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A Multi-Objective Supplier Selection and Order Allocation Model for Green Supply Chains

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Abstract- Considering the limited natural resources, increased consumption level of the world becomes an important problem for the human beings. This fact enforces the governments to make some regulations for the environment. Also, increased consumer consciousness puts a pressure on the companies for being more environmentally friendly. Companies are not only responsible for their own production environment, but also responsible for their suppliers. Hence, the supplier selection and order allocation processes have to be greener. For this purpose, in this study a multi-objective supplier selection and order allocation model is proposed for green supply chains regarding multi-item and multi-supplier case. So as to validate the proposed methodology including three stages, a numerical example is provided by inspiring from the real applications in Turkey.

Keywords- Multi-objective linear programming; Green supply chains; Supplier selection; Order allocation.

1. Introduction

Greening supply chain from raw material procurement through final product delivery gains importance from both customers' perspective and environmental regulations. The obligations from these stakeholders' force companies incorporating with sustainable suppliers. Environmentally conscious suppliers serve firms in developing its competitive edge in terms of cost reduction, quality enhancement and minimization of negative environmental impacts (Chen et al., 2016). Increasing environmental concerns contribute the initiative of Green Supply Chain Management (GSCM). The difference between traditional and green supply chain is the environmental issues (Seuring and Müller, 2008).

In GSCM, suppliers should meet the firm's expectations for waste-disposal, reverse logistics activities, energy consumption reduction efforts.

The outstanding criteria for selecting suppliers in GSCM are environmental efficiency, green competence and life-cycle cost (Noci, 1997). Environmental issues such as green competence of a firm include reuse, remanufacturing and repairing activities. Especially reuse and remanufacturing activities require backward flow of goods and materials through the supply chain which implies reverse logistics term.

Reverse logistics can be defined simply as the recovery of the used products (Kilic et al., 2015). Materials flow from customer to supplier in reverse logistics. The aim of reverse logistic activities is to maximize the value of the used product by means of a suitable way such as recycling, reusing or disposing (Kannan et al., 2009). Recycling, reusing contribute the reduction of natural resources consumption and decrease solid waste (Bonney and Jaber, 2011).

The importance of reverse logistics activities in supply chain is emphasized in study of Min and Ko (2008) by stating 1% through 35% of total sales constitute product returns. Product reuse in manufacturing is a profitable one and also supports green logistics by improving environmental awareness (Kannan et al., 2009).

The supply chain becomes a closed loop system when backward flows exist. In backward flow, storage of

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used products and disposal of wastes are planned and controlled (Fleischmann, 2001). Some of the criteria are more important in closed loop supply chain systems. For instance, product performance criteria that include strength, durability, reusable and recoverable, environmental criteria including recycling, pollution reduction capacity and clean technology are more important in closed loop systems (Amin and Zhang, 2012).

The management of reverse logistics activities can be handled; by the company, by reverse logistics providers, by cooperatives of waste pickers or municipal organizations (Bai and Sarkis, 2013). From green supply chain management perspective without efficient support of reverse logistics providers, the goals are not realized (Seuring and Müller, 2008).

Specialization in reverse logistics activities requires a special information system for tracing/tracking data and thorough equipment for returns (Kannan et al., 2009). The advantages of specialized third party reverse logistics providers (3PRLP) are reduced logistics costs and companies can concentrate on their own business (Kannan et al., 2009). Reverse logistics provides advantages on reducing cycle time and increasing delivery performance. By using 3PRLP, a company can get the advantage of economies of scale which results important cost savings. Another reason to use 3PRLPs is that product nature may require different reverse logistics activities. The ambiguity of unit cost differences on returned products, different space requirements in the warehouse may lead firms to work more than one 3PRLPs (Efendigil et al., 2008).

The selection criteria should be identified carefully for 3PRLPs. One of the most important criteria is the environmental consciousness as stated in previous paragraphs (Carter and Ellram 1998), quality, capability, flexibility, production and process innovation are the other criteria in selecting 3PRLP (Talluri and Sarkis, 2002). Efendigil et al. (2008) considered on time delivery ratio, confirmed fill rate, service quality level, operation cost, capacity usage ratio, cycle time flexibility index, index of integration level, increment in market share, research and development ratio, environmental expenditures, and customer satisfaction index criteria in selecting the best 3PRLPs.

Several methods in the related literature can be found on supplier selection problems. Ho et al. (2010) listed approaches for multiple supplier option. They concluded that an integrated approach consisting of Analytic Hierarchy Process (AHP) and Goal programming is commonly used in solving multiple supplier selection option. Trisna et al. (2015) reviewed the related literature for supply chain management for multi-objective optimization. Research direction is focused on five classes, i.e. problem definition, formulation of the problem, considered multi objective framework, solution approaches and representation of the supply chain.

The other methods that are used in the literature; LP, total cost ownership, data envelopment analysis and simulation is included in class of single models. The integrated models which are commonly found in the literature can be listed as; AHP and Linear programming, AHP and Fuzzy set theory, Data envelopment analysis and multi objective programming (Kannan et al., 2013).

Besides these methods, Fuzzy set theory is the mostly utilized topic in assigning weights to suppliers (Amid et al., 2006; Bevilacqua et al., 2006; Chou and Chang, 2008; Shu and Wu 2009; Wang et al., 2009; Tuzkaya, 2013).

In this study, a two phase fuzzy goal programming approach is applied to the multi-objective reverse logistics supplier selection and order allocation problem. Objective functions are assumed as fuzzy functions and proper membership functions are constructed for them. In the second section, a literature review of the research scope is presented. In the third section, proposed methodology is summarized. In the fourth section, a numerical example and results are given and the final section is the conclusion.

2. Literature Review

In this part of the study the literature considering both green supply chain management and 3PRLPs selection studies are handled. The methodologies and criteria considered in literature are briefly discussed.

Frequently used criteria in the literature in GSCM are quality, delivery price/cost, manufacturing capability, service management, technology, pollution production, resource consumption, Eco-design, green image, environmental management system, commitment of GSCM from managers, use of environmentally friendly technology, use of environmentally friendly materials and staff environmental training, quality rejection percentage, late delivery percentage (Shen et al., 2013; Ho et al., 2010; Shaw et al., 2012).

Awashthi et al. (2010) utilized fuzzy AHP and fuzzy TOPSIS method to weight criteria importance in supplier selection problem. A fuzzy multi objective LP approach is developed for both selecting suppliers and allocating orders among selected suppliers. Considered criteria in GSCM, clean material availability, green image, environmental costs, legislative management, existence of green products and green process management. Kannan et al. (2013) also applied fuzzy multi attribute utility theory and multi objective programming approach to select suppliers and assign order quantities. Subjective weights are assigned via fuzzy decision making techniques AHP and TOPSIS. Developed model aims to maximize total value of purchasing. Developed model is applied in an automobile manufacturing company. A similar study of Shaw et al. (2012) considered the following factors: carbon emission issue, late delivery, demand and quality.

The sustainability also serves the green supply chain. Brandenburg et al. (2014) identified 134 papers on qualitative, formal models which focus on sustainability in supply chain.

The reverse logistics activities are an important part of green supply chain management (Sbihi and Eglese, 2007). As stated earlier, the technology and process are different in reverse logistics activities and require specialized information tracking capability, firms generally consider working with 3PRLPs. Sheu et al. (2005) investigated the sustainability issue in terms of used-product reverse logistics perspective. An integrated multi-objective model is developed. The results of the applied model indicate that 21.1% net profits are gained.

Guarnieri et al. (2014) focused on outsourcing reverse logistics activities which are imposed by Brazilian government. They proposed a systematic approach to select 3PRLP and a conceptual framework utilizing multi criteria decision aid modeling. They also performed a brief literature review to define the set of criteria for decision makers. They divided 6 groups of criteria; forward logistics, reverse logistics, financial, capacity, and environmental alliances. The interesting criteria under each group can be listed as; tracking and tracing, service quality level, system flexibility index, increment in market share, research and development ratio, cost of maintaining a repair facility, recapturing value, capacity usage ratio, technical and engineering capability, green products, mentoring of suppliers, formation of strategic alliances and product recovery options. Mak and Nebebe (2016) developed a diverse factor analysis method to cope with the misinterpretation of the factors especially that have high importance weights. The improved methodology aims to analyze standalone effects of each criterion in supplier selection problem. Dotoli et al. (2016) proposed a hierarchical efficiency maximization hierarchical technique. In first step supplier selection under conflicting criteria is proposed. In second and third step, a model is developed to assign order quantities and a heuristic method that improves the results of the second step respectively.

Efendigil et al. (2008) proposed a combined artificial neural network and fuzzy logic approaches to determine the best 3PRLP. Min and Ko (2008) proposed a mixed integer programming model and a genetic algorithm approach to select the location of repair facilities for 3PRLPs. They applied the developed methodology in a numerical example. Prakash and Barua (2016) integrated fuzzy AHP and VIKOR to evaluate and select the best 3PRLPs. The methodology is applied to an Indian electronics manufacturer. The robustness of the methodology is performed via sensitivity analyses.

Kannan et al. (2009) developed a multi criteria group decision making model to choose the reverse logistics provider. Since the selection process involves vagueness they utilized fuzzy set theory. They used interpretive structural modeling and fuzzy TOPSIS method. The effectiveness of the model is illustrated on a battery producer in India.

Another issue related with reverse logistics activities which parts and/or which strategies will be adopted in manufacturing. Tahirow et al. (2016) developed a mathematical model to evaluate the reverse logistics strategies. Considered strategies are remanufacturing, only manufacturing from virgin raw materials and a mixed strategy remanufacturing and pure manufacturing.

When multi-supplier case is adopted the issue is allocating order quantities in addition to supplier selection. Gupta et al. (2016) considered supplier selection and order allocation problem in all units discount strategy. A fuzzy multi- objective integer linear model that is integrated with analytic hierarchy process is developed. The superiority of the developed

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model is shown on relevant fuzzy programming approaches from the literature. In supplier selection model developed by Moghaddam (2015) best suppliers and allocated order quantities by selected suppliers are found in reverse logistics case. Developed model considers the uncertainty in customer demand, supplier capacity and returned product percentage.

Regarding the reviewed studies, it can be concluded that there is a limited number of studies including the selection of suppliers in green supply chains. It is aimed to fill this gap in this study with a multi-objective model under the environment of multi-item/multi-supplier.

3. Methodology

There are three stages in the proposed methodology as shown in Figure 1. In the first stage, the alternatives, criteria and parameter values about the system are determined. In the second stage, the Reverse Logistics Score (RLS) of each supplier is obtained via Analytic Hierarchy Process (AHP) and then the obtained scores are used as inputs in the developed multi-objective mathematical model. Two objectives exist in the mathematical model. The first one is to maximize Total RLS score and the latter one is to minimize the total cost including variable and fixed costs.

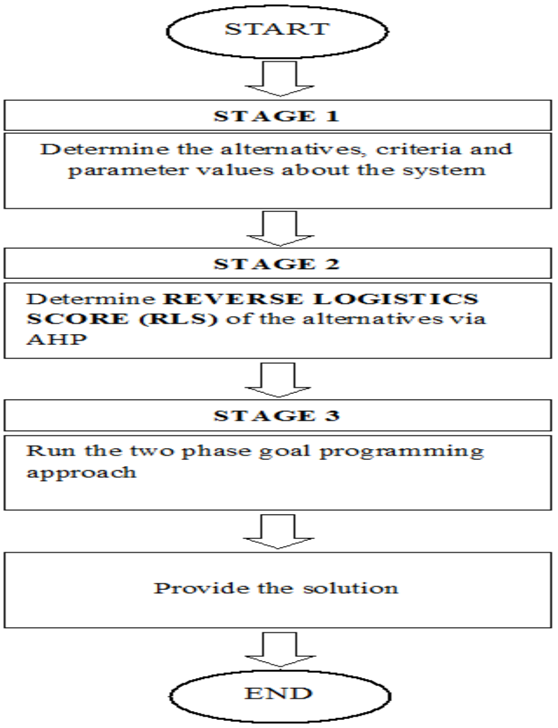

Fig. 1. The steps of the proposed methodology

Details of the used methods is provided in the following sub-sections.

3.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of the most popular multi-criteria decision making techniques. It was firstly proposed by Saaty in the early 70s and after that year it was used to solve numerous evaluation and selection problems. AHP structures a decision problem in a hierarchical order and by applying pairwise comparisons and integrating the comparisons, it tries to assign weights to the alternatives. Details of AHP can be found in Saaty (1980, 1994, 2005, and 2008).

3.2 Mathematical Model

A mixed integer linear programming (MILP) model is proposed to determine the suppliers and the allocated demand to them. There exist two main objectives in the model. The first one is to maximize the score specifically called **“Reverse Logistics Score (RLS)”** gathered from the evaluation of alternatives with respect to the criteria by the help of expert opinions via AHP. However, the other objective is to minimize the **“Total Cost”** consisting of variable and fixed costs. The proposed model is as follows:

Assumptions

Each recycling material in a region can be allocated to only one of the alternatives. The amount of recyclable material expected to occur in a region is deterministic.

Indices

i	Index for suppliers	$i \in I$
j	Index for region	$j \in J$
k	Index for recycling material	$k \in K$

Parameters

C_{ik}	Capacity of supplier “i” for recycling material *“k”*
D_{jk}	Recycling material “k” amount to be collected in region *“j”*
F_{ijk}	Fixed cost of each supplier *“i”* for each region *“j”* for recycling material *“k”*
M	A big number
$MaxR_j$	Maximum number of suppliers allowed in region *“j”*
$MaxS$	Total amount of suppliers allowed in the system
RLS_i	Reverse Logistics Score of supplier *“i”*
V_{ijk}	Variable cost of each supplier *“i”* for each region *“j”* for per ton of recycling material *“k”* (TL/ton)

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Decision Variables

X_{ijk} Supplier *"i"* is assigned to recycling material *"k"* in region *"j"*

Y_{ij} Supplier *"i"* is assigned to region *"j"*

Z_i Supplier *"i"* is selected or not selected (1 or 0)

Objective Functions

Objective 1: First objective function is the maximization of Total Reverse Logistics Score (TRLS)

$$\text{Max } \mathbf{TRLS} = \sum_i \sum_j \sum_k (RLS_i * X_{ijk} * D_{jk}) \qquad (1)$$

Objective 2: Second objective function is the minimization of total cost (TCOST)

$$\text{Min } \mathbf{TCOST} = \sum_i \sum_j \sum_k (X_{ijk} * D_{jk} * V_{ijk}) + \sum_i \sum_j \sum_k (X_{ijk} * F_{ijk}) \qquad (2)$$

Constraints

$$\sum_i (X_{ijk} * D_{jk}) = D_{jk} \quad \forall_j, \forall_k \qquad (3)$$

$$\sum_j (X_{ijk} * D_{jk}) \le C_{ik} \quad \forall_i, \forall_k \qquad (4)$$

$$M * Y_{ij} \ge \sum_k X_{ijk} \quad \forall_i, \forall_j \qquad (5)$$

$$M * Z_i \ge \sum_j \sum_k X_{ijk} \quad \forall_i \qquad (6)$$

$$\sum_i Y_{ij} \le maxR_j \quad \forall_j \qquad (7)$$

$$\sum_i X_{ijk} = 1 \quad \forall_j, \forall_k \qquad (8)$$

$$\sum_i Z_i \le maxS \qquad (9)$$

$$X_{ijk},\ Y_{ij},\ Z_i \in \{0,1\}\ binary\ integers,$$

$$\forall_i, \forall_j, \forall_k \qquad (10)$$

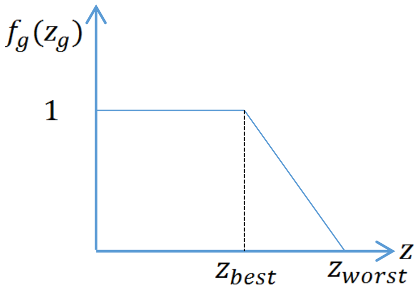
Equation (1) shows the first objective function. It tries to maximize the Total Reverse Logistics Score (TRLS) including the sum of the multiplications of each supplier's Reverse Logistics Score (RLS) by the quantities assigned to them. Equation (2) shows the second objective of the model. It tries to minimize the Total Cost (TCOST) including the sum of the variable and fixed costs. Equation (3) tries to guarantee that demand of each region *"j"* with respect to each material *"k"* is satisfied. Equation (4) tries to guarantee that the capacity of each supplier *"i"* with respect to each recycling material *"k"* is not exceeded. Equation (5) tries to guarantee that a supplier "i" is assigned to a region *"j"*, if any of the *"k"* recycling material at that region is provided by it. Equation (6) tries to guarantee that a supplier *"i"* is selected if any of the recycling material *"k"* at any region *"j"* is provided by it. Equation (7) tries to guarantee that maximum number of suppliers in a region is not exceeded. Equation (8) tries to guarantee that a *"k"* recycling material from a certain "*j*" region can only be collected by one supplier type "*i*". Equation (9) tries to guarantee that maximum number of suppliers in the system is restricted by an upper value. Equation (10) tries to guarantee that decision variables are to be binary integers.

3.3 Two phase fuzzy goal programming approach

Two phase fuzzy goal programming approach is utilized in this study. First of all, best (z_{best}) and worst (z_{worst}) values for each of the objective functions is to be found. Objective function value is z_g .Those values are used to establish membership functions ($f_g(z_g)$) (Figure 2). Membership functions for minimization (Figure 2a) and maximization (Figure 2b) are given in Figure 2 and related equations are given in Equation 11 and 12, respectively (Amid et al., 2011).

$$f_g(z_g) = \begin{cases} 1 & z_g \le z_{best}^g \\ \dfrac{z_{worst}^g - z_g}{z_{worst}^g - z_{best}^g} & z_{best}^g \le z_g \le z_{worst}^g \\ 0 & z_g \ge z_{worst}^g \end{cases} \qquad (11)$$

$$f_g(z_g) = \begin{cases} 1 & z_g \ge z_{best}^g \\ \dfrac{z_g - z_{worst}^g}{z_{best}^g - z_{worst}^g} & z_{worst}^g \le z_g \le z_{best}^g \\ 0 & z_g \le z_{worst}^g \end{cases} \qquad (12)$$



a. Membership function for a minimization function

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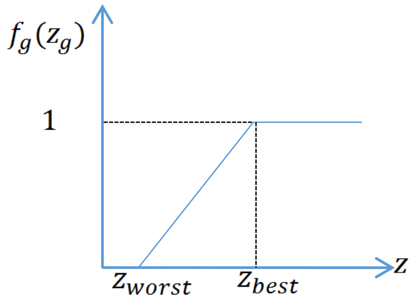

b.Membership function for a maximization function

Fig.2. Membership functions for objective functions (Ashayeri and Tuzkaya, 2011; Kongar and Gupta, 2006).

Two phase approach is adapted from Liang (2010) and details are given below:

Phase 1. Max-min approach: This approach tries to improve the satisfaction degree of the objective function which has a minimum satisfaction degree. General satisfaction degree (GSD1) is tried to be maximized and for each objective function, $f_g(z_g)$ values should be more than or equal to GSD1.

$$Max\ GSD1 \qquad (13)$$

$s.t.$

$$0 \leq \text{GSD1} \leq f_g(z_g) \qquad \forall g \qquad (14)$$

Equations (3)-(10)

Phase 2. Weighted sum approach: In this phase, objective function satisfaction degrees obtained in the first phase ($OFSD_g^1$) are taken as a constraint (a minimum bound) for each objective function satisfaction degree. Each objective function's satisfaction degree ($OFSD_g$) obtained in this phase is weighted considering the relative importance of the weights. Total weighted objective function satisfaction degrees is tried to be maximized and this total is general satisfaction degree (GSD2).

$$Max\ GSD2 = \sum_{g=1}^{K} w_{g*} OFSD_g \qquad (15)$$

$s.t.$

$$OFSD_g^1 \leq OFSD_g \leq f_g(z_g) \qquad \forall g \qquad (16)$$

$$\sum_{g=1}^{K} w_g = 1 \qquad (17)$$

Equations (3)-(9)

$$0 \leq GSD2 \leq 1 \qquad (18)$$

$$0 \leq OFSD_g^1 \leq 1 \quad \forall g \qquad (19)$$

$$0 \leq OFSD_g \leq 1 \quad \forall g \qquad (20)$$

$$0 \leq w_g \leq 1 \quad \forall g \qquad (21)$$

4. A Numerical Example

A numerical example is constructed for the application of the proposed methodology. While constructing the numerical example, it is benefited from the real applications in the municipalities. Within the numerical example, it is assumed that there is a municipality which wants to outsource the collection of five recyclable materials such as battery, glass, plastic, paper and electronic waste. The related outsourcing firms will not only be responsible for the collection of the recyclable materials but also will construct the infrastructure by providing the containers and the related equipment that are suitable for the storage and handling of them.

While selecting the related suppliers, five criteria such as **timeliness** (conforming to the delivery schedule), **operation time** (loading-unloading time which affects the traffic condition), **environmentally friendliness** of the containers and the equipment used for handling them, **financial situation** and **references** of the supplier are considered. The importance weights of the criteria and each supplier's Reverse Logistics Score (RLS) are determined via AHP. The related hierarchy is provided as in Figure 3.

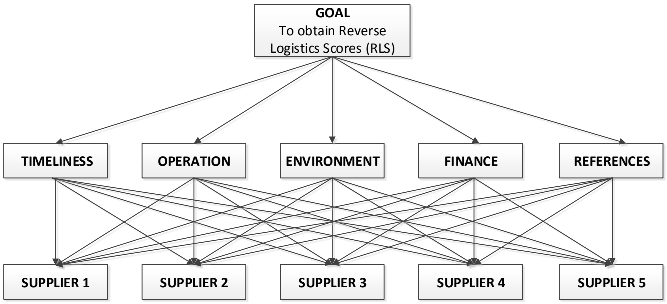

Fig. 3. The hierarchical structure for determining the reverse logistics scores for the suppliers

The related pairwise comparison matrices are formed and solved by Super Decisions software and the Reverse Logistics Scores for the suppliers are obtained as Supplier 1: 0.155; Supplier 2: 0.219; Supplier 3: 0.189; Supplier 4: 0.247; Supplier 5: 0.190.

After determining the Reverse Logistics Scores of the alternatives, the related parameters that will be used in the mathematical models are determined as follows:

There are 10 regions (shown with "R") within the land of municipality. The expected quantities to occur for

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each recyclable material within each region are depicted in Table 1.

There are 5 alternative outsourcing firms to collect the recyclable waste. The firms have limited capacities with respect to each recyclable material as shown in Table 2.

The variable costs mainly including the transportation and handling costs that suppliers offer change depending on the region and recycling material type. The related parameters are shown as in Table 3. Although the variable costs could change with respect to recycling material type, they are accepted as same within a region in this example.

Besides the variable costs, there is the cost of containers. Each of the supplier demands a fixed cost for containers for each region. The fixed costs could also change with respect to each recycling material type, but they are also accepted as same within a region in this example (Table 4).

Table 1. The expected quantities of recyclable materials for 10 regions

Quantities (ton)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Battery	25	10	30	15	18	20	36	33	23	28
Glass	1,000	600	1,200	750	1,000	900	1,500	1,250	950	1050
Plastic	9000	6000	10000	7500	8000	8000	12000	11000	8500	7000
Paper	8000	5000	9000	8000	7500	8000	10000	12000	9000	7500
Electronic Waste	12	8	15	9	10	11	18	16	12	10

Table 2. The capacities of alternatives with respect to each recyclable material

Capacity (ton)	**Battery**	**Glass**	**Plastic**	**Paper**	**Electronic Waste**
Suuplier 1	75	-	25000	23000	30
Supplier 2	10	5000	30000	25000	-
Supplier 3	55	4000	22500	20000	50
Supplier 4	100	4500	27500	25000	60
Supplier 5	-	5000	15000	17000	55

Table 3. The variable costs offered by alternatives with respect to each region from R1 to R10 for each recycling material type

Variable cost (TL/ton)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Supplier 1	24	35	33	25	40	34	28	36	27	42
Supplier 2	33	40	26	36	35	28	41	25	37	29
Supplier 3	25	25	35	40	28	36	30	24	25	33
Supplier 4	40	20	27	25	30	39	22	27	38	27
Supplier 5	25	44	30	33	24	29	39	41	23	38

Table 4. The fixed costs offered by alternatives with respect to each region from R1 to R10 for each recycling material type

Fixed cost (TL)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Supplier 1	25000	10000	28000	15000	17500	18000	30000	29000	26000	28000
Supplier 2	24000	11000	30000	14000	16000	20000	27000	28000	27500	29000
Supplier 3	27000	12000	35000	18000	19000	19000	33000	32000	30000	31000
Supplier 4	22000	9000	29000	20000	18000	24000	31000	34000	28000	27000
Supplier 5	30000	13000	32000	19000	22000	23000	32000	33000	31000	30500

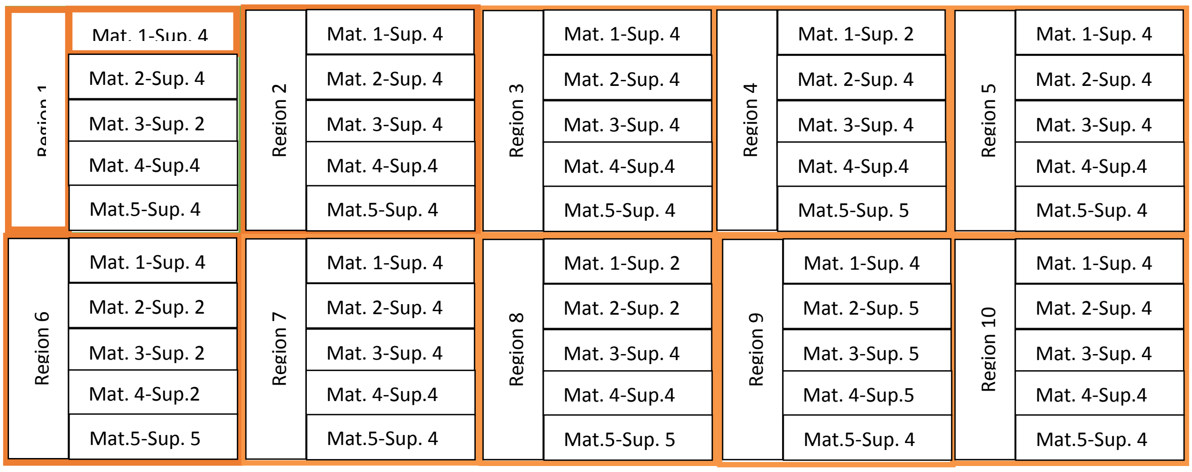
4. Results and analysis

First of all, the model is solved for single objective functions to find the best and worst values of the objective functions. Also, it should be noted that, maximum number of supplier is accepted to be three for the explained numerical example. Solution of the model with the first objective (OF1) gives us the best value for the first objective function(z^1_{best}). The values of the decision variables under this case are used to find the value of the second objective (OF2). Second objective value under these circumstances gives the worst value for the second objective(z^2_{worst}). Next, the model is solved with OF2, and (z^1_{worst}) and (z^2_{best}) values are found. Summary of the results for single objective solutions are given in the Table 5. Following the best and worst value of objective functions determination phase, membership functions are constructed using Equations 11 and 12. When the model is solved for Phase 1, a solution is obtained for the multi-objective case. For this phase, general satisfaction degree value is obtained as 0.61296. Since, GSD1 should be less then and equal to membership values of the objective functions (Equation 14), its value is found equal the worst membership value which belongs to second objective function.

With the second phase, the general satisfaction degree level and the satisfaction degrees for each objective function is tried to be improved. For the second phase, model is re-written like as shown in Equations 15-21. Objective function satisfaction degrees obtained in first phase are set as minimum acceptable level of related objective functions (Equation 16). For phase two, objective functions weights are determined as 0.3 and 0.7 for OF1 and OF2, respectively. For the investigated numerical example and the data, with Phase 2 the results are not improved. Same general satisfaction degree and membership values are obtained with the Phase 1. The reason of this situation is the very close objective function membership values obtained in the Phase I. The meaning of this situation is that with the current conditions (with the data given in the example), parallel results can be obtained for the both objective functions. Since their membership values are close to each other, second phase approach would not provide an improvement opportunity. Results are summarized in Figure 4. Supplier 1 and 2 were not assigned to any region or recycling material. In the Figure 4, the recycling materials shown with green boxes are assigned to the third supplier; pink boxes are assigned to the fourth supplier; and blue boxes are assigned to the fifth supplier.

Table 5. Best and worst values for objective functions and Phase 1 results

Objective function type	**Maximization**	**Minimization**	**Membership functions**	
	OF1(z_1)	**OF2 (z_2)**	**$f_1(z_1)$**	**$f_2(z_2)$**
(Single objective) OF1	44845.07 (z^1_{best})	6571021(z^2_{worst})	1	-
(Single objective) OF2	40105.73 (z^1_{worst})	5673956 (z^2_{best})	-	1
Multi-objective solution	43029.83	6021156	0.6169840	0.6129600
General satisfaction degree (GSD1) for the multi-objective solution (Phase 1)			0.6129600	



Region 1	Region 2	Region 3	Region 4	Region 5
Mat. 1-Sup. 4	Mat. 1-Sup. 4	Mat. 1-Sup. 4	Mat. 1-Sup. 2	Mat. 1-Sup. 4
Mat. 2-Sup. 4	Mat. 2-Sup. 4	Mat. 2-Sup. 4	Mat. 2-Sup. 4	Mat. 2-Sup. 4
Mat. 3-Sup. 2	Mat. 3-Sup. 4	Mat. 3-Sup. 4	Mat. 3-Sup. 4	Mat. 3-Sup. 4
Mat. 4-Sup.4	Mat. 4-Sup.4	Mat. 4-Sup.4	Mat. 4-Sup.4	Mat. 4-Sup.4
Mat.5-Sup. 4	Mat.5-Sup. 4	Mat.5-Sup. 4	Mat.5-Sup. 5	Mat.5-Sup. 4

Region 6	Region 7	Region 8	Region 9	Region 10
Mat. 1-Sup. 4	Mat. 1-Sup. 4	Mat. 1-Sup. 2	Mat. 1-Sup. 4	Mat. 1-Sup. 4
Mat. 2-Sup. 2	Mat. 2-Sup. 4	Mat. 2-Sup. 2	Mat. 2-Sup. 5	Mat. 2-Sup. 4
Mat. 3-Sup. 2	Mat. 3-Sup. 4	Mat. 3-Sup. 4	Mat. 3-Sup. 5	Mat. 3-Sup. 4
Mat. 4-Sup.2	Mat. 4-Sup.4	Mat. 4-Sup.4	Mat. 4-Sup.5	Mat. 4-Sup.4
Mat.5-Sup. 5	Mat.5-Sup. 4	Mat.5-Sup. 5	Mat.5-Sup. 4	Mat.5-Sup. 4

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5. Conclusions

In this study, a multi-objective model is developed for the supplier selection and order allocation processes. Environmental aspects are also considered during the evaluation process. An integrated AHP-two phase fuzzy goal programming methodology is applied as the solution methodology. Multi-supplier and multi-product case is investigated for a hypothetical example. For the future researches, a real life case may be investigated. Also, to handle the multiple-objectives, Linear Physical Programming, which provides the objective function weights thanks to its weighting algorithm, may be applied.

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