is a multi-stakeholder area of research.

International Organization for Standardization (ISO) has initiated development of ISO 26000 international standard on social responsibility [11]. In doing so, they have considered 6 main stakeholder groups that are industry, government, consumer, labor, non-governmental organizations and service, support, research and others.

De brito [12] has mapped the supply chain and its broader stakeholders minding the environment, society and business as shown in Figure 1.

When tackling sustainable development in a multi-stakeholder environment, the problem becomes achieving agreement between stakeholders on the balance between the different aspects of the sustainable development. Achieving such balance can be hard [13]. For example Matos and Hall [4] have explored how the complexity associated with defining, coordinating and interacting with stakeholders increases substantially, in their work on integrating sustainability into the supply chain. Hall and Vredenburg [14] have also argued that sustainable development pressures, especially social issues, can be conflicting or difficult to reconcile.

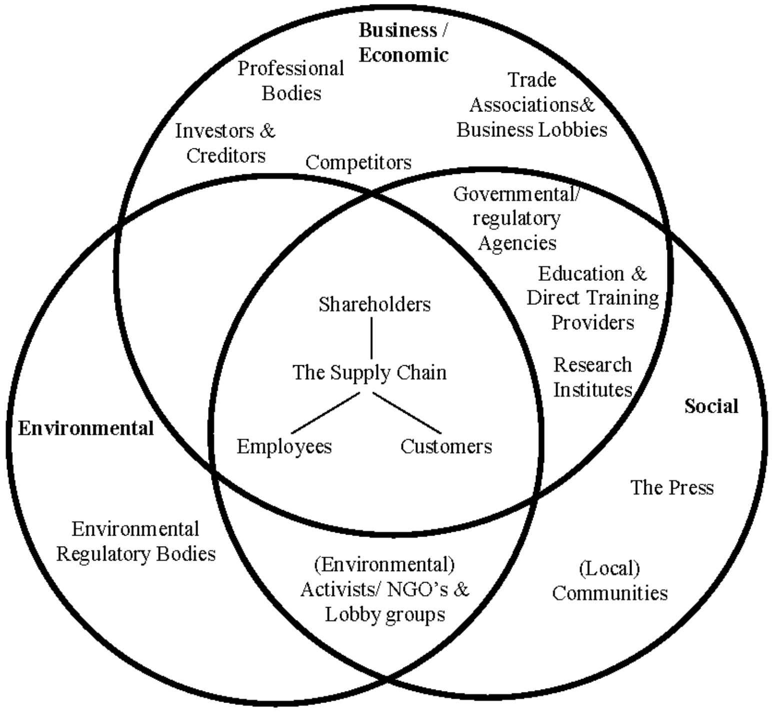

Fig. 1: The Supply chain and its stakeholders, Source: [12]

It seems that three dimension of sustainability are almost conflicting in such a way that it is very difficult to improve one sustainability aspect without deteriorating others.

However, on the other hand, it can be seen that a growing number of firms have begun to use environmental, health and safety (EHS) and social indicators [15]. A group of companies has gone further and achieved economic gains from the adoption of environment-friendly logistics networks. IBM, for instance, has profited from its programs to receive end-of-use products [16].

Traditionally, private sector seeks the economical benefits and considers other dimensions of sustainability with less importance. However, with increasing awareness of the society in general, green image of the company is gaining considerable importance for the managers. For example Marks & Spencer (M&S) that is a well-known chain store in UK, has initiated a voluntary five-years plan to make the company carbon neutral [17]. Under its "eco-plan", the company has announced it will cut energy consumption, stop using landfill sites and stock more products made from recycled materials. Chief executive of M&S has said: "we believe responsible business can be profitable business". Another example relates to Chinese enterprises that have initiated implementation of a number of environmental practices due to motivational drivers such as exports and sales to foreign customers [18]. Zhu *et al.* [19] argue that joining the World Trade Organization (WTO) has provided Chinese enterprises with additional opportunities to establish relationships with foreign enterprises. At the same time, these opportunities have also brought significant challenges to Chinese enterprises such as overcoming 'green barriers' and increasing their international competitive ability. They have exemplified a number of well-known companies such as, Bristol-Myers, Squibb, IBM and Xerox that have encouraged their Chinese suppliers to develop environmental management systems in compliance with ISO 14001. International laws in other regions such as the European Community Directives on Waste Electrical and Electronic Equipment (WEEE) have led companies to increase organizational efforts for product recovery. The polluter pay principle (PPP) has been applied in seeking to implement WEEE directive, ensuring that manufacturers are involved in the reduction of wasteful consumption of natural resources and pollution. Furthermore, in some countries, such as Sweden, there are local laws for producer responsibilities [20].

Similar to the environmental considerations, paying more attention to social dimension of sustainability can be a reasonable and beneficial strategy. Castka and Balzarova [11] declare that the social responsibility in supply chain management gain growing attention amongst supply chain professionals since it can have a significant impact on a firm's reputation and long-term success.

Regard to above mentioned facts, it can be concluded that there are main drivers and pressures that leads organizations to adopt their operations in accordance with sustainability considerations. These drivers and pressures could be categorized in obligatory and voluntary issues. When the organizations involved in a supply chain face with mandating legislations in environmental and social areas, they must operate according to the legislations. For example WEEE forces the European companies to take back and recover their electronic wastes. In the case of voluntary initiations, there are some cases such as M&S that has started its eco-plan to get green image of its stores in order to improve customer satisfaction in a long term view. There are also cases like IBM that conducted a voluntary system to receive EOL products. The main motivation of IBM has been gaining financial benefits. In these cases different stakeholders' preferences in economical, environmental and social aspects could be achievable through cooperation and negotiation among them.

It can be seen that the importance of sustainable supply chain and social awareness are growing. An increasing number of countries have initiated to establish the relevant legislations taking into account the different stakeholders' environmental and social preferences. Accordingly supply chains should prepare themselves to overcome upcoming barriers. Therefore, providing a balance among the different stakeholders' preferences in the three aspects of sustainable development can create a win-win situation through cooperation in such a way that the supply chains attain their economical benefits at the same time environmental and social stakeholders are satisfied.

In this research, we assume that different stakeholders cooperate with each other through teamwork to reach a compromise solution in multi-objective optimization of operations in supply chain management. Such a solution can be obtained during the application of interactive multi-objective decision making Interactive MODM Methods.

Interactive Modm Methods: The investigations in the field of multiple objective linear programming have shown that interactive algorithms are the most promising for solving multiple objective programming problems [21]. We first provide the basic concepts of the interactive methods.

Basic Concepts: Consider the following multi-objective problem:

(P):

$$\begin{aligned} &Max\ \{f_1(x) = z_1\} \\ &\vdots \\ &Max\ \{f_k(x) = z_k\} \\ &s.t.\ x \in S, \end{aligned}$$

A solution $\bar{x} \in S$ is efficient (Pareto optimal or non-dominated) for the problem (P) if and only if there is no $x \in S$ such that $f_i(x) \geq f_i(\bar{x})$ and there is at least one $f_i(x) > f_i(\bar{x})$ for all $i \in \{1,...,k\}$. A solution $\bar{x} \in S$ is weakly efficient for the problem (P) if and only if there is no $x \in S$ such that $f_i(x) \geq f_i(\bar{x})$ for all $i \in \{1,...,k\}$.

Methods for dealing with MODM problem may be non-interactive or interactive. Non-interactive, in general, generating methods designed to find the whole set or a subset of the efficient solutions. Interactive methods are characterized by human intervention through the phases of computation [22].

Generating methods may require an excessive amount of computational efforts in processing time, which may be inadequate to deal with large problems. Further, if a large set of alternatives is presented at the final of the procedure, this will introduce additional difficulties in such a way that analyzing and making the final choice will become difficult for the DMs [22].

According to Luque, *et al.* [7], a solution pattern in interactive methods is formed and iteratively repeated and the DM takes active part in the solution process by specifying and refining preference information. So, only such non-dominated solutions are generated that are interesting to the DM. Assuming the DM has enough time to take part in an interactive solution process, the final solution can be expected to be more satisfactory than with the other approaches because the DM can genuinely affect and direct the solution process in order to find a desired final solution.

To integrate sustainability considerations into the supply chain operation management, there is a need to incorporate different stakeholders in decision making process. Therefore, interactive MODM can be a suitable option to cope with multi-objective nature of sustainable supply chain operations optimization. Among the best suitable methodologies to deal with multi-objective problems within the management of environmental systems is the so-called *reference point method* [23].

To introduce reference point method, first consider the weighted sums of the objective functions as follows:

$$max \sum_{i=1}^{k} \lambda_i f_i(x)$$
$$s.t.\ x \in S,$$

Where: $\sum_{i=1}^{k} \lambda_i = 1$

Weighted sums of the objective functions do not provide every non-dominated solution in the case of non-convex feasible solutions.

For avoiding this, Tchebycheff metric-based scalarizing programs was introduced by Bowman [24] that has the advantage over weighted-sums programs of being able to reach, not only supported, but also unsupported non-dominated solutions.

Let us denote w-weighted Tchebycheff metric by $\max_{1 \le i \le k}$ where $w_i \ge 0; \forall i, \sum_{i=1}^{k} w_i = 1,$ and $\bar{f}$ denotes a reference point of the objective space. Considering $\bar{f} > f(x)$ for all $x \in S$ Bowman [24] proved that $\min(\max_{1 \le i \le k} \{w_i |\bar{f}_i - f_i(x)|\}),$ generates the non-dominated set.

Since the program $\min(\max_{1 \le i \le k} \{w_i |\bar{f}_i - f_i(x)|\})$ may yield weakly non-dominated solution, the augmented weighted Tchebycheff program has been introduced to avoid this. Augmented weighted Tchebycheff program can be shown by:

$$\min \quad \left\{\alpha - \rho \sum_{i=1}^{k} f_i(x)\right\}$$
$$s.t. \quad w_i(\bar{f}_i - f_i(x)) \le \alpha,\ 1 \le i \le k,$$
$$x \in S,$$
$$\alpha \ge 0.$$

Where ρ is a small positive value.

In general, reference point approaches for multiobjective problems (considering discrete variables or not) rely on the definition of an achievement scalarizing function by means of aspiration levels (reference point) for the objective functions. The achievement scalarizing function projects the reference point onto the non-dominated set, for instance, through the minimization of a (weighted) Tchebycheff distance to the reference point [25]. For more information about aspiration based decision support systems see [23]. A latest review of interactive methods for multiobjective integer and mixed-integer programming can also be found in [22]. Reeves and Macleod [26] have proposed an alternative approach to reducing the set of non-dominated solutions within a Tchebycheff framework that is reservation level driven Tchebycheff procedure (RLTP).

In this paper, reservation level (reference point) driven Tchebycheff procedure have been applied to find a compromise solution in multi-objective mixed integer programming model of sustainable scrap tire recovery network design.

A Reservation Level Driven Tchebycheff Procedure: A reservation level (RL) driven Tchebycheff procedure (RLTP) can be described in terms of an initialization phase followed by one or more iterations. Each iteration consists of sampling, solution and adjustment [26].

Step 1. Initialization. Specify the number of solutions, P, to be presented to the DM at each iteration, where $P \ge k$. Compute a reference objective vector, z^{**} where $z_i^{**} = \max\{f_i(x) \mid x \in S\} + \varepsilon_i$ and the ε_i are small positive scalars, for use in solving the Tchebycheff programs.

Set $Rl_i = -\infty$, $i = 1,..., k$, where RL_i is the reservation level for the ith objective. The maximum number of iterations could be pre-specified also, if desired, as part of the initialization process.

Step 2 Sampling. Generate a group of $2P$ dispersed weight vectors,

$$\Lambda = \left\{\lambda \in R^k \mid \lambda_i \in (0,1), \sum_{i=1}^{k} \lambda_i = 1\right\}.$$

Step 3. Solution. Solve the associated Tchebycheff program for each weight vector:

$$\min\left\{\alpha - \rho \sum z_i\right\}$$
$$s.t.\ \alpha \ge \lambda_i(z_i^{**} - z_i);\quad i = 1,\dots k$$
$$f_i(x) = z_i;\qquad i = 1,\dots k$$
$$z_i \ge RL_i;\qquad i = 1,\dots k$$
$$x \in S.$$

Where ρ is a small positive scalar. Present the P most different of the resulting objective vectors to the DM. If the DM wishes to continue to search for an improved solution, proceed to step 4. Otherwise, have the DM select his/her current most preferred solution and stop.

Step 4. Adjustment. Have the DM partition the current solutions into more preferred and less preferred subsets, adjust the RLs and return to step 2.

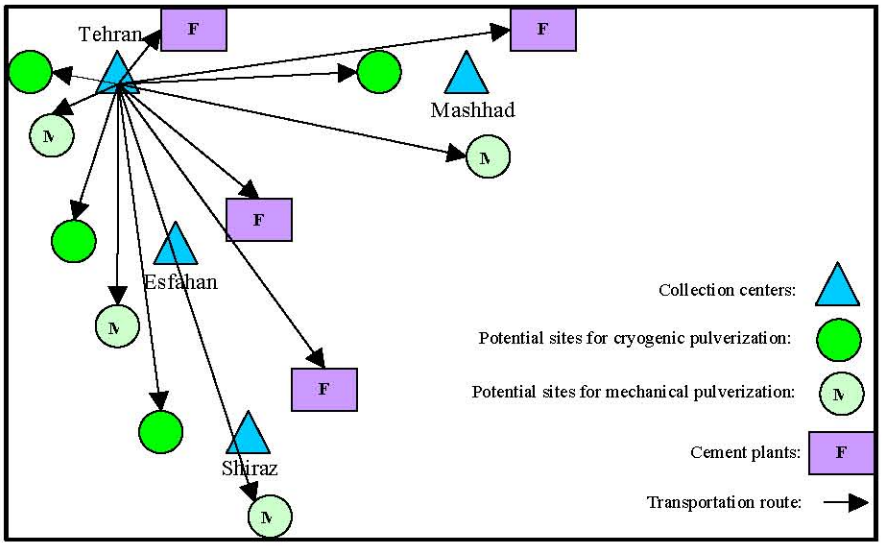

Fig. 2: Illustration of scrap tire recovery network design problem

Tire Recovery Network Design in Sustainable Environment: In spite of governmental regulations for waste treatment in Iran, about 70 percent of scrap tires disposed in stockpiles. Only 30 percent of discarded tires are processed in retreading (19 companies) and recycling plants. According to [27] three types of EOL processing can be feasible for scrap tires in the country. These are:

- Mechanical pulverization (Ambient) that is a mechanical grinding system that operates at room temperature and tears the tire material apart.
- Cryogenic pulverization that is a freezing process where scrap tires are frozen at very low temperatures by liquid nitrogen and then shattered like breaking glass.
- Incineration in cement kiln that is an option for energy recovery. Cement kilns can burn tires up to 20-25% of their total fuel consumption.

The discarded stockpiles have negative environmental impact. The country also losses economical and social benefits, which can be achievable from treating these scraps [27]. To design a sustainable recovery network of scrap tire, it has been assumed that there are 3 EOL options for scrap tire recovery that are mechanical pulverization, cryogenic pulverization and incineration in cement kiln for energy recovery. The location of collection centers and the amount of tire stocks are known. Therefore location and type of scrap tires processing plants should be found as well as their shipment quantity from collection centers to each plant (including pulverization and cement plants).

Mathematical Formulation for a Case Study: Four large Iranian cities were selected to be included in the developed model (Tehran, Mashhad, Esfahan, Shiraz). For smaller cities that stockpiles far less tires, similar approach could be conducted. A number of capacity levels have been considered for pulverization plants. One candidate cement plant in each city is considered to use maximum 50% of generated scrap tires of that city as the fossil fuel substitute. Figure 2 summarizes the case described here. Possible transportation routes for shipment of scrap tires from Tehran collection center to the potential EOL plant site is shown in this figure via arrows. There are similar routes for other collection centers. For detail information please refer to [8].

A multi-objective mixed integer programming model has been proposed to design such recovery network. The detail information about the model has been provided in Appendix A. The objectives are the maximization of economical and social benefits and the minimization of negative environmental impacts. The three subsequent subsections provide more information about these objective functions.

Maximization of Profit: Processing scrap tires produce valuable products such as crumb rubber that has international price and customers. Acquiring such benefits needs two main expenditures that are: capital cost of installing and operating new factories and cost of transportation. These economical parameters have been considered to construct profit objective function that should be maximized through equation (1). The used notation has been provided in Appendix A.

$$Max\,Z_1 = \sum_i \sum_j \sum_l \sum_k X_{ijl} \alpha_{jk} S_{jk} - \sum_j \sum_h \sum_l C_j^h V_{jl}^h - C^T \left[\sum_i \sum_j \sum_l X_{ijl} d_{il} + \sum_i \sum_m Y_{im} \bar{d}_{im} \right] \quad (1)$$

Minimization of Environmental Impact: Life cycle assessment (LCA) is a tool for quantitative assessment of materials, energy flows and environmental impacts of products, services and technologies. LCA starts with (1) definition of the functional unit, then (2) a quantitative inventory of all inputs and outputs is performed, followed by (3) classification and impact assessment and, finally, (4) evaluations. In the impact assessment step all environmental impact can be quantified through Eco-indicator method [28]. Eco-indicator provides a single indicator that indicates the environmental impact of each process. Such indicator is always proportional with the mass of each process, i.e., the environmental impact of processing one unit of inputs is indicated by corresponding Eco-indicator. Regarding this, the single indicator obtained from the eco-indicator methodology is used to construct the environmental objective of mathematical programming as equation (2).

$$Min\,Z_2 = \sum_i \sum_j \sum_l X_{ijl} EI_j + EI^T \left[\sum_i \sum_j \sum_l X_{ijl} d_{il} + \sum_i \sum_m Y_{im} \bar{d}_{im} \right] \quad (2)$$

Maximization of Social Benefits: With respect to important concerns of developing countries such as Iran, four criteria in social considerations were chosen. These criteria are briefly described in Table 1.

Based of qualitative nature of social impacts, Analytical hierarchy process (AHP) [29] that is popular in multi-criteria decision making methods has been applied to get a single indicator that describes social impact of different EOL alternatives. Normalized weight obtained from AHP is used as social single indicator of different EOL activities. This indicator indicates the social impact of treating EOL product in each EOL option. The final normalized weight for different locations can be included in mathematical representation of social objective function as equation (3).

$$Max\,Z_3 = \sum_j \sum_h \sum_l (W_{em} EM_{jl}^h + W_{ld} LD_{jh}^l + W_{dm} DM_{jl}^h + W_{pr} PR_{jl}^h) V_{jl}^h \quad (3)$$

Applying RLTP Approach to Scrap Tire Recovery Network Design: In order to handle the multi-objective programming model of the scrap tire case study, there is a need to pass over the following steps:

Constitution a Team of Major DMs: Such a team can be constituted from chief stakeholders involved in scrap tire recovery network design. The main stakeholders that could be included in such network are potential EOL processing plant owner(s), end customer of the recycled materials, society (mainly people who are affected by the impact of environmental issues of EOL processing plants in one hand and those who are looking for jobs on the other hand) and environmental protecting and labor NGOs. It is convenient to consider the government as a major DM that preserves society and NGO's social and environmental preferences. It is also useful to include a representative agent as another DM who seeks the plants' preferences. We select these two DMs to constitute a team.

Team Participation in Interactive MODM to Select a Compromise Solution: The input data for the case study has been presented in Table 2 and 3. Social indicator (output of AHP method) for different EOL options in different location and capacity levels has been given in Table 4.

To initiate RLTP, 8 solutions were presented to the team of Dms at each iteration (P=8). Hyper LINGO 4. was utilized to calculate ideal solution (z^*) and z^{**}. The optimum objective value of each single optimization model constructs the elements of z^*, where $z_i^* = \max\{f_i(x) \mid x \in S\}$. The value of z^* is:

z^* = (34637460, − 476567, 281). The elements of the ideal solution vectors are profit, environment and social objective function, respectively. Reference objective vector, z^{**}, where $z_i^{**} = \max\{f_i(x) \mid x \in S\} + \varepsilon_i$ and ε_i = 0.5 is:

$$z^{**} = (34637460.5, -476566.5, 281.5)$$

Given that different objective functions have different scales, each objective function was divided by its ideal objective vector to obtain dispersed efficient solutions.

Since, DMs have no idea about the values of objective functions, it is convenient to declare their preferences linguistically. For example they would like to achieve at least %70 of their ideal situation. In order to incorporate these terms into specifying more and less

Table 1: Social issues

Criteria	Description
Employment	Different EOL option creates different number of job opportunity
Damage to workers	It means working conditions may expose workers to hazardous environment. For example, Health hazards of chronic nature due to long term exposure to chemical elements. The damage of emissions was excluded here
Product risk	Consumers perceive different risk in consuming different recycled materials. For example retreading tires may have greater risk in transportation
Local development	Installing new facilities in less developed areas can cause community development that is an important issue in any government social responsibilities

Table 2: Example data

		Scrap tire needs per year				
		Mechanical plant				
		Production level				
City	Scrap tire per year (tone)	1	2	3	Cryogenic plant	Cement plant
Tehran	21600	6000	12000	18000	6000	10800
Mashhad	10800	6000	12000	18000	6000	5400
Esfahan	9000	6000	12000	18000	6000	4500
Shiraz	5400	6000	12000	18000	6000	2500

Table 3: Social, Environmental and economical data for EOL options

EOLs	Opening and operating cost per year for base capacity level (1000 Rials)	Profit of one tone of output (1000 Rials)	Environmental impact of one tone of processing
Mechanical	2200000	1200	0.278
Cryogenic	2650000	1260	42.543
Fuel substitution	425000	100	-8.100

Table 4: Social indicator of each EOL option obtained from AHP

EOL specifications			
Type	Location	Capacity level	Social indicator (× 1000)
Mechanical	Tehran	1	32
Mechanical	Tehran	2	59
Mechanical	Tehran	3	86
Cryogenic	Tehran	1	35
Cement	Tehran	1	22
Mechanical	Mashhad	1	34
Mechanical	Mashhad	2	61
Mechanical	Mashhad	3	89
Cryogenic	Mashhad	1	36
Cement	Mashhad	1	22
Mechanical	Esfahan	1	36
Mechanical	Esfahan	2	64
Mechanical	Esfahan	3	94
Cryogenic	Esfahan	1	38
Cement	Esfahan	1	22
Mechanical	Shiraz	1	38
Mechanical	Shiraz	2	69
Mechanical	Shiraz	3	100
Cryogenic	Shiraz	1	40
Cement	Shiraz	1	22

Table 5: Most preferred solution at first iteration of RLTP

Solution #	Z1	Z2	Z3	pc_1	pc_2	pc_3
1	29888230	-550973	216	86.29	84.39	76.87
2	25359660	-476567	209	73.21	100.00	74.38
3	29699500	-586127	238	85.74	77.01	84.70
4	24656840	-555551	222	71.19	83.43	79.00
5	25442870	-515249	187	73.45	91.88	66.55

Table 6: Details of final solutions obtained by RLTP

				Source &shipment quantity			
Solution #	Plant location	EOL type	Capacity level	Tehran	Mashhad	Esfahan	Shiraz
1	Tehran	Mechanical Plant	3	18000			
	Mashhad	Mechanical Plant	1	600	5400		
		Cement	1		5400		
	Esfahan	Mechanical Plant	1			6000	
	Shiraz	Mechanical Plant	1			600	5400

Table 7: Results of sensitivity analysis

*RL*1	*RL*2	*RL*3	Z1	Z2	Z3	pc_1	pc_2	pc_3
29888230	-550973	216	No feasible solution					
29888230	-8	216	34637460	-754794	221	100	41.6	78.6
29888230	-550973	-8	No feasible solution					

Table 8: Different solutions obtained in first iteration of RLTP

λ_1	λ_2	λ_3	Z1	Z2	Z3
0.5	0.25	0.25	29888230	-550973	216
0.25	0.5	0.25	25359660	-476567	209
0.25	0.25	0.5	29699500	-586127	238
0.6	0.3	0.1	29888230	-550973	216
0.1	0.6	0.3	2535966	-476567	209
0.3	0.1	0.6	29609500	-839717	244
0.8	0.1	0.1	34637460	-754794	221
0.1	0.8	0.1	25359660	-476567	209
0.1	0.1	0.8	34358730	-1043538	252
0.4	0.4	0.2	29888230	-550973	216
0.2	0.4	0.4	24656840	-555551	222
0.4	0.2	0.4	29699500	-586127	238
0.3	0.6	0.1	25442870	-515249	187
0.7	0.2	0.1	34637460	-754794	221
0.2	0.1	0.7	34358730	-1043538	252
0.1	0.7	0.2	25359660	-476567	209

preferred solutions, an indicator was introduced that shows how closely an objective function corresponds to DMs' preferences as equation (4).

$$pc_i = 100 \times (1 - \frac{|f_i - f_i^*|}{f_i^*}); \; i = 1,2,3.$$

In equation (4), pc_i calculates the percent of correspondence of objective function f_i with its ideal value (f_i^*).

The associated Tchebycheff program (with $\rho = 0.001$) has been solved for different groups of weight vector. All solutions related to 16 groups of weight vectors have been shown in Table 8. The most preferred solutions identified at first iteration of RLTP are given in Table 5. At first iteration DMs decided to select the solutions that their pc_i are at least %50. It means that they seek the solutions that satisfy at least %50 of the ideal situation in three objective functions.

In iteration 2, *RL*s for each objective have been set equal to the worst value for that objective among the current more preferred solutions. Therefore we have *RL*1= 24656840, *RL*2= -586127 and *RL*3=187. Regard to these new *RL*s solving associated Tchebycheff program again results in solution number 1 and 3 that are given in Table 5. DMs set *RL*1=29699500, *RL*2= -586127 and *RL*3=216 in next iteration but there is no feasible solution for these values of *RL*s. So DMs finally satisfied with solution number 1 as a compromise solution. Solution 1 has been presented in more detail in Table 6. As can be seen, solution 1 tends to install more mechanical pulverization plants.

To give more information about tradeoffs between three mentioned objective functions, sensitivity analysis was conducted by changing the *RL*s. At first, objective values of the final solution obtained by RLTP has been considered as RLs (i.e., *RL*1= 29888230, *RL*2= -550973 and *RL*3= 216).For this arrangement there is no feasible solution for associated Tchebycheff program. So we relaxed the environmental objective value and put *RL*2=-8. The corresponding objective values are: Z1=346337460, Z2= -754794, Z3=221 for all groups of weight vectors. As can be seen, profit objective reaches its ideal value. These values of objective functions means that growth about %14 in profit incur about %43 decreasing in environmental objective function and about %2 growth in social objective function regard to corresponding pc_i. Next we relaxed the social objective function (i.e., *RL*1= 29888230, *RL*2= -550973 and *RL*3= -8). There is also no feasible solution for this set of *RL*s. It can be concluded that the major conflict has been occurred between profit and environmental objective functions. Table 7 presents the information about the solutions regard to different arrangement for *RL*s.

One of the main advantages of interactive methods such as RLTP, is that there is no need to search all efficient solutions. Such approach leads DM to the most preferred solution without wasting his/her time in taking efforts to search all efficient solutions. For comparison, one could see that in the previous contribution [8] NSGA-II algorithm [30] in multi-objective genetic algorithm area has been applied to the similar multi-objective problem. NSGA-II has provided 25 different Pareto-optimal solutions in about 45 minutes run of the corresponding Matlab code. Such an approach took also much expert's effort in coding the algorithm in Matlab software. On the contrary, in RLTP, single optimization problem can be solved in about 0.01 seconds. There is also no need to generate new coding structure for the algorithm since it solves the single optimization problem using well-known solver that is simple and user-friendly. In addition modifying the RLs could lead DMs to generate dispersed Pareto-optimal solutions which can also be provided by NSGA-II. So there will not be more difference in quality of the solutions. Therefore, interactive approach is an efficient solution in dealing with multi-objective nature of the problems in sustainable environment.

SUMMARY AND CONCLUSIONS

In this paper RLTP, that is an interactive approach in MODM problems, was applied in sustainable recovery network design of scrap tires. Since sustainability requires considering economical, environmental and social issues simultaneously, different stakeholders should be taken into account regard to these three dimensions. It seems these issues are almost conflicting but literature shows that there are drivers for organizations to pay attention to environmental and social considerations voluntarily. For instance, creating a green image of the organization in customers' mind could motivate them to incorporate environmental considerations in decision making. So it could be concluded that cooperation and negotiation between different stakeholders is a reasonable way to reach a compromise solution in multi-objective problems in sustainable development environment. In doing so, a team of DMs was constituted regard to three dimensions of sustainability, to participate in RLTP. Results showed that interactive methods are efficient approach in dealing with multi-objective optimization problems in sustainable development environment.

Appendix A. Mathematical Model:

Indices and parameters:

I : Index set of collection centers.
J : Index set of EOL options (different plants).
K : Index set of output of different type of processing.
L : Index set of potential plant sites.
M : Index set of existing cement factories.
H : Index set of capacity levels available to the potential facilities.
Z : Index set of social criteria.
EI_j : Environmental impact of processing one tone of scrap tire using option *j*.
C_j^h : Fixed cost per unit of time for opening and operating plant *j* with capacity level *h*.

S_{jk} : Sale price of product *k* of plant *j*.
α_{jk} : Percent of product k obtained from plant j per tone of input processing.
ST_i : Quantity of scrap tires collected in collection center *i* per unit of time.
e_j^h : Capacity with level *h* for the potential plant at site *j*.
N_m : Maximum need of scrap tire in cement plant m per unit of time.
d_{il} : Distance between collection center *i* and potential plant site *l*.
$\bar{d}_{im}$: distance between collection center *i* and cement plant site *m*.
C^T : Cost of shipping one tone of scrap tire per kilometer.
EI^T : Environmental impact of shipping one tone of scrap tire per kilometer.
LD_{jl}^h : local development score of potential plant *j* at site *l*.
EM_{jl}^h : Employment score of potential plant *j* at site *l*.
DM_{jl}^h : Damage score of potential plant *j* at site *l*.
PR_{jl}^h : Product risk of potential plant *j* at site *l*.
W_{ld} : Normalized weight of local development.
W_{em} : Normalized weight of employment.
W_{dm} : Normalized weight of hazardous working conditions.
W_{pr} : Normalized weight of product risk.

Variables:

X_{ijl} : Quantity of shipments from collection center *i* to plant *j* at site *l*.
Y_{im} : Quantity of shipments from collection center *i* to cement plant *m*.

$$V_{jl}^h = \begin{cases} 1 & \text{;if plant } j \text{ with capacity level } h \text{ located at site } l \\ 0 & \text{;otherwise} \end{cases}$$

In terms of the above notation, the problem can be formulated as follows:

$$Max\,Z_1 = \sum_i \sum_j \sum_l \sum_k X_{ijl}\alpha_{jk}S_{jk} - \sum_j \sum_h \sum_l C_j^h V_{jl}^h - C^T \left[\sum_i \sum_j \sum_l X_{ijl}d_{il} + \sum_i \sum_m Y_{im}\bar{d}_{im} \right]$$

$$Min\,Z_2 = \sum_i \sum_j \sum_l X_{ijl}EI_j + EI^T \left[\sum_i \sum_j \sum_l X_{ijl}d_{il} + \sum_i \sum_m Y_{im}\bar{d}_{im} \right]$$

$$Max\,Z_3 = \sum_j \sum_h \sum_l (W_{em}EM_{jl}^h + W_{ld}LD_{jh}^l + W_{dm}DM_{jl}^h + W_{pr}PR_{jl}^h)V_{jl}^h$$

Subject to:

$$\sum_j \sum_l X_{ijl} + \sum_m y_{im} \le ST_i\,; \quad \forall i$$

$$\sum_i X_{ijl} = \sum_h V_{jl}^h.e_j^h\,; \quad \forall j,l$$

$$\sum_h V_{jl}^h \le 1\,; \forall\, j,l$$

$$\sum_i y_{im} \le N_m\,; \forall\, m$$

$$X_{ijl} \ge 0\,; \forall\, j,l$$

$$V_{jl}^h \in (0,1); \quad \forall j,l,h$$

REFERENCES

1. Cowell S.J. and S. Parkinson, 2003. Localisation of UK food production: an analysis using land area and energy as indicators, Agriculture, Ecosystems and Environment, 94: 221-236.
2. Linton, J.D., R. Klassen and V. Jayaraman, 2007. Sustainable Supply Chains: An Introduction, J. Operations Management, 25(6): 1075-1082.
3. Hall, J. and H. Vredenburg, 2005. Managing the dynamics of stakeholder ambiguity. MIT Sloan Management Review, 47(1): 11-13.
4. Matos, S. and J. Hall, 2007. Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology, J. Operation Management, 25: 1083-1102.
5. Freeman, R., 1984. Strategic Management: A Stakeholder Approach. Pitman, Boston.
6. Dehghanian, F. and S. Mansour, 2008. A framework for moving toward sustainable supply chain management, Proceeding of 38th international conference on computers and industrial engineering, Beijing, China.

7. Luque, M., K. Miettinen, P. Eskelinen and F. Ruiz, 2009. Incorporating preference information in interactive reference point methods for multiobjective optimization, Omega 37: 450-462.
8. Dehghanian, F. and S. Mansour, 2009. Designing sustainable recovery network of end-of-life products using genetic algorithm. Resour Conserv Recy doi:10.1016/j.resconrec. 2009.04.007.
9. Henriques, I. and P. Sadorsky, 1996. The determinants of an environmentally responsive firm: an empirical approach. J. Environmental Economics and Management, 30: 81-95.
10. WBCSD, 1999. Corporate Social Responsibility. World Business Council for Sustainable Development, Geneva.
11. Castka, P. and M.A. Balzarova, 2008. ISO 26000 and supply chains-On the diffusion of the social responsibility standard, Int. J. Production Economics, 111: 274-286.
12. De Brito, M.P., 2007. Towards Sustainable Supply Chains: a methodology, SIMPOI/POMS proceedings, 8-10 August, Rio de Janeiro, Brazil.
13. White, L. and G.J. Lee, 2009. Operational research and sustainable development: Tackling the social dimension, Operational research and sustainable Development, 193(3): 683-692.
14. Hall, J. and h. Vredenburg, 2003. The challenges of innovating for sustainable development. Sloan Management Review, 45(1): 61-68.
15. Veleva V. and M. Ellenbecker, 2001. Indicators of sustainable production: framework and methodology, J. Cleaner Production, 9: 519-549.
16. Fleischmann, M., J.A.E.E. Van Nunen and B. Grave, 2003. Integrating closed-loop supply chains and spare-parts management at IBM, Interfaces, 33(6): 44-56.
17. BBC news, Monday, 15 January 2007, available at: http://news.bbc.co.uk/2/hi/help/3681938.stm.
18. Christmann, P. and G. Taylor, 2001. Globalization and the environment: determinants of firm self-regulation in China. J. International Business Studies, 32(3): 439-458.
19. Zhu, Q., J. Sarkis and K.H. Lai, 2008. Green supply chain management implications for closing the loop, Transportation Research Part E, 44: 1-18.
20. Sundin, E. and B. Bras, 2005. Making functional sales environmentally and economically beneficial through product remanufacturing, J. Cleaner Production, 13: 913-925.
21. Vassilev, V. and S.C. Narula, 1993. A reference direction algorithm for solving multiple objective integer linear programming problems. J. the Operational Research Society, 44(12): 1201-1209.
22. Alves, M.J. and J. Climaco, 2007. A review of interactive methods for multiobjective integer and mixed-integer programming, European J. Operational Res., 180: 99-115.
23. Wierzbicki, A.P., M. Makoski and J. Wessels, 2000. Model-based Decision Support Methodology with Environmental Applications. Kluwer Academic Publishers, pp: 475.
24. Bowman, V.J., 1976. On the relationship of the Tchebycheff norm and the efficient frontier of multiple-criteria objectives. Lecture Notes in Economics and Mathematical Systems, 130: 76-86. cited in M.J. Alves and J. Climaco, 2007. A review of interactive methods for multiobjective integer and mixed-integer programming, European J. Operational Res., 180: 99-115.
25. Demirtas E.A. and O. Ustun, 2008. An integrated multiobjective decision making process for supplier selection and order allocation, Omega, 36: 76-90.
26. Reeves, G.R. and K.R. MacLeod, 1999. Some experiments in Tchebycheff-based approaches for interactive multiple objective decision making. Computers and Operations Res., 26: 1311-21.
27. Samadian, F., 2006. Tire recycling report, Iran ministry of mining and industry, Central library (in Persian).
28. Goedkoop, M. and R. Spriensma, 2001. Eco-indicator 99-a damage oriented method for life cycle assessment, Methodology report, Third edition, Available from: www.pre.nl.
29. Saaty, T.L., 1980. The analytical hierarchy process, planning, priority setting, resource allocation. New York: McGraw-Hill.
30. Deb, K., A. Pratap, S. Agarwal and T. Meyarivan, 2002. A fast and elitist multi-objective genetic algorithm: NSGA-II. IEEE Transactions on Evolutionary Computations, 6: 182-197.