# Multi-Criteria Supplier Selection Decisions in Supply Chain Networks:
# A Multi-Objective Optimization Approach

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## ABSTRACT

Competition among firms in current global market shifts to competition among networks of firms and it forces supply networks to negotiate and cooperate with all partners more than ever. Collaborative initiatives such as collaborative design, collaborative planning, forecasting and open collective innovations are increasingly accepted as approaches to effectively support decision-making processes in a variety of domains, including, manufacturing, education, healthcare and software industry (Camilleri and Hernández, 2016). Demands and constraints in the supply chain design operations are worthy of attention. The present paper is intended to study the supplier selection problem in a network of suppliers and buyers in the context of a multi-product supply chain. In the beginning, quality measures for supplier selection are collected and categorized into seven areas. Every quality area has been evaluated using the proposed fuzzy variables. In order to rank each product of each supplier in the view of every buyer, fuzzy AHP algorithm was applied. A multi-objective integer programing model was designed to make the whole network beneficial from cost as well as quality metrics. A Genetic Algorithm (3 dimensional) was presented in this study to gain acceptable solution in an advance way. An illustrative example is presented in this paper to transparent the proposed algorithm.

Keywords: Supply Chain, Supplier Selection, Linguistic Variables, Fuzzy AHP, Genetic Algorithm

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## 1. INTRODUCTION

Nowadays, business is undertaken on a global scale and enterprises have to be prepared for intense global competition and for reacting to unexpected changes in the market environment, for instance, in situations where high demand variability occurs. The basis of competition is multi-faceted and competitive performance is partially predicated on the quality of the flow of information across enterprises (Hernández *et al.*, 2016). Manufacturing and distribution systems in today's competitive mar-

kets face a myriad of dynamic challenges that require not only exceptional planning capacity, but also robust supply networks with coordination mechanisms. The ability to intelligently address inbound and outbound issues not only keeps the wheels of business turning, but it also gives the company a relative advantage over its competitors (Ventura *et al.*, 2013). Optimization is no longer a luxury and has been applied in order to solve many multi-objective supplier selection problems (Wu and Barnes, 2011).

Many research areas of coordination are discussed in the relevant literature. Selecting the appropriate suppliers

in a supply chain or supply network is one of the aspects that affect the output quality of the chain, directly. Selection of appropriate suppliers in supply chain management is a challenging issue because it requires many of evaluation criteria/attributes, which are characterized by complexity, elusiveness, and uncertainty in nature (Tseng *et al.*, 2009). Selecting proper suppliers is one of the most important stages in a supply chain management that regards all the activities from the purchasing of raw material and it is a critical process affecting the consecutive stages. It is simply desired to select the best supplier for each specific product (Kilic, 2013). The contemporary supply management is meant to maintain long term partnership with suppliers that are highly reliable, but quite few in number. For this reason, selecting the right suppliers requires much more than scanning a series of price lists; and thus choices to be made will depend on a wide range of quantitative and qualitative factors (Ho *et al.*, 2010). Most studies in the relevant literature were concerned with selection of suppliers in a chain but group deciding process has not been studied thoroughly in comparison with other relevant fields. Also taking into consideration the many objectives regarding optimization of the networks are poorly discussed. For Example, most studies considered price of the supplies as a part of quality factors instead of taking it as an independent deciding factor. Sun *et al.* (2012) categorized the products offered by different suppliers in price, product quality, and delivery performance. They claimed that an optimal supplier selection could minimize the total cost and maximize product quality and delivery performance. Mohebbi and Li (2012) divided the supplier selection problem into three overlapping services including matching of partners, proposal generations, and long-term contract management.

In this paper, we dealt with the supplier selection issue in a network of buyers and suppliers on the basis of multi-product needs.

In most studies, supplier selection problems normally deal with one buyer and many providers. Moreover, modeling the various products in a supply network is not widely considered in the literature. In most studies only quality metrics are developed in order to rank the suppliers by the use of a single objective function model. In this paper, multi-buyer group optimization in a network of buyers and suppliers will be taken into consideration in the presented integer-programming model. Furthermore, the GA is designed to analyze the proposed multi-product and multi-buyer supplier selection model intended to optimize two objective functions simultaneously. To evaluate suppliers in the proposed ranking model, buyers used linguistic variables. Fuzzy AHP ranking model was used to rank each product of every single supplier from the viewpoint of buyers. Based on the network optimization problem, a model was proposed in order not to surpass the constraints of production capacity as well as demand limitations. Finally, a novel GA was designed in order to gain adequate solution that regards both quality and cost objectives in the model.

Having reviewed the relevant literature in section 2, the supplier selection problem is discussed and the evaluation model consisting in 7 sets of indices is proposed in section 3. In section 4, designing the linguistic variables for the betterment of evaluation is discussed. Later in the same section, the model of supplier selection is offered and the proposed solving algorithm is introduced respectively. In section 5, an illustrative example is presented to explain the solving method thoroughly. Finally, section 6 will provide the readership with discussion and conclusion obtained in this study.

## 2. REVIEW OF THE LITERATURE

Due to the significance of supplier selection in a supply network a large number of studies have been conducted.

In a research done by (Wang *et al.*, 2009), considering the limited production capacity of suppliers, selecting the best combination of suppliers has been studied. A genetic algorithm (GA) was proposed to deal with their presented mathematical model of selecting suppliers and acceptable procurement strategies were achieved. They proposed a fuzzy hierarchical TOPSIS[1] which made use of simplified metric distance. Their model was used for evaluating fuzziness and uncertainty problems. Tseng *et al.* (2009) proposed a hierarchical evaluation framework to assist the expert groups to select the optimal supplier in supply chain management network. The rationales for the evaluation framework were based upon multi-criteria decision making (MCDM) analysis or selecting the appropriate alternative from a finite set of alternatives. In their research analytic network process (ANP) technique has been used to eliminate the interactivity of expert subjective judgment problems.

In supplier selection problem, many techniques like integrated fuzzy and AHP are applied widely (Ho *et al.*, 2010). In a research done by Shu and Wu (2009), the quality-based supplier selection and evaluation was studied through using fuzzy data. Certain optimization problems were categorized and solved to obtain an optimal supply assignment by the use of membership functions of fuzzy variables so as to estimate the quality. Fuzzy ranking method was utilized in order to sort the suppliers based on their quality. In the paper presented by Amindoust *et al.* (2012) the sustainable supplier selection criteria and sub-criteria are determined through the literature survey; on the basis of those criteria and sub-criteria,

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1) The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

a methodology was proposed regarding the evaluation and ranking of a given set of suppliers. To handle the subjectivity of decision makers' assessments, the fuzzy logic was applied and a new ranking method on the basis of fuzzy inference system (FIS) was proposed for the problem. Erdem and Göçen (2012) were intended to develop a decision support system (DSS) for the improvement of supplier evaluation in the supply chain they had in mind. They offered an analytic hierarchy process (AHP) model, developed for qualitative and quantitative evaluation of suppliers. Also they developed a model of goal programming (GP) so as to assign the amount of each order to the related providers.

Rezaei and Ortt (2013) developed a fuzzy Analytic Hierarchy Process (AHP) to make use of fuzzy preference relations to eliminate the ambiguities and uncertainties that usually exist in human judgment. Their proposed methodology was used to segment the suppliers of a broiler company. Considering the inherent connection between supplier selection and inventory management, Ventura *et al*. (2013) presented a multi-period inventory lot-sizing model for a single product in a serial supply chain, where raw materials may be purchased from multiple suppliers at the first stage of the supply chain.

Similar to the variety in supplier selection criteria, various solution methodologies have been used for the supplier selection problem. Although most of these methodologies are used singly, a considerable amount of them are used along with other techniques (Ho *et al*., 2010).

Current technologies and organizational forms require involvement of more decision-makers. The influence of these developments on the complexity and importance of purchasing decisions includes of large set of criteria, spreading purchasing function, and increase in outsourcing (Boer *et al*., 2001).

The fuzzy set of theories was employed due to the presence of vagueness of information with the help of weighted max-min fuzzy model by Amid *et al*. (2006) and their work developed to multi-objective selection of suppliers (Amid *et al*., 2011). In their paper, an analytic hierarchy process (AHP) is used to determine the weights of criteria to find out the appropriate assignment of orders to each supplier, and to manage supply chain performance consisting in cost, quality and service. In order to find the best supplier mixture in the multi-item/multi-supplier environment, an integrated approach including fuzzy TOPSIS and mixed integer linear programming model was proposed by (Kilic, 2013). In this model, importance values of each supplier are obtained via fuzzy TOPSIS and they are used in the mixed integer linear programming (MILP) model in order to find the best suppliers and the assigned items. Extensive multi-criteria decision making approaches such as the analytic hierarchy process (AHP), analytic network process (ANP), case-based reasoning (CBR), data envelopment

analysis (DEA), fuzzy theory, genetic algorithm (GA), mathematical programming, simple multi-attribute rating technique (SMART), and their hybrids have been employed aimed at selecting appropriate suppliers (Ho *et al*., 2010).

Supplier selection is a multiple criteria decision-making (MCDM) problem which is affected by several conflicting factors and it consists of both qualitative and quantitative factors. So, There are many methods for supplier selection problems including analytic hierarchy process (AHP), fuzzy sets theory (FST), genetic algorithm (GA), goal programming (GP), and other methods (Dahel, 2003).

There are various integrated AHP-based approaches for supplier selection, and also AHP has been integrated with other soft computing techniques, including: fuzzy set theory, goal programming (GP), and multi-objective programming (MOP). Although, the integrated AHP-GP approach is the most popular, the major reason to utilize the individual techniques let the decision makers to review and revise their judgments. Consequently, the judgments made are guaranteed to be consistent, which is the basic ingredient for making good decisions Simić *et al*. (2017).

Tavana *et al*. (2013) offered a hypothetical model to extract the fuzzy relative importance weights of the attributes in the multi-attribute project selection problem using a fuzzy ANP method. The model was presented to rank the alternatives using the fuzzy TOPSIS method. Both the relative importance weight of the attributes and the performance score of the alternatives are assumed to be triangular fuzzy numbers (TFNs). Also MCDM techniques are applied in many different areas such as selecting among alternatives regards the performance ratings of the providers on qualitative criteria. Moreover, fuzzy sets are used mostly to deal with the imprecision and subjectivity involved in the evaluation process of provider selection problems (Büyüközkan *et al*., 2012). Regarding the supplier selection area, some of the techniques used singly are as follows: analytic hierarchy process (AHP), analytic network process (ANP), data envelopment analysis (DEA), mathematical programming, case-based reasoning, fuzzy set theory, simple multi-attribute rating technique and genetic algorithm. In addition, some of the integrated techniques like integrated fuzzy approaches (integrated fuzzy and AHP, integrated fuzzy AHP and cluster analysis, integrated fuzzy and genetic algorithm, integrated fuzzy and quality function deployment, and the like) are also applied widely (Ho *et al*., 2010).

One of the popular methods used to deal with multiple criteria decision-making is the technique for order preference by similarity (TOPSIS). This method has been used as fuzzy MCDM problem solving approach in selecting the optimal suppliers in supply chain management problems (Rouhani *et al*., 2012).

# 3. SUPPLIER SELECTION CRITERIA

Many metrics can be used in an evaluation model in order to rank the suppliers' performance and quality. Most of the metrics cannot be evaluated and categorized as quantitative ones. Also some metrics may have different scores in the view of different buyers in a supply network.

Huang and Keskar (2007) proposed a model that includes 13 levels of metrics in five categories-delivery reliability, responsiveness, flexibility, costs, and asset management efficiency. Based on organizational strategy, the management configures an appropriate set of indices to measure supplier performance. They organize these categories into three tracks, i.e., product related, supplier related, and society related, for easier user configuration. Tseng *et al.* (2009) presented a hierarchical structure of evaluation framework for SCMS, an MCDM analysis combined with ANP to select the optimal suppliers for the case of each PCB manufacturing firm. Their model consists in five categories listed as follows:

- Customer focus
- Competitive priority
- Strategic purchasing
- Top management support
- Information technology
- proposed an evaluation model for selecting the best supplier consists in four classes:
- CLASS I: Performance strategy
- CLASS II: Quality of service
- CLASS III: Innovation
- CLASS IV: Risk

Mani *et al.* (2014) formulated a Delphi group to identify the social sustainability metrics in this problem.

In the present study, the researchers categorized standards for selecting suppliers into seven sets of indices with the help of experts of the related field by adoption of Delphi method. The method formed in 3 phases consist in an interview, in order to collect all the metrics, a questionnaire for sharing the whole experts indices, and finally another questionnaire in order to finalizing and assigning all indices into categories. Each category consists in as many indices as the experts agreed on, through three phases of checking and evaluating of the interviews.

Table 1 Indicates seven sets of indices for the selection of suppliers presented in this study.

Each seven sets of indices consist of many factors, which should be considered by buyers in the network in order to provide adequate evaluations. Each area is defined as follows:

- ✓ Quality of products: This evaluation is a most important factor which affects the quality of final products of supply network. This factor can be measured by three metrics:
  - Percentage of acceptable products delivered from a

**Table 1.** Quality indices for selecting suppliers

| Set of indices (Quality criteria) | Indices |
|---|---|
| Quality of products | • Percentage of rejected (damaged) parts<br>• Standards<br>• Flexibility |
| Performance of services | • Delivery Robustness<br>• After sale services<br>• Preventive actions<br>• Corrective actions<br>• Ease of ordering |
| Price | • Pricing accuracy<br>• Purchase conditions |
| Market | • Market presence<br>• Market share<br>• Brand awareness |
| Development | • R&D performance<br>• Service innovation<br>• IT engagement |
| Environment | • Environmental engagement<br>• Safety standards<br>• Energy consumption |
| Risk | • Geographical location<br>• Political stability<br>• Economic stability |

specific supplier, which may vary in the view of each buyer according to quality and standards of its manufacturer.
- Level of standards each supplier observes in their productions.
- Flexibility in the manufacturing process of the products in order to make the necessary changes.
- ✓ Performance of services: Most services of suppliers are concerned with their agility in the delivery of the right order in the right time. Also other service quality can be defined as a response time to the requests made by buyers. This factor indicates the performance of necessary actions and can be measured by five indices:
  - Percentage of products delivered to buyers in the proper time interval
  - Quality of support services and other after sale services
  - Quality of preventive actions taken by suppliers to minimize delivery failures
  - Quality of corrective measures that suppliers can take in the case of a problem occurring in delivery or production process. Also response time to the request for corrective action can be evaluated
  - Ease of ordering and procurement process of each supplier
- ✓ Price: Price of each product for each buyer and also the purchasing conditions set by suppliers such as payment due times and down payments are measured in this category. The unit of exchange rate be-

tween buyers and suppliers should be taken into account, especially on the global market atmosphere.

✓ Market: How powerful is the supplier's brand on the relevant market might be indicative of how the supplier performs in quality metrics. What is the background of suppliers on the market; what is the market share of their products on relevant market. All this must be measured in the category.

✓ Development: The more progress the suppliers make in the development of their services and production quality, the more reliable they will most probably be. In this categorization, three indices have to be taken into consideration:

• Research and development performance of each specific supplier in design process, production as well as market development.

• Innovations in the provision of services together with designing new ways of business.

• To what extent they make use of IT and its related products.

✓ Environment: Nowadays, industries are integrated with environmental factors and every reliable firm has to take care of the environment thoroughly. In this category, protection of the environment, reduction of energy consumption, and finally observation of the safety standards of the staff members have to be taken into consideration as well.

✓ Risk: The final quality category that experts agreed on is the set of indices related to the risk of providing supplies from providers. Long-term trade conditions have to be anticipated in this category. The extent of provision of services by any provider must be measured by the following indices:

• How far and safe is the location of provider? How social status and geographical location of a supplier can support the long-term conditions of trade?

• Political stability in the area of production or service provision must be evaluated.

• Economic stability of supplier's location has to be taken into account.

## 4. SUPPLY NETWORK MODEL

The researchers propose a supply network model of buyers and suppliers with regard to multi products. As presented in Figure 1, each buyer may procure each required product from a different supplier at a different price. Each supplier can produce only a limited amount of each product but the total products of every specific product must be more than the total request made by the buyers.

The following notation is used to describe the model:
• $i$ : Index of buyers
• $m$: Total number of buyers in the network
• $j$: Index of products in the supply network
• $n$: Total number of products modeled in the supply network
• $k$: Index of suppliers
• $s$: Total number of probable suppliers in the network
• o: Number of decision making sets of indices
• z: Number of decision making criterion
• $c_{kz}^{ij}$ : Score of criterion $z$ for supplier $k$ regarding product $j$ from the viewpoint of buyer $i$
• $CC_{ij}^{k}$ : The quality closeness coefficient (to the ideal point) of each alternatives' product from the viewpoint of buyer $i$
• $w_z^{ij}$ : Weight of quality criteria z regarding product j from the viewpoint of buyer $i$
• $x_{ij}^{k}$ : Number of provided product $j$ from supplier k to the buyer $i$
• $D_{ij}$ : Total demand of product $j$ from buyer $i$
• $C_{jk}$ : Maximum production capacity of product $j$ in supplier $k$
• $d_{ik}$ : The distance of logistic between buyer $i$ and supplier $k$
• $p(x_{ij}^{k})$ : Price function for $x$ request of product $j$ from supplier k to buyer $i$
• $c(x_{ij}^{k})$ : Logistic cost function for $x$ request of product $j$ from supplier $k$ to buyer $i$

The researcher's proposed model is comprised of two objective functions. First objective function is in-
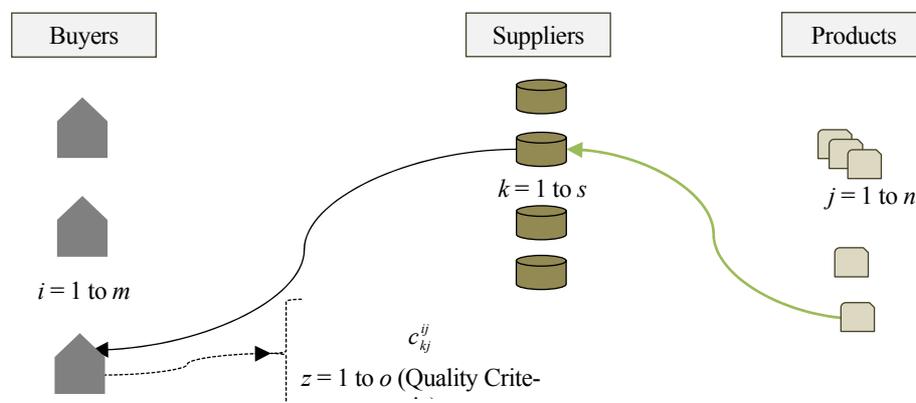


**Figure 1**. Multi-product supplier selection model.

tended to maximize the total quality closeness to the ideal point of buyers' procurements, as proposed in equation 1.

$$Z_1 = max \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{s} CC_{ij}^k \times x_{ij}^k \qquad (1)$$

Second objective function is aimed to minimize the total logistic cost as well as the products' prices in the network which can comprise the equation 2.

$$Z_2 = Min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=}^{s} (c(x_{ij}^k) + p(x_{ij}^k)) \qquad (2)$$

$c(x_{ij}^k)$ is a known logistic function of $x_{ij}^k$.

Constraints of the proposed model can fall into three categories.

First limitations are the ones that keep the total demand of a specific product requested by each buyer constant. These kinds of constraints are depicted in the equation 3.

$$\forall i, j : \sum_{k=1}^{s} x_{ij}^k = D_{ij} \qquad (3)$$

Second category of constraints corresponding to the total production of a supplier is indicative of the rule that the total requested number of every specific product on behalf of all buyers from each supplier should not exceed the maximum production capacity of that supplier.

$$\forall j, k : \sum_{i=1}^{m} x_{ij}^k \le C_{jk} \qquad (4)$$

The third category of constraints limits the variables to positive and integer:

$$\forall i, j, k : x_{ij}^k \ge 0 \quad \forall i, j, k : x_{ij}^k \ge 0 \; ; \; x_{ij}^k$$
is an integer variable $\qquad (5)$

## 4.1 Variable Design

Fuzzy set theories are employed due to the presence of vagueness and imprecision of information in the supplier selection problem (Amid *et al*., 2006). In a real situation regarding supplier selection, many input data are not known precisely taking into consideration that views of the individuals are merely subjective. While making decisions, the value of many decisions is expressed in such vague terms as ''very high in quality'' or ''low in price.'' Numerical variables cannot easily interpret this vagueness. In such cases, using fuzzy variables is one of the best methods for handling uncertainties in human decision making processes. By the use of fuzzy variables proposed by Zadeh (1965) decision makers can evaluate the suppliers more adequately without making an effort to adopt their viewpoints to the framework of quantitative values. In the following tables, available choices for decision makers corresponding to fuzzy numbers have been shown. In this paper, three groups of fuzzy variables are presented. Decision makers provide their viewpoints in linguistic frame-work. The first group is the most useful one applied in many researches such as Bevilacqua *et al*. (2006) and Zouggari and Benyoucef (2012) which help the decision makers to score every point by the tolerance of positive or negative changes. These choices are translated into fuzzy parameters in the form of isosceles triangle. Choices and their translations into fuzzy sets were shown in Table 2:

**Table 2.** Linguistic choices and their corresponding fuzzy variable

| | Choice | Abbreviation | Corresponding Fuzzy Variable | Demonstration |
|---|---|---|---|---|
| Group 1 | Very Low | VL | (0 0.1 0.2) | |
| | Low | L | (0.2 0.3 0.4) | |
| | Medium | M | (0.4 0.5 0.6) | |
| | Good | G | (0.6 0.7 0.8) | |
| | Excellent | E | (0.8 0.9 1) | |
| Group 2 | At most low | ML | (0.2 0.2 0.4) | |
| | At most Medium | MM | (0.4 0.4 0.6) | |
| | At most Good | MG | (0.6 0.6 0.8) | |
| | At most Excellent | ME | (0.8 0.8 1) | |
| Group 3 | At Least Very Low | LVL | (0 0.2 0.2) | |
| | At Least Low | LL | (0.2 0.4 0.4) | |
| | At Least Medium | LM | (0.4 0.6 0.6) | |
| | At Least Good | LG | (0.6 0.8 0.8) | |

The second and the third group from among the fuzzy variables are used to translate the terms "at most" and "at least" respectively. The fuzzy variables of these groups resemble right-angled triangles. The variables and their fuzzy set translation are shown in Table 2, as well.

## 4.2 AHP Fuzzy Ranking

To determine the rank of each product of every supplier using the views of buyers, fuzzy AHP algorithm introduced by Hwang *et al.* (1993) is utilized (Hwang *et al.*, 1993). The outcome of this kind of ranking is used in the first objective function. Due to the definition of the model provided by the researchers, a single product of a specific supplier may rank differently on basis of the viewpoint of each buyer based on different factors of decision making process such as geographical distance, exchange rates, and other factors. So the aim of this part is to find $CC_k^{ij}$ which is the closeness coefficient (to the ideal point) of product $j$ of supplier $k$ in the viewpoint of buyer $i$.

Following steps should be taken for each product, which can possibly be requested by each buyer:

**Step 1**. Construct a decision matrix $D_{k(s*o)}^{ij}$, $k = 1; \dots; s$, for each buyer and product. The structure of the matrix can be depicted as equation 1,

$$D_{k(s*o)}^{ij} = \begin{matrix} & Z_z \\ S_k & \begin{bmatrix} c_{11}^{ij} & \cdots & c_{1o}^{ij} \\ \vdots & c_{kz}^{ij} & \vdots \\ c_{s1}^{ij} & \cdots & c_{so}^{ij} \end{bmatrix} \end{matrix} \quad (6)$$

where $S_k$ denotes the $k^{th}$ alternative, $k = 1; \dots; s$; $Z_z$ represents the $z^{th}$ decision criterion $z = 1; \dots; o$; which is quantitative fuzzy data. The elements of matrix D are $c_{kz}^{ij}$ which indicate the performance rate of product $j(j = 1; \dots; n)$ of alternative $k$ with respect to criterion z, scored by buyer $i$, $(i = 1; \dots; m)$.

**Step 2.** Construct the weighted normalized decision matrix $R_k^{ij}$ for each buyer in $o^{th}$ decision criterion of product $j(j = 1; \dots; n)$.

The normalized value of criterion z can be calculated as follows:

$$c_{kz}^{ij} = \left\{ \left( l_{kz}^{ij}, m_{kz}^{ij}, u_{kz}^{ij} \right) \right\} \quad (7)$$

And it is a fuzzy variable of decision process.

$$\tilde{c}_z^{ij} = \max_{k=1 \, to \, s} u_{kz}^{ij} \quad (8)$$

And it is a scalar variable of weight in each criterion for making decisions.

$$r_{kz}^{ij} = \frac{c_{kz}^{ij} \times w_z^{ij}}{\tilde{c}_z^{ij}} \quad \text{for } i^{th} \text{ buyer, } (i = 1; \dots; m)$$

and $j^{th}$ product, $(j = 1; \dots; n)$ (9)

Each decision maker may assign different weights for each criterion which can have an impact on the ranking outcome.

**Step 3:** The objective of this step is to determine the positive ideal solution and the negative ideal solution. The fuzzy positive ideal reference point (FPIRP) denoted by $A^+$ and fuzzy negative ideal reference point (FNIRP) denoted by $A^-$ can be defined as follows:

$$A^+ = \left( r_1^+, r_2^+, \dots, r_o^+ \right) = \left\{ \left( \max_k r_{kz}^{ij} | k = 1 \, to \, s \right), z = 1 \, to \, o \right\} \quad (10)$$

$$A^- = \left( r_1^-, r_2^-, \dots, r_o^- \right) = \left\{ \left( \min_k r_{kz}^{ij} | k = 1 \, to \, s \right), z = 1 \, to \, o \right\} \quad (11)$$

**Step 4:** The objective of this step is to calculate the measures of PIS and NIS which are benefit criteria of the group.

$$d_k^{ij+} = \sum_{z=1}^{o} d\left( r_{kz}^{ij}, w_z^{ij} \times (1,1,1) \right), \, k = 1, 2, \cdots, s \quad (12)$$

$$d_k^{ij-} = \sum_{z=1}^{o} d\left( r_{kz}^{ij}, (0,0,0) \right), k = 1, 2, \cdots, s \quad (13)$$

And finally, the closeness coefficient $CC_k^{ij}$ calculated as follows:

$$CC_k^{ij} = \frac{d_k^{ij-}}{d_k^{ij-} + d_k^{ij+}} \quad (14)$$

CC indicates the closeness of each alternative to the ideal point. The closest coefficient to 1 will be taken as the best choice, but the nearest to 0 is an undesirable alterative.

## 4.3 Solving Method

The developed and proposed model for –Methods for supplier assessment and selection– is discussed by (Simić *et al.*, 2017). They divided in two major approach groups of Individual fuzzy approaches such as Fuzzy Set Theory, Neural Networks, and GA, and the second one, group of integrated fuzzy approaches (Simić *et al.*, 2017).

As mentioned before, although the integrated fuzzy TOPSIS and GP approach is one of the most popular (Liao and Kao, 2011; Rouyendegh and Saputro, 2014), many researches utilized other individual techniques such as GA (Jain *et al.*, 2004), NSGA (Türk *et al.*, 2017), or PSO (PrasannaVenkatesan and and Goh, 2016) in order to gain more revised decisions in supplier selection problem.

GA was invented to imitate the process of generation survival, initiated by J. Holland and his associates at the University of Michigan 1960s and 1970s. These algorithms use a direct analogy between the representation of a complex structure by means of a vector of components,

and the idea, which is familiar to biologists, of the genetic structure of a chromosome (Li *et al.*, 1998).

Genetic Algorithms (GAs) implement optimization strategies based on simulation of the natural law of evolution of species by natural selection. The basic GA operators are:

- Encoding
- Recombination
- Crossover
- Mutation

GAs have been applied to solve the various optimization problems. It was shown to have been highly effective in searching a large, but poorly defined search space even in the presence of difficulties such as high-dimensionality and discontinuity.

In the present paper, a 3-dimensional chromosome is proposed in order to ease the modeling of the 3-dimensional $x_{ij}^k$ variables. Figure 2 depicts the chromosome offered in this paper.

As is demonstrated in the above figure, each horizontal level of the chromosomes represents a product in the supply network. Also sum of the assigned values in column $k$ in each of the $i$ rows (buyer) in the level $j$ must be equal to $D_{ij}$ according to the equation 3.

Moreover, sum of the values of genes in row $i$ in any specific $k$ column and $j$ level, must be at most equal to $C_{jk}$ in order to obtain the equation 4.

The optimization segment has the role of minimizing the cost of all logistic procurement as well as providing the most appropriate method to maximize the quality closeness to the ideal point. The following measures should be taken with regard to the proposed algorithm:

1. Generating $X$ (population size) random initial (3D) chromosomes, so as to constantly move within the framework of limitations of the model

2. Calculate both $Z_1$ and $Z_2$ objective functions regarding the generated population (all chromosomes)
3. Sort the answers by their objective functions values. Save the most powerful individuals with regard to their objective functions
4. Implement the process of crossover and mutation regarding the population. Generate next population
5. Apply the corrective process so as to create the feasible chromosomes
6. If GA has not met the ultimate condition(s), repeat last 4 phases
7. Introduce the best non-dominant individuals, end

### 4.3.1 Making initial Population

Initial population consists in as many chromosomes as defined, in accordance with the size of the model. As mentioned before, level $j$ of chromosomes (j from 1 to $n$) represents the allocation of the purchase of product $j$ of the supply network. Assignments must not surpass the limitations of demand and production capacity (in both $i$ and $k$ dimensions of the chromosomes respectively). Each random variable assigned to the genes in $i$ or $k$ dimensions must belong to an interval which is capable of observing the constraints.

### 4.3.2 Crossover

The designed crossover function in proposed algorithm may be a novel one. In order for every generated individual to maintain a valid representative after crossover process, each level of the chromosome is indicative of a product. In crossover process, one random level of a random chromosome exchanges with corresponding level of another chromosome. The process is illustrated in Figure 3.

Since design of the chromosomes is innovative, after the application of crossover process, the next generation will also be valid.
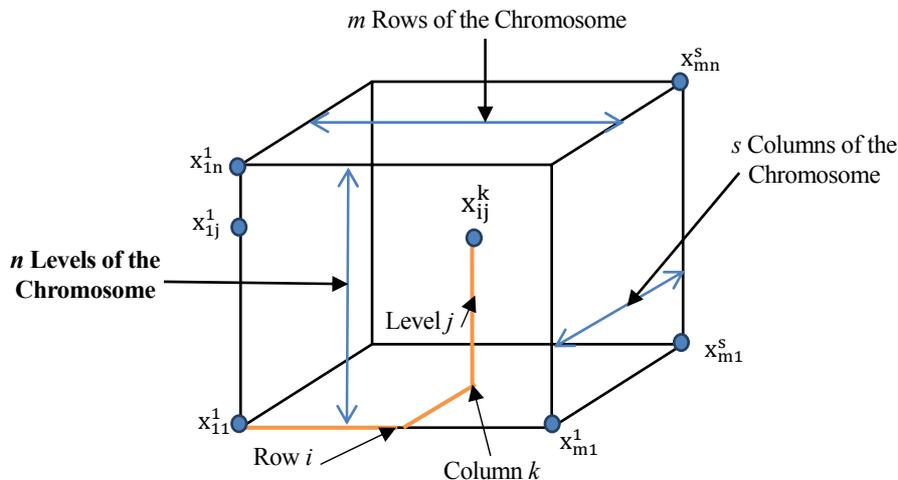


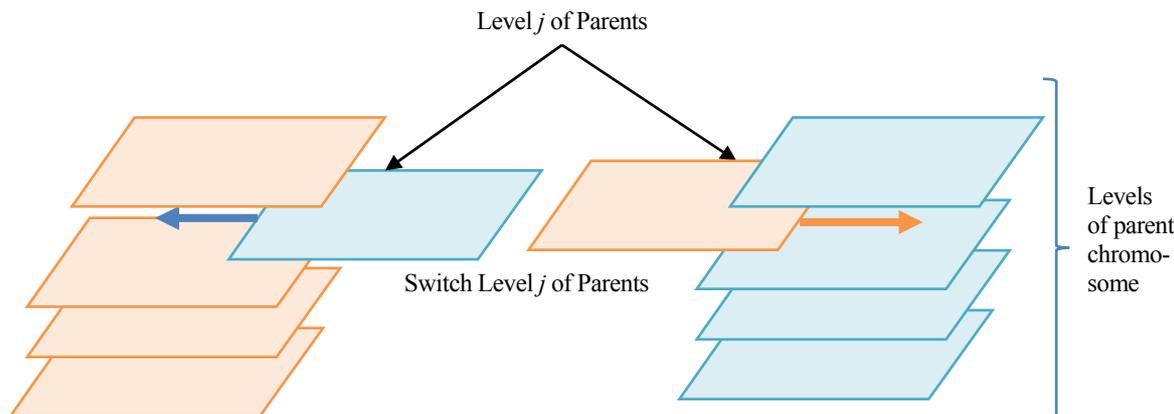**Figure 2.** Design of a 3-dimentional chromosome

**Figure 3.** Crossover process in the presented GA.

### 4.3.3 Mutation

Mutation process is designed in order to scatter the population from a local optimum area. In the proposed GA, one random gene of an individual is changed with regard to constraints of the model. However, due to the existence of crisscross constraints at every level of each chromosome, the newly mutated individual may not be feasible. In order to make all possible chromosomes of the new generation feasible, a corrective function is used after the mutation process.

### 4.3.4 Corrective Function

A function called "corrective function" is designed to check each level of newly generated chromosomes in order to correct them in such a way that they wouldn't surpass the constraints of the model. After mutation process, sum of the values of $i$ row or $k$ column of a newly generated chromosome may reject the corresponding constraints. A corrective function is designed to check the availability of constraints and correct the answers in a way that all chromosomes of a population maintain feasible in the population. By making random changes in the antecedent or precedent genes of mutated gene bidirectional, corrective function keeps all chromosomes in the population, feasible. If the changes in antecedent or precedent genes were not enough for making the mutated chromosome feasible, corrective function makes changes in other genes in the row or column of the mutated gene until the whole mutated chromosome becomes a valid individual.

### 4.3.5 Ultimate Condition

In meta-heuristic algorithms, some rules have to be set in order to finish the search process in the solution area. These rules can be defined variously such as finite period of running time, finite number of generations (in GA) and/or any rules which optimizer defines in order to gain the acceptable solution in a reasonable period of time. In this study, the ultimate rule is defined in such a way that the two objective functions do not achieve better conditions amongst the last one thousand generations.

## 5. ILLUSTRATIVE EXAMPLE

In order to select proper suppliers in a supply network, an illustrative real case study is presented in this section. Products in this case are parts of a designed engine which assembled with many other parts in two fairly similar car engine manufacturers in car industry. The engine parts will be used by two rival companies which their products are sold to the same car manufacturer in the next level of supply chain. Therefore, there are three suppliers which produce the mentioned parts and two buyers are seeking the products simultaneously.

Based on the proposed model, a supply network consists in two buyers, three suppliers and four kinds of products have been presented in Figure 4.

The amount of demand for each product made by each buyer is presented in Table 3.

Also the capacity of the supply provided by each supplier with regard to each product is offered in Table 4.

**Table 3.** Products demand requested by each buyer (*100 per day)

|         |       | Demand for product j | | | |
|---------|-------|-------|-------|-------|-------|
|         |       | j = 1 | j = 2 | j = 3 | j = 4 |
| **Buyer i** | i = 1 | 3 | 9 | 4 | 5 |
|         | i = 2 | 0 | 6 | 7 | 6 |

**Table 4**. Production capacity of suppliers for each product

|         |       | Production capacity of product j | | | |
|---------|-------|-------|-------|-------|-------|
|         |       | j = 1 | j = 2 | j = 3 | j = 4 |
| **Supplier k** | k = 1 | 3 | 4 | 5 | 5 |
|         | k = 2 | 3 | 10 | 0 | 10 |
|         | k = 3 | 0 | 6 | 8 | 4 |

The logistic cost function is defined as freight rate times distance between suppliers and buyers for each product and can be seen in equation 15.

$$c(x_{ij}^k) = coff \; x_{ij}^k \times Distance \; i \; k \qquad (15)$$

In the real case study, freight rate is a function of the number of supplies planned to be transferred from a supplier to a buyer and is presented in Table 7. As can be seen in the Table 7, it is assumed that the objective function related to above equation is not linear and as mentioned in section 2, it makes the solutions method more complicated. Also, having compared the objective functions concurrently helps the decision makers to choose between multiple choices, which lead us to apply and modify a heuristic algorithm in order to solve the problem.

Also the distance between $k^{th}$ supplier and $i^{th}$ buyer is shown in Table 5. As can be seen in the Table 5, although the buyers and suppliers are in the nearly close area but the distance can change the costs as defined in Table 7.

**Table 5.** Logistic distance between suppliers and buyers (Kilometers)

|         |         | Supplier k | | |
|---------|---------|-------|-------|-------|
|         |         | k = 1 | k = 2 | k = 3 |
| **Buyer i** | i = 1 | 32 | 27 | 41 |
|         | i = 2 | 45 | 63 | 72 |

The product price of each supplier is different with regard to different buyers which influence the amount of supplies each buyer may decide to procure from each supplier. In Table 6, price list of different supplies from each provider is presented.

**Table 6.** Price of each supplier product ($)

|         |       | Price of product j | | | |
|---------|-------|-------|-------|-------|-------|
|         |       | j = 1 | j = 2 | j = 3 | j = 4 |
| **Supplier k** | k = 1 | 39 | 31 | 29 | 34 |
|         | k = 2 | 30 | 26 | - | 22 |
|         | k = 3 | - | 30 | 36 | 25 |
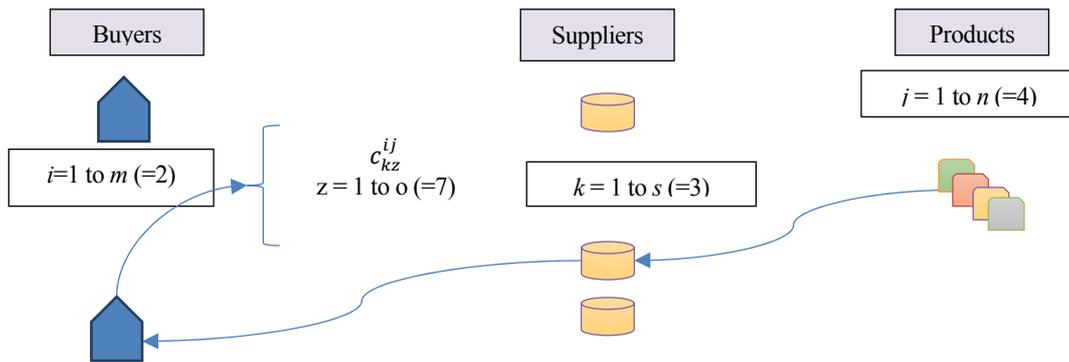


**Figure 4.** Example of supplier selection problem model.

**Table 7.** Example freight rate $(coff(x_{ij}^k))$

| $x_{ij}^k$ (*10 Km) | Freight rate per distance | Freight unit | $coff(x_{ij}^k)$ | Chart |
|---------|---------|---------|---------|---------|
| 0 |  |  | 0 |  |
| 1 | 7 | $ | 7 |  |
| 2 | 7 | $ | 7 |  |
| 3 | 7 | $ | 7 |  |
| 4 | 2 | $/unit | 8 |  |
| 5 | 2 | $/unit | 10 |  |
| 6 | 2 | $/unit | 12 |  |
| 7 | 1.8 | $/unit | 12.6 |  |
| 8 | 1.8 | $/unit | 14.4 |  |
| > 8 | 15 | $ | 15 |  |

**Table 8.** Linguistic quality score of each supplier's product in the viewpoint of buyers

| | | Quality of products | | | | Performance of services | | | | Price | | | | Market | | | | Development | | | | Environment | | | | Risk | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Quality set of indices** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | **Weight of aspect** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 0.2 | | | | **0.2** | | | | **0.15** | | | | 0.1 | | | | 0.1 | | | | 0.1 | | | | 1.5 | | | |
| | | **Product number (j)** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | **1** | **2** | **3** | **4** | 1 | 2 | 3 | 4 | **1** | **2** | **3** | **4** | 1 | 2 | 3 | 4 | **1** | **2** | **3** | **4** | 1 | 2 | 3 | 4 | **1** | **2** | **3** | **4** |
| $i=1$ | $k=1$ | **VL** | **ML** | **ML** | **G** | MM | G | L | LL | **L** | **M** | **G** | **ML** | G | ML | L | ML | **M** | **VL** | **G** | **LVL** | M | ML | G | MM | **M** | **G** | **ML** | **G** |
| | $k=2$ | **MG** | **VL** | **MM** | **ML** | ML | ML | LL | MG | **ML** | **E** | **MG** | **E** | VL | M | ML | MG | **G** | **L** | **G** | **LL** | G | G | LVL | G | **LL** | **G** | **LL** | **MG** |
| | $k=3$ | **MM** | **G** | **MG** | **G** | MG | MM | L | LG | **ML** | **M** | **ML** | **G** | L | G | MM | MG | **LVL** | **M** | **L** | **LM** | ML | L | LL | G | **LM** | **LL** | **LM** | **ML** |
| $i=2$ | $k=1$ | **M** | **G** | **ME** | **MG** | LL | G | G | MG | **MM** | **L** | **MM** | **LL** | M | G | MG | MM | **L** | **G** | **MM** | **LG** | MM | MG | LM | M | **LG** | **LM** | **LG** | **MG** |
| | $k=2$ | **G** | **MM** | **E** | **ME** | LM | ME | M | LM | **MG** | **M** | **G** | **LM** | G | ML | ME | MG | **MM** | **MG** | **LG** | **ML** | MG | M | LG | G | **M** | **LG** | **M** | **MG** |
| | $k=3$ | **E** | **ML** | **MM** | **MG** | LG | E | LM | E | **ME** | **G** | **ME** | **LG** | E | MM | M | ME | **G** | **MM** | **MG** | **MG** | ME | MM | M | E | **M** | **ML** | **M** | **ME** |

The assigned fuzzy variables which indicate each buyer's opinions about the products of each supplier are presented in the following table. As shown in Table 8, different buyers may have different viewpoints about the single product of a supplier. Furthermore, weights of each decision set of indices are shown in the following table respectively.

### 5.1 AHP Fuzzy Algorithm

Applying steps of the proposed algorithm, presented in section 4 of this paper, D matrixes for each buyer are created for every product of each supplier for each set of decision indices. For illustrating the D matrixes, matrix $D_{3*7}^{12}$ and $D_{3*7}^{23}$ are presented in following equations. Matrix $D_{3*7}^{12}$ is formed to rank the second product of each three suppliers in the viewpoint of buyer 1 and matrix $D_{3*7}^{23}$ is made to rank the third product of each three suppliers in the viewpoint of the second buyer.

$$D_{3*7}^{12} = {}_{k\,(1to}^{z\,(1to} \begin{pmatrix} ML & G & M & ML & VL & ML & G \\ G & MM & M & G & M & L & LL \end{pmatrix} \quad (16)$$

**Table 9.** Values of $CC_k^{ij}$ obtained by AHP fuzzy algorithm

| $CC_k^{ij}$ | $i=1$ | | | |
|---|---|---|---|---|
| | $j=1$ | $j=2$ | $j=3$ | $j=4$ |
| $k=1$ | 0.6280 | 0.5592 | 0.6246 | 0.5398 |
| $k=2$ | 0.6156 | 0.6002 | 0.6207 | 0.7022 |
| $k=3$ | 0.5902 | 0.6270 | 0.6358 | 0.7468 |
| | $i=2$ | | | |
| $k=1$ | 0.5212 | 0.7141 | 0.7287 | 0.6106 |
| $k=2$ | 0.6553 | 0.6851 | 0.7481 | 0.6425 |
| $k=3$ | 0.8241 | 0.5960 | 0.6377 | 0.8159 |

$$D_{3*7}^{23} = {}_{k\,(1to}^{\quad z\,(1to} \begin{pmatrix} ME & G & MM & MG & MM & LM & LG \\ MM & LM & ME & M & MG & M & M \end{pmatrix} \quad (17)$$

Implementing AHP fuzzy algorithm, $CC_k^{ij}$ matrix will be obtained, which is illustrated in Table 9.

Taking into consideration the model proposed in section 4, following equations is formed in which $c(x_{ij}^k)$ and $c(x_{ij}^k)$ functions are presented in this section.

$$Max \sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3} CC_{ij}^k \times x_{ij}^k \quad (18)$$

$$Min \sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{3} c(x_{ij}^k) + p(x_{ij}^k) \quad (19)$$

*Subject to*

$$\forall i, j : \sum_{k=1}^{3} x_{ij}^k = D_{ij} \quad (20)$$

$$\forall j, k : \sum_{i=1}^{2} x_{ij}^k \leq C_{jk} \quad (21)$$

$$\forall i, j, k : x_{ij}^k \geq 0 \text{ and it is an integer variable} \quad (22)$$

### 5.2 Results and Discussion

The defined Genetic Algorithm together with 3-Dimensional chromosomes explored in section 4, is formed in this study in order to find the best answers regarding minimization of the total cost as well as maintain in an acceptable level of quality. The presented algorithm was developed using MATLAB R12 which is a high-level technical computing language and interactive environment for algorithm development, data visualization, and data analysis (Inc, 2014).

**Table 10.** Distance to the best found results of different population size

| Population Size | number of Generations | Average best found of $Z_1$ | Average best found of $Z_2$ | Distance to the Global Best $Z_1$ | Distance to the Global Best $Z_2$ | Average Distance |
|---|---|---|---|---|---|---|
| 10 | 500 | 27.53736 | 1556.12 | 27.53736 | 1556.12 | 0.8521604 |
| 20 | 250 | 27.4804 | 1540.08 | 0.8682917 | 0 | 0.4341458 |
| 50 | 100 | 27.50746 | 1554.44 | 0.7706765 | 0.9324191 | 0.8515478 |
| 100* | 50 | 27.7211 | 1551.88 | 0 | 0.766194 | 0.383097 |
| 250 | 20 | 27.6308 | 1557.24 | 0.3257446 | 1.1142278 | 0.7199862 |

**Table 11.** Distance to the best found results of different mutation rate

| Mutation Rate (%) | Average best (max) found of $Z_1$ | Average best (min) found of $Z_2$ | Distance to the Global Best $Z_1$ | Distance to the Global Best $Z_2$ | Average Distance |
|---|---|---|---|---|---|
| 1 | 27.61398 | 1568.2 | 0.38642 | 1.218599 | 1.60502 |
| 2 | 27.65248 | 1552.4 | 0.247537 | 0.198797 | 0.446334 |
| 5* | 27.7211 | 1551.88 | 0 | 0.165234 | 0.165234 |
| 10 | 27.62658 | 1549.32 | 0.340968 | 0 | 0.340968 |
| 15 | 27.54062 | 1555.54 | 0.651056 | 0.401466 | 1.052523 |

Aiming at determining the beneficial size of population, we tried the different size of the GA population in the limited predefined calculation. Each population runs for the limited generations which lead the algorithm to process in nearly same calculation time. In the next table, the best solution found in limited calculation (average of 30 iterations) will be illustrated.

As can be seen in Table 10, the total number of population in each generation is determined as 4 times higher than all variables in the model. In Figure 5, the best solution found for the first objective function allocated for each generation of multi-objective GA is presented.

In the next phase, the best mutation rate of the GA has to be determined. Different mutation rates have been tested for the defined population size for 30 iterations and the mutation rate is defined as 5 percent due to the results shown in Table 11.

The chart indicates that there can be no better solution in the first objective function after 769 times of generation run.

Also in the second objective function $Z_2$, there is no more improvement after 1734 times of generation run (Figure 6). The ultimate rule terminates the process of producing more generations at 2734 runs of generation run.

As can be seen in following figure, no absolute optimal answer can be found to dominate the obtained answers in both objective functions.

There is no improvement in $Z_1$ (Figure 5) since 734th run but before 1734th Run, there is an improvement in $Z_2$ (Figure 6) which forces the algorithm to continue until both objective functions become steady in 1000 more runs.

But three answers are found which can dominate all answers found in both objectives and also none of them can dominate the other two in both objectives (Figure 7).

Decision makers of the whole supply network have to decide which point of optimization they should choose for the provision of supplies; if the additional cost aiming to assign orders to suppliers of higher quality can't be tolerated, they may prefer the lowest cost of the total network.
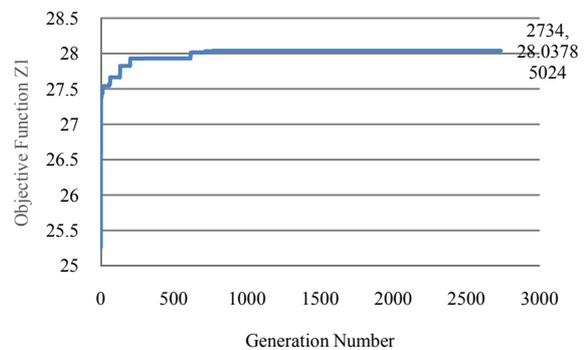


**Figure 5.** Optimization Trend of the first objective function ($Z_1$).
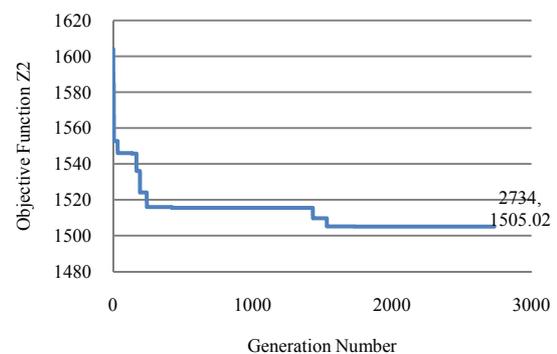


**Figure 6.** Optimization trend of the second objective function ($Z_2$).

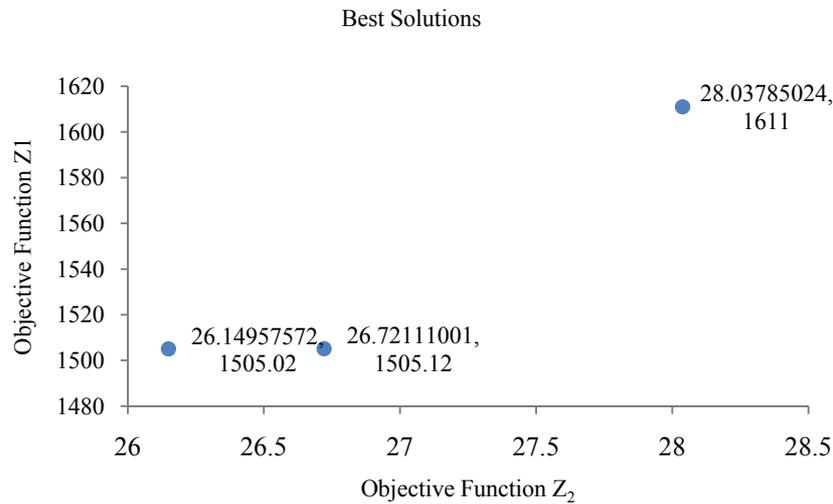Best Solutions



**Figure 7.** Best Solutions front of the multi-objective solution..



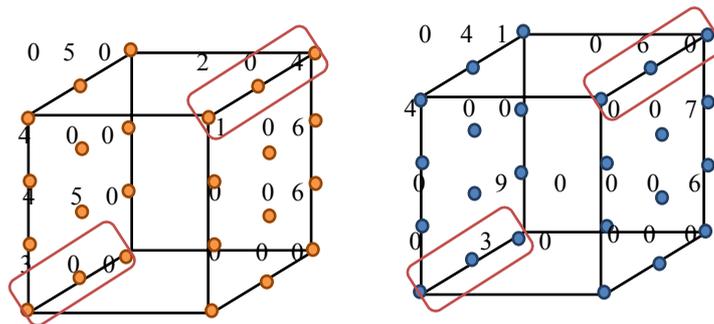**Figure 8.** Comparison between the best solutions found in both objective functions

**Table 12.** Scenario comparison by their objective functions

| | Objective Functions | | Loss of Z1 compares to the best found (%) | Loss of Z2 compares to the best found (%) |
|---|---|---|---|---|
| | $Z_1$ | $Z_2$ | | |
| Fist Scenario | 1611 | 28.04 | 7.0347 | 0 |
| Second Scenario | 1505.02 | 26.72 | 0.006644 | 4.707561 |
| Third Scenario | 1505.12 | 26.15 | 0 | 6.740371 |

Results show that by allocating less than eight percent of total network cost, the quality of the network can rise to an additional seven percent.

The solution resulting in the lowest cost is shown in Figure 8. The solution resulting in higher quality of performance in the network is presented in the same figure as well.

As can be seen in Figure 8, in the first solution (left chromosome), first buyer purchases the first product from the first provider. It should be pointed out that based on the information presented in Table 9, the first buyer prefers to provide the first product from the first supplier rather than the second supplier. But in the second solution (Figure 8, right chromosome), all the required products are intended to be purchased from the second provider. This helps the network to reduce purchasing cost and also

logistic costs with regard to Tables 5, 6, and 7. Similar conditions can be seen in purchasing strategies for the fourth product. Based on Table 9, the second buyer is intended to purchase the products from the third provider. However; purchasing products from another supplier may reduce costs. In the next table, three obtained scenarios will be compared in Table 12.

As can be seen in the results (Table 12), choosing different non dominated answers can lead the whole networks to different situation. By choosing the answer with the minimum $Z_1$ amount, the network will lose 7 percent of $Z_2$. On the other hand, preferring to have maximum of $Z_2$, the network has to bear more 7 percent of $Z_1$. Also the network can choose another answer which is 4 percent lower in $Z_2$ and less than 1 percent more $Z_1$.

# 6. CONCLUSION

Selection of suitable supplier is one of the most important activities of purchasing departments and also a multi-criteria decision making process (Amid *et al.*, 2011).

The problem becomes complex when many customers and suppliers are engaged in a single supply network. Generally, benefit of the whole network may endanger the single customer benefit, but due to the limited resources of supply, buyers must determine their optimal purchase from each supplier so that the network will perform efficiently. The problem becomes more complicated when different buyers differ in their viewpoint concerning the quality of the products of suppliers.

In this paper, ranking of suppliers are performed on the basis of buyers viewpoints. Furthermore, each buyer can evaluate each product differently. Many sets of indices can be used in order to rank suppliers. In the present paper, standards based on which suppliers are evaluated, are divided into seven categories, on the basis of which buyers can sort suppliers with the help of fuzzy variables. AHP fuzzy method applied to ranking of each supplier's product separately in every buyer's view. The outcome of ranking is used in the proposed model in order to exchange manner between providers and customers in the network. Two objective functions used in this study consist in closeness function of quality as well as costs function. The proposed GA was applied in order to obtain appropriate results which can improve both objective functions simultaneously. Results show that there is a collection of acceptable solutions, which do not dominate each other. Decision makers can choose an answer which can either lower the cost of the whole network or maximize the quality closeness or something in between.

If the network aims at having the lowest cost, it could apply the first scenario and having dedication to the quality criteria leads the network to execute the third scenario. However, applying the second scenario has the moderate situation.

In real case, historical data shown that the buyers tended to keep the costs as lower as possible. In this study, quality factors have been added to situation to help the decision makers to choose the scenarios wiser. As a result of the study and due to many complains about the quality of assembled parts, buyers decided to order the parts with more 4.7 percent costs to insure that the quality of the products raise to the near best found in the algorithm.

It is hoped that this research will help supply networks to decide more precisely so as to obtain better qualities with lower costs.

There are some opportunities for future research. As mentioned earlier, Goal Programming has been used widely in this research area. It will recommend to researchers to apply and compare the computational process of this method and GP at the first place.

Assuming some executional limitations can make the problem more applicable in the supply network field. Also assuming more executional logistics or other cost functions derived from the real network is in the attractive area of research.

At last but not the least, more objective functions like environmental or managerial preferences can lead the research to the more applicable Pareto solution.

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