



A Supplier Selection and Order Allocation Methodology for Green Supply Chains

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Abstract

Due to the fact that the natural resources are limited and the demand increase level has accelerated, being an environmentally benign organization is getting more and more important. Various environmental regulations and strategies have been embedded to the organizational processes in recent years. Green supply chain management is one of these important topics and the focus of this study is to design a supplier selection and order allocation methodology for this managerial aspect. Different from the most of the supplier selection studies of the related literature, multi-item and multi-supplier case is considered. A multi-criteria decision making methodology is embedded in and a multi-objective mathematical model is proposed for this case. Finally, a numerical example is presented and the results are analyzed.

Keywords: Multi-Objective Linear Programming, Reverse Logistics, Green Supply Chain, Supplier Selection, Order Allocation

Introduction

In today's global competitive environment, the issue is not only selecting the most cost effective supplier but also environmentally conscious suppliers. Environmental consciousness requires awareness on environmental pollution issues [1]. Environmental events such as global warming, air and water pollution and other events impose firms on being aware of environmental aspect for activities they performed [2]. Sarkis [3] and Lee et al. [4] listed the environment care practices as; life cycle analysis, total quality environmental management, Green Supply Chain Management (GSCM) and ISO 14000 standards.

The key criteria in selecting the best supplier have been changed through the years. In the late 1970s and early 1980s cost was the first criterion to select the best suppliers.

Whilst, in 1990s, cycle time and customer became the main factors to select the best supplier. However, in 2000s environmental factors became a key success issue in supplier selection. This factor created a new paradigm that gives rise to Green Supply Chain [1].

Environmentally conscious initiatives started with reducing energy consumption, emissions and waste and then clean technologies emerged to reduce the environmental impact in production process and nowadays the environmental aspect is involved in every step of the supply chain [2].

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Considering the environmental aspect of supply chain, generates the term green supply chain. The difference between traditional and green supply chain is the environmental issues [5]. Shen et al. [2] divide the environmental issues into two main approaches; one is proactive which includes environmentally conscious design and manufacturing, and the other is reactive approach which tries to avoid penalties that cause environmentally unconscious events. Environmental issues play a vital role in green logistics. The cost components of environmental issues include, recycling, clean technology, pollution reduction capacity and environmental cost [6].

Green supply chain concept started to become a must for organizations since environmental laws and regulations. Environmental performance of a firm is assessed with respect to its conformance to the environmental laws and regulations [1].

Reverse logistics which can be defined simply as the recovery of the used products [7]. 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 [8].

Min and Ko [9] state that product returns constitute 1% through 35% of total sales depending on the industry. Product reuse in manufacturing is a profitable one and also supports green logistics by improving environmental awareness [8]. This emphasizes the importance of reverse logistics activities in the supply chain.

Reverse logistics activities assist used materials being involved to their life cycle again by planning and operating the return of products [10]. The difference between reverse and forward logistics is that, reverse logistics controls the inbound flow and storage of used products to create value and dispose the used products [11]. The relationship between reverse logistics and environmental legislations comes from the requirement of reuse, recycling and proper disposal of dangerous products. The importance of collection, packaging, storage, sorting, transaction processing, delivery, integration and correct disposal which are the same with forward logistics becomes important again in reverse logistics activities [10].

There are several industries that utilize reverse logistics such as; automobiles, plastics, carpets, papers, chemicals and medical items [8].

The management of reverse logistics activities can be handled; by the company, by reverse logistics providers, by cooperatives of waste pickers or municipal organizations [12]. Specialization in reverse logistics activities requires a special information system for tracing/tracking data and thorough equipment for returns [8].

The advantages of specialized third party reverse logistics providers (3PRLP) are reduced logistics costs and companies can concentrate on their own business [8]. 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 of 3PRLPs 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 [13].



Assigning suppliers for reverse logistics activities is a critical task for sustainable supply chain [10]. There are important criteria in selecting the best supplier for reverse logistics. Aissaoui et al. [14] state that purchasing costs consist of more than 50% of expenses. This cost proportion implies the importance of purchasing activities for the firms.

The selection criteria should be identified carefully for 3PRLPs. One of the most important criteria is the environmental consciousness [15]. Quality, capability, flexibility, production and process innovation are the other criteria in selecting 3PRLP [16]. Efendigil et al. [13] 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.

There are two types of supplier selection option. One is single supplier selection problem. In this option, one supplier is selected for all purchasing activities. The next option is multiple supplier selection [1]-[17]. The issue in multiple supplier selection is selecting best suppliers and allocating the optimum order quantities based on several criteria.

Several methods in the related literature can be found on supplier selection problems. Ho et al. [18] 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. The other methods that are used in the literature; LP, Multi objective programming, 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 [1].

Besides these Fuzzy set theory is the mostly utilized topic in assigning weights to suppliers [19]-[20]-[21]-[22]-[23]-[24].

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 conclusions.

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 [2]-[18].



Awashthi et al. [25] constructed a hierarchy for supplier selection problem and determined criteria weights using fuzzy AHP and fuzzy TOPSIS method and select the best supplier. They listed criteria in GSCM as; availability of clean materials, environmental efficiency, green image, environmental costs, green products, environmental and legislative management and green process management. They developed a fuzzy multi objective linear programming approach to allocate order quantities to selected suppliers.

Kannan et al. [1] applied fuzzy multi attribute utility theory and multi objective programming approach to select suppliers and assign order quantities. They utilized fuzzy AHP and TOPSIS methods to assign the subjective importance weights to criteria they considered to rank the alternatives. Multi objective linear programming model is incorporated to define quality control, capacity constraints and several objectives. The objective of multi objective linear programming model was to maximize the total value of purchasing at the same time. They applied the method in an automobile manufacturing company.

The sustainability also serves the green supply chain. Brandenburg et al. [26] 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 [27]. 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. Guarnieri et al. [10] 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 set of 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.

Efendigil et al. [13] proposed a combined artificial neural network and fuzzy logic to determine the best 3PRLP. Min and Ko [9] proposed a mixed integer programming model and a genetic algorithm to select the location of repair facilities for 3PRLPs. They applied the developed methodology in a numerical example.

Kannan et al. [8] 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.

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



Proposed Methodology

The proposed methodology has two parts as shown in Figure 1. In the first part, the Reverse Logistics Score (RLS) of each supplier is obtained via taking the expert opinions and then the obtained scores are used as inputs in the developed multi-objective mathematical model. There are two objectives in the mathematical model. The first one is to maximize Total RLS score and the second one is to minimize the total cost including variable and fixed costs.

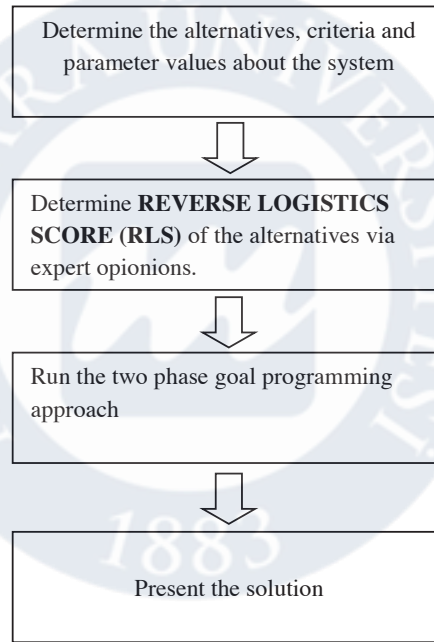


Figure 1. The steps of the proposed methodology

The related information about the used methods is provided in the following sub-sections.

Mathematical Model

A mixed integer linear programming (MILP) model is developed to determine the suppliers and allocated demand to them. There are two main objectives in the model. The first one is to maximize the score specifically called “**Reverse Logistics Score (RLS)**” obtained from the evaluation of alternatives with respect to the determined criteria via expert opinions by direct scoring. However, the other objective is to minimize the “**Total Cost**” including 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 ”, with respect to recycling material “ k ”



D_{jk}	Amount of recycling material “k” 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)

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)

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

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

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

Constraints

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

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

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

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

$$\sum_i Y_{ij} \leq \text{max}R_j \quad \forall_j \quad (7)$$

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

$$\sum_i Z_i \leq \text{max}S \quad (9)$$

$$X_{ijk}, Y_{ij}, Z_i \in \{0,1\} \text{ binary integers, } \forall_i, \forall_j, \forall_k \quad (10)$$

- (1) The first objective of the model is 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.
- (2) The second objective of the model is to minimize the Total Cost (TCOST) including the sum of the variable and fixed costs.
- (3) The demand of each region “j” with respect to each material “k” is satisfied.
- (4) The capacity of each supplier “i” with respect to each recycling material “k” is not exceeded.
- (5) A supplier “i” is assigned to a region “j”, if any of the “k” recycling material at that region is provided by it.
- (6) A supplier “i” is selected if any of the recycling material “k” at any region “j” is provided by it.
- (7) Maximum number of suppliers in a region is restricted by an upper value.
- (8) A “k” recycling material from a certain “j” region can only be collected by one supplier type “i”.
- (9) Maximum number of suppliers in the system is restricted by an upper value.



- (10) The decision variables are binary integers.

Two phase fuzzy goal programming approach

In this study, two phase fuzzy goal programming approach is applied. First of all, best (z_{best}) and worst (z_{worst}) values for each 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 [28].

$$f_g(z_g) = \begin{cases} 1 & z_g \leq z_{best}^g \\ \frac{z_{worst}^g - z_g}{z_{worst}^g - z_{best}^g} & z_{best}^g \leq z_g \leq z_{worst}^g \\ 0 & z_g \geq z_{worst}^g \end{cases} \quad (11)$$

$$f_g(z_g) = \begin{cases} 1 & z_g \geq z_{best}^g \\ \frac{z_g - z_{worst}^g}{z_{best}^g - z_{worst}^g} & z_{worst}^g \leq z_g \leq z_{best}^g \\ 0 & z_g \leq z_{worst}^g \end{cases} \quad (12)$$

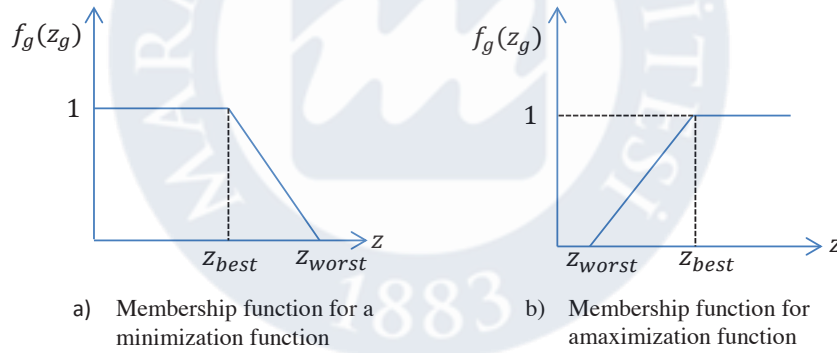


Figure 2. Membership functions for objective functions [29]-[30].

Two phase approach is adapted from Liang [31] 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.

$$\text{Max GSD1} \quad (13)$$

s. t.

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

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).

$$\text{Max GSD2} = \sum_{g=1}^K w_g \cdot OFSD_g \quad (15)$$

s. t.

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



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

Equations (3)-(9)

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

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

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

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

Numerical Example

The proposed methodology is applied in a numerical example. The numerical example is constructed by benefiting from the real applications in the municipalities. Within the numerical example, there is a municipality and it wants to outsource the collection of four recyclable materials such as battery, glass, package and electronic waste. The related outsourcing firms will not only collect the recyclable material but also construct the infrastructure by providing the containers that are suitable for the storage of them.

While selecting the related suppliers, four 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 and **financial situation** of the supplier. Since this is a numerical example it is assumed that expert opinions are taken to evaluate the suppliers and weights are obtained as 0.01, 0.09, 0.5, 0.1, and 0.3 for supplier 1, 2, 3, 4 and 5 respectively.

There are 10 regions (shown with “R”) within the land of municipality. The expected quantities to occur for each recyclable material within each region are depicted in Table 1.

Table 1. The expected quantities of recyclable materials to occur in 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
Package	9,000	6,000	10,000	7,500	8,000	8,000	12,000	11,000	8,500	7,000
Electronic Waste	12	8	15	9	10	11	18	16	12	10

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.

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

Capacity (ton)	Battery	Glass	Package	Electronic Waste
Alternative 1	375	-	125	150
Alternative 2	50	25	150	-
Alternative 3	275	20	112,5	250
Alternative 4	325	22,5	137,5	300
Alternative 5	-	25	75	275



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.

Table 3. The variable costs offered by each alternative 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
Alternative 1	24	35	33	25	40	34	28	36	27	42
Alternative 2	33	40	26	36	35	28	41	25	37	29
Alternative 3	25	25	35	40	28	36	30	24	25	33
Alternative 4	40	20	27	25	30	39	22	27	38	27
Alternative 5	25	44	30	33	24	29	39	41	23	38

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 4. The fixed costs offered by each alternative 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
Alternative 1	25,000	10,000	28,000	15,000	17,500	18,000	30,000	29,000	26,000	28,000
Alternative 2	24,000	11,000	30,000	14,000	16,000	20,000	27,000	28,000	27,500	29,000
Alternative 3	27,000	12,000	35,000	18,000	19,000	19,000	33,000	32,000	30,000	31,000
Alternative 4	22,000	9,000	29,000	20,000	18,000	24,000	31,000	34,000	28,000	27,000
Alternative 5	30,000	13,000	32,000	19,000	22,000	23,000	32,000	33,000	31,000	30,500

Results

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_{best}^1). 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_{worst}^2). Next, the model is solved with OF2, and (z_{worst}^1) and (z_{best}^2) 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 Equation 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 0.6423685. Since, GSD1 should be less than 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.



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	48779 (z_{best}^1)	3945035 (z_{worst}^2)	1	-
(Single objective) OF2	15129 (z_{worst}^1)	3358456 (z_{best}^2)	-	1
Multi-objective solution	36744	3568205	0.6423685	0.6424199
General satisfaction degree (GSD1) for the multi-objective solution (Phase 1)			0.6423685	

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 3. Supplier 1 and 2 were not assigned to any region or recycling material. In the Figure 3, 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.

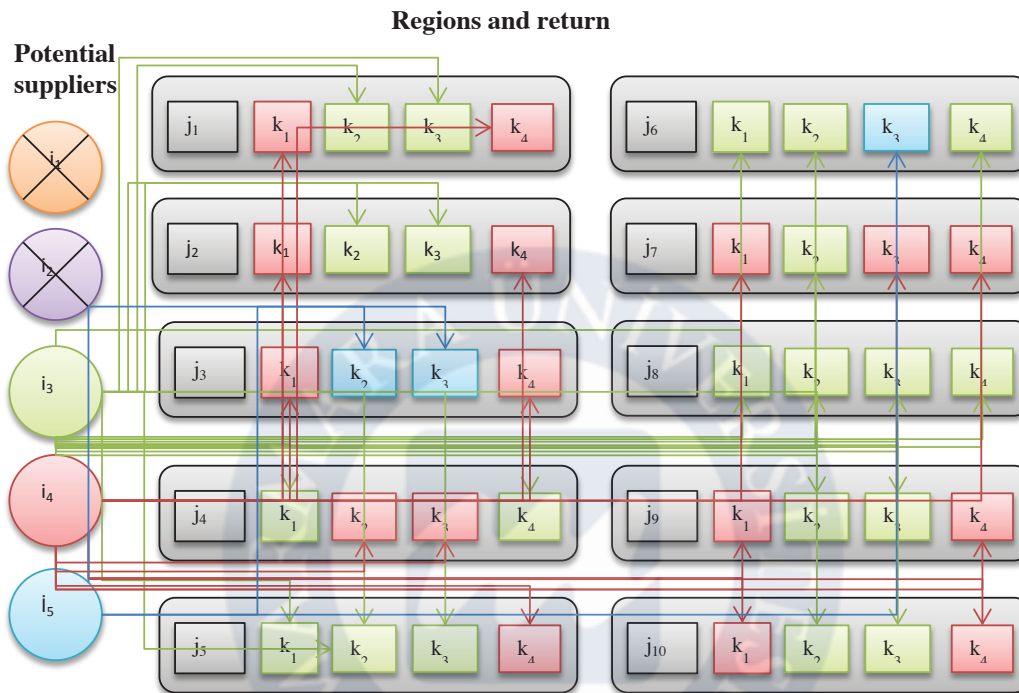


Figure 3. Supplier assignments

Conclusions

In this study, a multi-objective supplier selection and order allocation model is investigated for reverse supply chain networks. Different types of return products for different regions are tried to be assigned to the proper suppliers. As a solution methodology, two phase fuzzy goal programming is applied. At the first phase, a max-min operator is applied to integrate two objective functions into one objective function. Since only the objective function with the worst satisfaction degree is tried to be improved with this operator, an improvement opportunity is investigated with the second phase. At the second phase, a weighted sum operator is applied to integrate objective functions. During this phase, objective function membership degrees obtained at the first phase are put as constraints for related objective functions satisfaction degrees. An improvement is not observed since the first phase objective function membership degrees are very close to each other.

For the future researches, a real life case may be investigated. Also, membership functions of objective functions may be set as piece-wise linear function which may provide us to make a more detailed analysis. Also, some of the parameters such as demand volumes and cost values may be set as fuzzy numbers considering the vague nature of those kinds of environments.

Moreover, for determining the reverse logistics score (RLS) of the suppliers, a scoring system can be improved by validating multiple criteria decision making techniques such as fuzzy AHP and ANP.

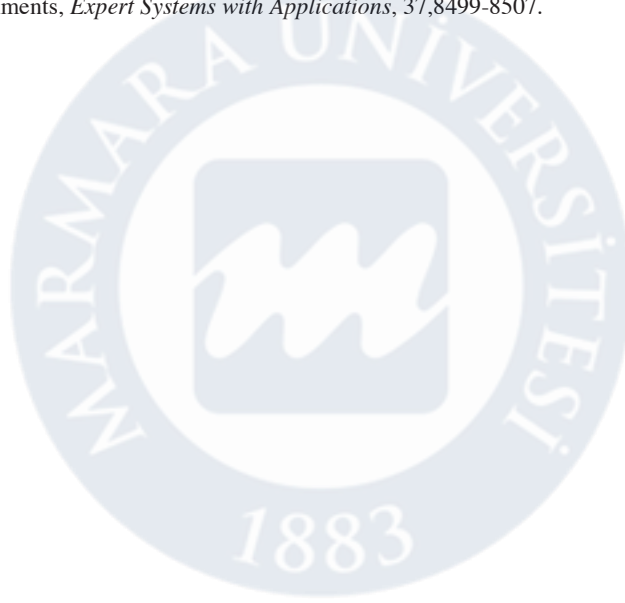


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