A Two-phase Model for Product Design Development and Evaluation and Supplier Selection in Product Configuration Change Process (Case study: SUPCO)

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Abstract

A supply chain is composed of a complex sequence of processing stages, ranging from raw materials supplies, parts manufacturing, components and end-products assembling, to the delivery of end products. In the context of supply chain management, supplier selection decision is considered one of the key issues faced by operations and purchasing managers to remain competitive. Therefore, requirements of engineers or customers may result in product configuration change with product life cycle. Effective management of product configuration can actually enhance productivity and customer satisfaction. This study proposes a two-phase model in the first phase of which an innovative design for new parts will be proposed by contradiction matrix, and translating contradictions into 39 engineering parameters of TRIZ , solving them by 40 innovative principals and by means of AHP fuzzy. In the second phase, an appropriate supplier for new product will be selected by value engineering and target costing. Finally, a case of clutch system in SUPCO is used to approve the applicability of the proposed approach. In this study, the best choice is the use of fuzzy AHP. After determining the total cost of the target product and initial screening of the suppliers based on that, the index values are calculated for each supplier according to the criteria of the organization. Thus, the best suppliers with the highest value to the organization have been selected.

Keywords:

TRIZ, Product configuration change, Fuzzy AHP, Target costing, Value engineering

1. Introduction

Nowadays, change in the products is unavoidable due to heavy competition in the market, the need for increasing customer satisfaction, improving product performance and enhancing the product added value. Therefore, manufacturers must invest a lot of time and cost to change the product components during the life of a product. In general, lack of attention to this issue will lead to an unfavorable system operation. So, this matter determines the importance of the issue even more. Therefore, change in the product parts should be based on the overall performance of the piece with other components [1]. Due to the significant decrease in the mean length of product life, product configuration change and subsequently change in components of a product will be a critical issue for manufacturers. Continuous improvement of product during production includes improvement of product weaknesses, introduction of new technology and improvements in the manufacturing process. Providing optimal approach not only increases the life of the product, but will also properly meet the needs of its customers. In other words, to maintain the competitiveness of the product,

organizations need to adaptation that help to change the process in product parts. After change in the parts, the process of selecting the right supplier is very important [2].

In this study, a two-phase model for product configuration change will be presented. In the first stage of the model, in order to find the appropriate part for emplacement in the product design and removing inconsistencies resulting from the replacement of the new parts, with regard to the criteria of the organization, an integration of TRIZ[1] and FAHP[2] methods is used. In order to find the appropriate solutions to identify inconsistencies and good part design, 40 principles of TRIZ and 39 engineering parameters of that are applied. Then, the fuzzy AHP method is used to select the appropriate part, by considering the intangible criteria.

To select the appropriate supplier in the second phase, value engineering and target costing methods are used. These two processes are complementary. While value engineering determines should be considered for cost reduction, target costing specifies the organization's profit to achieve the target [3]. Therefore, at first, target costing is used to determine the cost of the goal and then according to different criteria of organization, the best supplier is selected using the value index of value engineering.

TRIZ is the theory of innovative problem solving method. This method is based on a technical evaluation of product, and operates for increasing the ideality level of the product through investigating and resolving conflicts and using the least resources. TRIZ always shows that applying usual strategies for resolving contradictions can greatly improve product and system design [4].

In the fuzzy analytic hierarchy process (FAHP) method which is a multi-criteria decision-making route, decisions that are related to the various measures can be made. In this method, at first the structure of the decision is determined and then various alternatives based on decision-making criteria are compared with each other and finally the priority of each choice is determined. In fact, FAHPis a broader model of analytic hierarchy process that efficiently applies uncertainty phenomenon in the decision-making process [5].

To supply the replaced parts in the process of product configuration change, new manufacturers and suppliers are needed [1]. Therefore, finding the right supplier is very important in the process of product configuration change.In order to select a supplier that can produce and supply the part with more competitivepricethan others while maintaining the product quality, given the current competitive conditions, in the second phase of the study a combination of value engineering and target costing methods has been used.

Target costing ensures the adequacy of income by taking advantage of income and expenditure planning at the same time. Target costing is actually the amount of the virtual cost that can be created about a product and achieve the required profits [6]. Also, value engineering is one of the most successful methodologies of problem-solving, cost reduction, and performance and quality improvement [7]. Value engineering is indeed the new way of process looking at the problem that includes the objective evaluation of operations made by parts, components, products, services and everything that is charging any costs [8]. So, in this research, in the target costing section, at first the target cost is calculated, and primary screening of suppliers with regard to the total cost of the

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[1] . Theory of Inventive problem solving (TRIZ)
[2] . Fuzzy Analytic Hierarchy Process (FAHP)

target is carried out. Then, using the techniques of value engineering, the value index of each of the suppliers in relation to criteria is determined and finally a supplier is selected that provides the part with the price determined by target costing and has the highest index according to the criteria specified by value engineering.

2. Literature review

a new definition of product configuration change was expressed by Christiansen (1997). In this definition, in order to improve the value of commercial products, change in product configuration is considered necessary. This is rooted in the development of competitive advantage due to change in the parts in their lifetime. Many researchers and engineers have used phrases such as part change management and engineering change management rather than product configuration change. It is evident that product configuration change always leads to the sustainability of product performance from the technical and physical viewpoint [9]. Also, Barkan considered a change or improvement in product parts as a change in engineering design [10]. After that, some other studies were carried out about product configuration change and different models were proposed to solve the problem. Wang and Che presented a model in TFT-LCD for change in the product parts based on the needs related to parts change, fuzzy performance indicators and a set of different characteristics in selecting suitable part suppliers for modeling commercial goods [11]. By presenting a three-stage model, Wang et al. provided a new methodology to solve problems related to product configuration change. In their study, at first, the intended part was selected by analyzing the bill of material (BOM) of the product and then primary screening of the part suppliers was done through value engineering techniques. In this method the selection of the most suitable supplier of part was done by the use of genetic algorithms and considering existing criteria such as quality, price, time and reliability [46]. In order to make changes in the spare parts, Wang et al. continued their research by developing a mathematical model. Besides having the ability to evaluate the implementation of change programs, the designed model can also evaluate the suppliers and distributors of needed parts. In this model the analytic hierarchy process (AHP) decision-making method is used to formulate weights [12]. In a research conducted in 2011 by Huang et al., a two- phase model was provided to solve the problem of change in the product parts and to find a suitable supplier. In the first phase the AHP and expert panel were used to analyze and select the priorities of the product change. Then, the process of selecting suppliers, including the construction of a mathematical model, began based on the PSO algorithm [2].

Therefore, due to changes in product parts and design and replacement of new parts in the product, a new model that can solve the contradictions of the replacement seems to be necessary for changing product configuration.

The TRIZ theory is an innovative method for solving problems and has been established by Altshuller. In his innovative theory, he presents a model for solving technical problems of a system using 40 key principles and solving conflicts matrix [13]. Liu and Chen stated the core of TRIZ as 40 principles and contradiction matrix, and introduced it as a means to aid engineers in modeling and analysis. TRIZ has long been used to solve the problems of product design [14]. In another research, the product innovative design problem has been discussed. Innovative design has become an important value in many businesses in the product development process. Innovative designs are sometimes used in connection with the conflicts in parameters that speed, reliability, quality and

price are important. This study focuses on the combination of TRIZ innovative problem solving theory and fuzzy analytic hierarchy process methods for the design of automated manufacturing systems. Also, in this study the contradiction matrix that contains 40 principles and 39 creative engineering parameters has been used [2].Cascini et al. launched extensive research to optimize product design. According to TRIZ, they have pointed out that a system malfunction is the best reference for its improvement.

In this study, an objective function of the system operations that the designer wants to improve and achieve is defined. System variables are actually design variables set. To provide the system needs, a set of limitations are also defined. Two cases are considered in this study: designing a new part and. Re designing a part or sub-parts.

If the optimization is to bring about successful results, the design work will be completed successfully. But if the optimization results of problem are inconsistent, contradiction analysis should be performed. More exactly, the result of optimizing operations is converted into a series of physical contradictions. So, the main challenge is to find contradictions. Physical contradiction can be resolved through separation principles. These design principles can overcome design problems. Cascini and his colleagues state that design improvement system can play an associated role in order to identify geometrical inconsistencies even with changing conditions of their use [15].

As is clear from a review of TRIZ literature and due to inconsistencies from replacement in the design of new parts, this method can be helpful. Moreover, this method can introduce several alternative plans, so we need a method that can choose the best design among proposed design according to different intended criteria.

To select the best alternative systems, a combination of TRIZ and fuzzy AHP can be used as mentioned in the survey conducted by li and Huang [4]. Fuzzy analytic hierarchy process (FAHP)is used in many evaluation and selection problems. For integrated design and production process Wecket al. used fuzzy AHP method to evaluate product cycle alternatives and have overcome the difficult decision-making process. In the next research, product design and selection approach was presented. This approach deals with combining fuzzy quality function deployment and fuzzy MCDM. This model helps product developers to identify important factors engineering and choose the best model [16].

According to the literature review, it can be noted that for selecting an alternative design of the product and eliminating the replacement contradictions and finally choosing the best possible design, TRIZ can be used to resolve the contradictions and fuzzy AHP can be used in the evaluation and selection.

Following the discussion of product configuration change, the selection of a suitable supplier of parts should be considered. Evaluation and selection of suppliers has been widely investigated. Various approaches have been used to solve this problem. Among the methods that have been used alone data envelopment analysis (DEA) can be cited. Of the 78 articles presented in this field, 14 articles have used this method to select suitable suppliers. Other 9 articles have used mathematical programming techniques such as linear programming, integer linear and nonlinear programming, goal programming and multi-objective decision making methods. Also, in some articles the AHP method has been used. The ANP method has been used in 3articles, and other studies use a combination of the mentioned methods to select a suitable supplier [18]. A review of previous researches shows that a new method must be used to select a supplier that insures organization's

profit while guaranteeing product quality. In the research conducted by Hejazi, it has been stated that besides creating and extending relationship with suppliers, selection of the suppliers based on predefined targets also raises the creativity of the suppliers. Furthermore, under established strong long-term relationships with suppliers, target costing is most effective. The aim of this work is to continuously innovate and reduce costs [19]. According to the concepts of value and product cost a combination of value engineering and target costing can be used. In the study conducted by Cooper the relationship between target costing and value engineering was investigated, and it was decided that instead of using the term "cost reduction" the term "cost management" should be used [20]. In the studies conducted by Ibusuki and Kaminski only variable costs were used to calculate the target costs. By providing a new methodology in product improvement process, value engineering and target based cost were used [3]. Based on the previous literature review on target costing and value engineering it can be inferred that the combination of these two methods have not been used for selecting the supplier of parts. Therefore, due to the importance of selecting suitable suppliers in the current competitive environment, maintaining quality and ensuring corporate profits, a research gap can be found in the extant literature. As such, the present study is aimed to cover the above case.

3. Material and methods

3.1 Product configuration change

Product configuration change is considered an important trend in engineering changes. In order to make their product competitive, organizations must comply with the constant and persistent changes in the customers' needs. Since redesigning a product means giving up the first design idea, resulting in the waste of resources and money, organizations tend to improve the previous design of their products. Considering the market demand for the product, its constituent parts can be changed and replaced with the appropriate parts that have either better performance or added value. Thus, considering the needs of customers and limited resources, to survive or even stay in such a competitive environment, changes in product engineering seems quite essential.

Replacement of each part with a new part will cause conflicts of the structure, construction conditions and the final status of the product. Therefore, in the process of product configuration change, any change can cause a chain reaction. Sometimes, the changes are so effective that may even lead to changes in the parts where there was no need for changing them at all [21].

A product configuration change creates combined solutions of a set of fixed pre-defined components. Each of these components is known by unique features, relationship and interaction with other components, its functional limitations and other structural constraints. Product configuration change can include two aspects of scaling and integration [22].

Usually, the products in which certain changes are made consist of several parts, each of which can be supplied by a different producers. Needless to say, in order to improve product performance, suitable parts suppliers who produce high quality products and simultaneously can meet the requirements of engineering and customer needs must be selected [11].

Research has shown that multiple product configuration change needs careful practical and operational estimations, so it should be examined in connection with the strategic objectives of the organization [23].

3.2 TRIZ

TRIZ is a problem solving methodology based on systematic approach and logic that has been obtained from the investigation of thousands of registered inventions and the analysis of technology development. Inconsistency analysis is a new way of looking at a problem [24].

TRIZ is still in the early stages of its evolution. It provides tools for analysis and problem solving; as a result, it contributes to the adoption and getting ideas from other domains and using them in the new areas. TRIZ innovative design research approach mainly focuses on the following a spects: identifying the problem, identifying opportunities, innovative methods that merged and integrated with other methods, TRIZ application in multiple modern practices and innovation through computer [24].

So, any challenging problem can often be described as a technical or physical contradiction. The terms "technical" and "physical" are conventional words, but have been common in the TRIZ terminology. The term "technical contradiction" as we used means when improvement in a design feature is at the expense of losing another features. In other words, improving the parameter *a* will damage the parameter *b*. For example, as the diameter of a container wall becomes greater, its stability increases but it will be heavier. If a product or service feature has two different desired statuses, a physical contradiction has been established. For example, consider a product that should be hot as well as cold. Technical and physical contradictions constitute the foundation of TRIZ. If the problem does not contain technical contradiction, the problem will not be innovative TRIZ problem. Altshuller has introduced 40 innovative principles that can be used to eliminate these technical contradictions. He has also identified 39 parameters of technical systems that could be used to describe and develop technical contradictions. Ways of resolving physical contradictions include: using the principles of separation of contradictory properties in time, system deformation, phase change, or substances physical- chemical change.

3.3 Fuzzy theory

By introducing the fuzzy theory for the first time, Zadeh provided preliminaries for modeling and simulation of inaccurate information and approximate reasoning by mathematical equations which in turn have led to a renaissance in classical mathematics and logic. Fuzzy approximate reasoning approach- which is known as the fuzzy system- is proposed for systems with high complexity and uncertainty in which adequate and accurate information is not available. In recent decades, the fuzzy set theory has been a useful tool in dealing with uncertain and ambiguous data and models and some researchers have developed and expanded a variety of useful fuzzy ways considering this ambiguity and uncertainty [26].

According to the definition, if $M_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is considered as a triangular fuzzy number, the sum two fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ and inverse is defined as follows:

$$(l_1, m_1, u_1) \ (\oplus l_2, m_2, u_2)(= l_1 + l_2 , \ m_1 + m_2 \ , u_1 + u_2)$$

$$(l_1, m_1, u_1)^{-1} = (1/u_1, \ 1/m_1 , 1/l_1) \tag{1}$$

3.4 Fuzzy analytic hierarchy process (FAHP)

Fuzzy analytic hierarchy process is one of the most popular multi-criteria decision-making techniques invented by Saati in the 1970s. This method can be helpful when the act of decision making is faced with several choices and decisions indexes [28]. Currently, the method is one of most popular and most commonly used methods. The main advantages include comprehensiveness, optimal analysis of decision-making process in a multi-layer hierarchical structure with transparent assessment surfaces, possibility to compare paired criteria (options) in a layer with the above layer criteria and precise control of the estimates (continuity of comparisons matrix) using the cohesion ratio (CR) [29]. FAHP methodology is the developed version of AHP that uses fuzzy set theory in solving uncertain problem [30].

In 1996, another method entitled extent analysis method presented by Yung Chang [28]. In this method, using verbal phrases in the Table1, the fuzzy concepts in the determination of paired comparison matrixes are included.

Table 1. Verbal phrase to determine the priority

Verbal phrase to determine the priority	Triangular fuzzy numbers
Exactly equal priority or importance	$(1,1,1)$
Roughly equal priority or importance	$(\frac{1}{2},1,\frac{3}{2})$
Low priority or importance	$(1,\frac{3}{2},2)$
Stronger priority or importance	$(\frac{3}{2},2,\frac{5}{2})$
Very strong priority or importance	$(2,\frac{5}{2},3)$
Complete and absolute priority or importance	$(\frac{5}{2},3,\frac{7}{2})$

Fuzzy AHP algorithm is as follows:

The first step: Creating a hierarchical structure for the problem.

The second step: In fuzzy state, the amount corresponding to the verbal preferences can be determined with triangular fuzzy numbers, according to the above Table.

It is worth mentioning that all the elements on the main diameter of paired comparisons matrix are equal to $(1,1,1)$;moreover, if the element of row i and column j of paired comparisons matrix is equal to $M_{g_i}^j = (l_{ij} , m_{ij} \ u_{ij})$, then the element of row j and column i of the matrix is equal to:

$$M_{g_i}^j = (M_{g_i}^j)^{-1} = (l_{ij} , m_{ij} , u_{ij})^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}) \qquad (2)$$

The third step: Calculating the relative weights of the criteria and options: considering each criterion and relative weight of the criteria with respect to the goal, Chang's extent analysis method is used for each paired comparison matrixes. Thus, corresponding to the relative weight of the matrix a vector is obtained for each matrix [28].

3.5 Chang's extent analysis method

Phase 1: Obtaining a fuzzy composed extension for each goal

For every m goals if $M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m$ are the analysis values of the i-th goal, the fuzzy composed extension of m goals is defined as follows for the i-th goal:

$$S_i = \sum_{j=1}^m M_{g_i}^j \otimes \left(\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j \right)^{-1} \tag{3}$$

If $M_{g_i}^j = (l_{ij}, m_{ij}, u_{ij})$, then by the fuzzy addition operator m on the extent analysis of m goals $\sum_{j=1}^m M_{g_i}^j$ is defined as:

$$\sum_{j=1}^m M_{g_i}^j = (l_{i1}, m_{i1}, u_{i1}) \oplus (l_{i2}, m_{i2}, u_{i2}) \oplus \dots \oplus (l_{im}, m_{im}, u_{im}) \tag{4}$$

$$S_i = \sum_{j=1}^m M_{g_i}^j \otimes \left(\sum_{i=1}^n \sum_{j=1}^m M_{g_i}^j \right)^{-1}$$

$$= (l_i', m_i', u_i') \otimes \left(\frac{1}{\sum_{i=1}^n u_i'}, \frac{1}{\sum_{i=1}^n m_i'}, \frac{1}{\sum_{i=1}^n l_i'} \right) = \left(\frac{l_i'}{\sum_{i=1}^n u_i'}, \frac{m_i'}{\sum_{i=1}^n m_i'}, \frac{u_i'}{\sum_{i=1}^n l_i'} \right) = (l_i, m_i, u_i) \tag{5}$$

Phase 2: Calculating the degree of priority (degree of feasibility) of S_i to S_k: if $S_i = (l_i, m_i, u_i)$ and $S_k = (l_k, m_k, u_k)$, the degree of priority of S_i to S_k which is shown as v($S_i \geq S_k$) for triangular fuzzy numbers is defined as follows:

$$V(S_i \geq S_k) = \alpha_{S_i}(d) = \begin{cases} 1 & \text{if } (m_i \geq m_k) \\ 1 & \text{if } (l_k \geq u_i) \\ \dfrac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)} & \text{otherwise} \end{cases} \tag{6}$$

Phase 3: The calculation of the degree of priority (degree of feasibility) of a convex fuzzy number s that is greater than k convex fuzzy numbers s_i ; $i=1,2,\dots,k$ is defined as:

$$V(S \geq S_1, S_2, \dots, S_k) = V\big((S \geq S_1).(S \geq S_2)\dots(S \geq S_k)\big) \tag{7}$$

If we assume that $d'(A_i) = \min v(s_i \geq s_k)$, then the weight vector is obtained as follows:

$$W' = \big(d'(A_1), d'(A_2), \dots, d'(A_n)\big) \tag{8}$$

Phase 4: Normalizing the vector $\tilde{w}$ and obtaining the normalized weight vector of w

The fourth step: Calculating the total weight of the options: the total weight is obtained by the combination of the relative weights [30, 31].

3.6 Value engineering

Value is the least cost to meet the required functions with reliability in desired time and place, high quality and other factors related to the efficiency required to satisfy the needs of consumers. In other words, value is the provision of functions and services at the lowest cost in time and place and with the required quality [32]. Value engineering is a systematic process to achieve the essential functions at the lowest life cycle costs according to the required performance, reliability, availability, quality and security for a specific product. Value engineering focuses not on cost

reduction but on adding value. It is a practical approach that illustrates the relationship between "what you get" (performance) and "the value that it is worth" (source), as a definition of value [33]. Therefore, by focusing on function as a strategic factor for value improvement, the following equation is defined:

$$\text{Value} = \frac{function}{cost} \tag{9}$$

This relationship is the most selected definition and explanation of value management concept. Although the relationship appears to be very simple, determining the exact function, cost and numerical values requires sufficient considerations and time. As can be seen, value is changed with variations in function and cost. Function improvement can directly enhance value [7].

3.7 Targets costing
Cooper states that the purpose of target based costing is to determine the cost of a proposed product in a way that it meets the desired gross profit at the sale time. The emphasis of target costing is on reducing costs through changes in the product design. It is used within the product design phase [34]. Target costing method is a cost management tool that designers use in the design phase to reduce the cost of production in the future [35]. In fact, by estimating the price of an expected product and reducing the expected profit margin, target based costs of the product (product target cost) is determined. The key point is to design a product that was made with a certain cost and customer satisfaction is achieved. When target costing of a new product is determined, multi-functional product design teams break it to determine the cost of the parts. In order to avoid past deviations, competitive plans and other relevant data are used. When target cost of a part or a set is determined, an interactive process makes sure that their total cost is equal to the target cost of the product and creates relationships that link customers and parts suppliers with designing engineers of the firm to help them find solutions to design product with lower cost [19].

3.8 Key factors in selecting suppliers
Today's organizations who want to see sustainable growth and development need to continuously evaluate strategic performance of their own and partners and a reliable evaluation system, due to constant changes in demand and customer needs, short life cycles of products, presence in global and competitive markets [36].
A supply chain is formed of a complex sequence of processing steps, including suppliers of raw materials, parts manufacturing and assembly of components and finished products to provide a complete product. Supplier selection is one of the key issues in the field of supply chain management faced by purchasing and operations managers to achieve competitive advantage [37] since suppliers are a critical component of an organization that can exert much control on organizational performance. Due to these various effects, a revision of procedures in the selection of suppliers is essential [38]. Nowadays, organizations have found that the proposed price is not the only criterion for selecting and cooperating with suppliers. Supplier selection problem is a complicated process that includes several qualitative and quantitative criteria. In addition, because of the relationship between these criteria, different limitations such as the budget, capacity, and so forth, the selection of suppliers is a multi-criteria decision making in practice. Considering the

importance of discussing the selection of the supplier and its effects on the company's performance, models should be used to select suppliers by taking into account the relative importance of the criteria and interaction between them [39]. In general it can be said that in the decision to select suppliers two issues should be considered: first, what criteria should be used; second, what method should be used to compare suppliers. Weber et al. pointed out that due to the complexity of the decision on the selection of suppliers, various criteria can be considered for selection and this also applies to the use of different approaches to the selection of suppliers. In fact, in selecting suppliers, the analysis of these two issues is considered by many academics and practitioners in purchasing since the 1960s [40]. The criteria for selecting appropriate suppliers are reviewed in various articles. Early studies date back to Dickson's investigations. He examined 23 important criteria in the selection of suppliers. These 23 criteria almost overlap with the criteria that have been considered in various articles so far [41]. Table 2 summarizes the criteria considered in various articles.

Table 2. The criteria for suppliers' selection in different references

Reference	The criteria for suppliers' selection
Dickson (1996) [41]	Quality, on time delivery, administrative records, warranty and returns plan, manufacturing ability, price, technical ability, financial status, problems complaint system, communication system, reputation and prestige, the amount of interest in business, organization management, functional monitoring, after sale services, employees' ethics and behavior, company's packing ability, employees working relationships, geographic location, the level and amount of previous businesses, educational assistance, the amount of bilateral agreements
Muralidharan et al. (2002) [42]	Quality, on time delivery, price, manufacturing ability, financial status, supplier's working experiences, flexibility, services
Humphreys et al. (2003) [43]	Price, quality, costs, supplier's name and brand, use of environmentally friendly materials, flexibility, reputation, suppliers' commercial brand
Choy et al. (2003) [44]	Price, delivery time, customer satisfaction, product quality, after sale services, supplier flexibility, culture and working relationships, long-term experience in supplying
Dulmin at al. (2003) [45]	Quality, delivery time, product costs, customer satisfaction, management costs, shipping process
Wang et al. (2004) [46]	Delivery reliability, flexibility and delivery, supply chain response time, price, product flexibility, product shipping costs, product warranty costs or the cost of returned parts, the amount of circulation capital
Degraeve et al. (2004) [47]	Cost, quality, price of the final product, having working experience with the supplier, supplier's competence and experience, ability and integrity of the sales staff
Bharadwaj et al. (2004) [48]	On time delivery, product quality, the ability to respond to urgent requests, the transparency of financial accounts, the ability to design product, after sale services, product price
Lin et al. (2005) [49]	Quality of final product, cost, on time delivery, reliability, flexibility and innovation, cooperation, long-term relationship between customer and supplier, adoption of new technology by supplier transparent financial performance, the ability to product design, quality of product components
Liu and Hai(2005) [50]	Quality, responsiveness, on time delivery, financial ability, management, technical capability, supplier's resources
Araz et al. (2006) [51]	Financial ability, reliability, flexibility, information flow, product quality, on time delivery

Shyur et al. (2006) [52]	On time delivery, product quality, product price, technology and production level, responding (meeting) to meet customer needs, professionalism, sales staff, quality of relationships
Chan et al. (2007) [53]	Cost, customer satisfaction, quality, financial ability, technical ability, personnel training, organizational culture, research and development, safety
Su and Hou(2007) [54]	Quality, cost, technology, manufacturing capability, research and development, on time delivery, provided services
Ha and krishnan (2008) [55]	Manufacturing ability, quality management, before and after sale services, quality, on time delivery, the amount of control of the organization, business plans, customer relationship
Mendoza and Ventura (2008) [56]	Flexibility, quality, price, service, on time delivery
Ho and Xu(2009) [57]	Quality, on time delivery, price, production ability, services, management, research and development, financial ability, flexibility, reputation and credibility

By surveying the literature, from 2000 to 2010 in more than 80 articles it becomes clear that the most important criteria used to select suppliers (the first 6 criteria) are, respectively: quality, on time delivery, price, production ability, after sale services and management [57]. Also, according to the survey from 1960 to 1996, the most important used criteria (the first 6 criteria) are: price, on time delivery, quality, machinery and equipment, geographic location, technical ability [58]. Of the most important ranking and selection criteria of suppliers in the automotive industry are: quality, delivery reliability, frequency of delivery, the exact number of shipment delivery, the level of human resources knowledge, collaborative relationships, technical expertise, competitive pricing, statistical process control, product design capability, communication, flexibility, production capacity and facilities, commitment, past performance, policies and safeguards to ensure the goods, financial status, the desirability of doing business with suppliers, supplier's management and organization, after sale services, the ability of packaging, reputation and prestige, geographic location, future prospects, small shipments, shipping method, and motivation system [59, 60].

In this study, the selection of criteria has been finalized by reviewing and summarizing the criteria considered in Table 2, the most widely used criteria in the previous studies and the views of SUPCO subsidiaries' experts, professors and administrators and those involved in the automotive industry and work in connection with the supply of spare parts. Therefore, the selection of suppliers is carried out based on the following criteria which have had the highest degree of importance:

1. Costs and prices: This can be defined as total costs, pricing and payment policies.
2. Quality: Includes defective rate, product design, standards and quality certificates.
3. Services: Includes delivery period of goods that is the normal mean time between order and delivery of goods in the delivery period of goods. This factor can have a minimum and a maximum time.
4. Organization: Includes organization's financial ability, experience and fame and position in the industry. A supplier can have a high reputation in various dimensions. For example, a supplier may have a good reputation in fulfilling obligations, but another supplier has good reputation after sale services. Therefore, careful consideration should be taken to assess the field of supplier's reputation and experience. Suppliers' backgrounds and records may be an appropriate criterion for comparing the experience of suppliers [61].

5. Managerial capability: supplier's managerial capability has multiple areas such as the ability to manage supply chain and simultaneous customer management;

6. Technical ability: This covers production capacity and flexibility, daily or annual production of goods, diversification of production and the ability to produce similar products. Producing similar products means to produce products that can be substituted technically for the original product.

4. Results and Discussion

4.1 The proposed model
According to the literature review and previously conducted researches, a model has not presented for product configuration change and its improvement in which part selection product for replacement in product and contradictions resulting from the replacement, fixing them and achieving optimal designs, using TRIZ and fuzzy hierarchy process. Our study also offers a new approach to the selection of suppliers in which deals with the selection of the best supplier with the two target costing and value engineering methods.

As specified in the proposed method, the model includes two phases: in the first stage of this phase after analyzing the product, its weaknesses and customer needs, the product is selected for improvement. Contradictions are discussed in the next step. After translating them into TRIZ engineering parameters and solutions to solve contradictions by TRIZ principles, part improvement designs are presented. In the next step, according to the criteria the best design is selected among the presented designs using fuzzy AHP method. The second phase deals with the selection of an appropriate parts supplier. In the first step, the selling price of target product is determined. Then, the total cost of the target product is specified. The cost is multiplexed to product parts in the next step. Therefore, the cost of all the parts is determined. Considering the cost of parts and presenting it to the suppliers, suppliers who agree to supply parts with the desired cost and quality are selected. So, the initial screening of suppliers is performed. Finally, according to the criteria, the final selection of suppliers is done by determining the value index of each supplier.
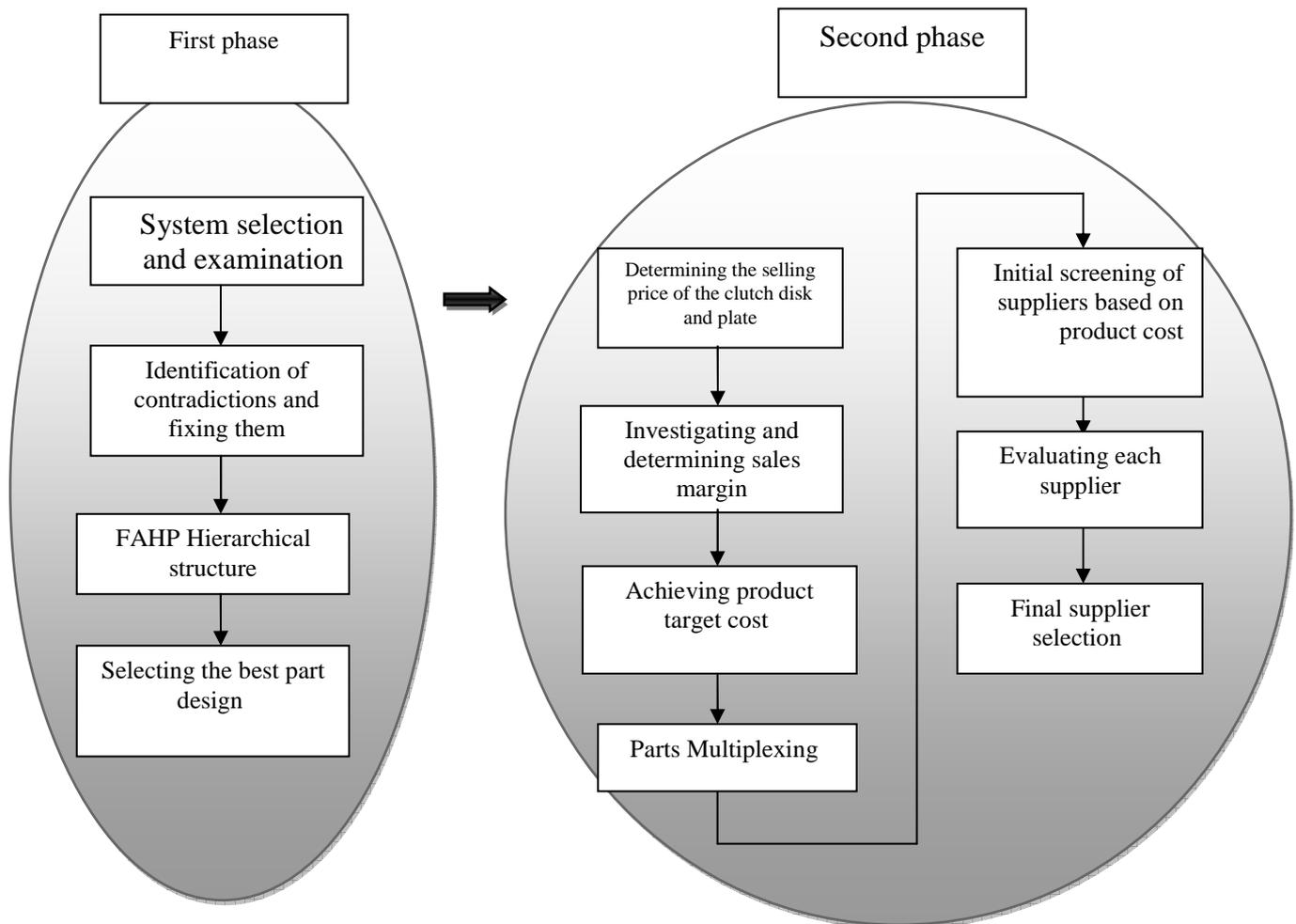
Figure 1. Model presented for the process of product configuration change

4.2 Case study

With a background more than a century, the automobile industry is known as the locomotive of other industries in the world. The industry is among the widest and most productive economic-industrial activities and is classified in the category of major industries in terms of its importance. Therefore, in order to validate the above model, this model has been implemented in the Iran Khodro's design, engineering and supply Parts Company (SUPCO). In order to meet customer satisfaction and increase the quality of manufactured parts, the company's engineering department has considered and implemented improvement projects as one of the main affecting parameters. One of the reported problems has been the gear noise in the stasis state of car. To solve this problem, many improvement projects have been presented that could not completely solve the problem although they have been effective to some extent. Therefore, it is necessary to define new improvement projects. Thus, according to experts gear noise problem is selected as the improvement project.

The first phase- selecting the appropriate part using TRIZ and fuzzy hierarchy process:

Stepone- System selection and evaluation:

According to the evaluation of the causes of gear noise at rest state by LUK- one of the leading companies in the disk and clutch manufacturing, design and troubleshooting- experts' views, investigating the causes of gear noise, limitations on changes in the design and also the problem background and the improvements have been made in this field it has been concluded that one of the causes of noise is abrasion. The abrasion has taken place in the range of the hub collision with the hub page. With investigations done in this area and results from frequent meetings with the design team, in order to solve the problem of abrasion, design engineers concluded that the solution could be adding a new part to the abrasion place.

Step two- Identifying and resolving contradictions using TRIZ:

In this step, actually the problems raised by the system are translated into engineering parameters provided by TRIZ. To solve them, the relationship between the provided 39 engineering parameters and 40 principles is determined.

Table 3. The contradictions and principles used to resolve them

Contradictions	Translation them into 39 TRIZ engineering parameters	The principles provided by TRIZ	The used principles
Temperature rise in the system and deformation the part added	The contradiction between temperature and maintain the integrity of the object	1, 32 and 35	Change in the material
Tight connection to the system without the need for machinery	Robustness and ease of use	2, 25, 32 and 40	The system should solve the problem itself (creating an appendage on the system).
Low weight of part and resistance to stretch	The amount of materials, tension and pressure	3, 10, 14 and 36	Linear components can be replaced with curved components, flat surfaces with curved surfaces and cubic shapes with spherical shapes
The ability to adapt and improve the accuracy of the system, lack of ease of manufacturing	Adaptability and ease of manufacturing	1, 13 and 31	The object be porous

According to the contradictions and solutions provided by TRIZ the two following designs have been proposed by the design team:
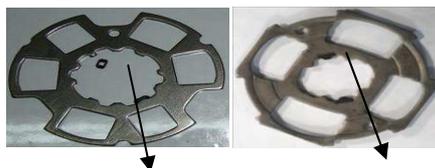
Figure 2. The first design   Figure 3. The second design

Step three- Creating fuzzy AHP hierarchy to select the best design:

In consultation with the director of planning the following management criteria were identified for this system based on the preference: accuracy, time, flexibility and reliability.

4.3 Problem solving using fuzzy AHP
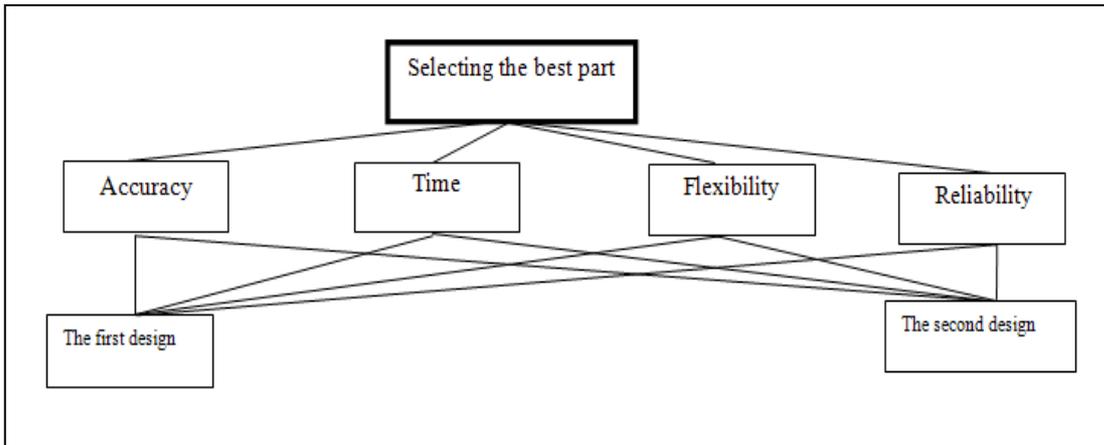
Figure 4.Fuzzy AHP hierarchy

Target

	Reliability	Flexibility	Time	Accuracy
Reliability	$(1,1,1)$	$(\frac{3}{2},2,\frac{5}{2})$	$(2,\frac{5}{2},3)$	$(\frac{1}{2},1,\frac{3}{2})$
Flexibility	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(1,1,1)$	$(\frac{3}{2},2,\frac{5}{2})$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$
Time	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(1,1,1)$	$(\frac{1}{3},\frac{2}{5},\frac{1}{2})$
Accuracy	$(\frac{2}{3},1,2)$	$(\frac{3}{2},2,\frac{5}{2})$	$(2,\frac{5}{2},3)$	$(1,1,1)$

Reliability

$P_1=$

X_1	X_1	X_2
X_1	$(1,1,1)$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$
x_2	$(\frac{3}{2},2,\frac{5}{2})$	$(1,1,1)$

Time

$P_3=$

	X_1	X_2
X_1	$(1,1,1)$	$(\frac{3}{2},2,\frac{5}{2})$
X_2	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$	$(1,1,1)$

Flexibility

$P_2=$

	X_1	X_2
X_1	$(1,1,1)$	$(\frac{2}{3},1,2)$
X_2	$(1,\frac{3}{2},2)$	$(1,1,1)$

Accuracy

$P_4=$

	X_1	X_2
X_1	$(1,1,1)$	$(\frac{2}{5},\frac{1}{2},\frac{2}{3})$
x_2	$(\frac{3}{2},2,\frac{5}{2})$	$(1,1,1)$

q:

$$\sum_{j=1}^{4} M_{g_1}^j = (1, 1, 1) \oplus (\frac{3}{2}, 2,\frac{5}{2}) \oplus (2,\frac{5}{2},3) \oplus 1,\frac{3}{2}) = (5, 6.5, 8)$$

$$\sum_{j=1}^{4} M_{g_2}^j = (\frac{2}{5}, \frac{1}{2},\frac{2}{3}) \oplus (1,1,1) \oplus (\frac{3}{2},2,\frac{5}{2}) \oplus (\frac{2}{5}, \frac{1}{2},\frac{2}{3}) = (3.3, 4, 4.83)$$

$$\sum_{j=1}^{4} M_{g_3}^j = (\frac{1}{3}, \frac{2}{5},\frac{1}{2}) \oplus (\frac{2}{5}, \frac{1}{2},\frac{2}{3}) \oplus (1,1,1) \oplus (\frac{1}{3}, \frac{2}{5},\frac{1}{2}) = (2.063, 2.3, 2.67)$$

$$\sum_{j=1}^{4} M_{g_4}^j = (\frac{2}{3}, 1, 2) \oplus (\frac{3}{2}, 2,\frac{5}{2}) \oplus (2,\frac{5}{2},3) \oplus (1,1,1) = (5.17, 6.5, 8.5)$$

$$\sum_{i=1}^{4}\sum_{j=1}^{4} M_{g_i}^j = (5, 6.5, 8) \oplus (3.3, 4, 4.83) \oplus (2.063, 2.3, 2.67) \oplus (5.17, 6.5, 8.5) = (15.53, 19.3, 24)$$

$$\left(\sum_{i=1}^{4}\sum_{j=1}^{4} M_{g_i}^j\right)^{-1} = \left(\frac{1}{24}, \frac{1}{19.3}, \frac{1}{15.53}\right) = (0.041, 0.052, 0.064)$$

Reliability: $S_1 = (5, 6.5, 8) \otimes (0.041, 0.052, 0.064) = (0.205, 0.338, 0.512)$

Flexibility: $S_2 = (3.3, 4, 4.83) \otimes (0.041, 0.052, 0.064) = (0.135, 0.208, 0.309)$

Time: $S_3 = (2.063, 2.3, 2.67) \otimes (0.041, 0.052, 0.064) = (0.084, 0.1196, 0.1708)$

Accuracy: $S_4 = (5.17, 6.5, 8.5) \otimes (0.041, 0.052, 0.064) = (0.211, 0.338, 0.554)$

$S_1 = (0.2744, 0.3333, 0.4096)$ and $S_2 = (0.49, 0.66666, 0.8974)$

P_2:

$S_1 = (0.3, 0.3984, 0.57)$ and $S_2 = (0.4, 0.6, 0.855)$

P_3:

$S_1 = (0.49, 0.666, 0.896)$ and $S_2 = (0.274, 0.33, 0.4096)$

P_4:

$S_1 = (0.2744, 0.3333, 0.4096)$ and $S_2 = (0.49, 0.66666, 0.8974)$

$V (S_1 \geq S_3) = \frac{0.084 - 0.512}{(0.338 - 0.512) - (0.1196 - 0.084)} = \frac{-0.428}{-0.174 - 0.0356} = \frac{0.428}{0.2096} = 2.0419$

$V (S_2 \geq S_4) = 0.449$, $v (S_2 \geq S_1) = 0.444$, $v (S_3 \geq S_2) = 0.1902$

$V (S_4 \geq S_2) = 1$, $v (S_1 \geq S_2) = 1$, $v (S_1 \geq S_4) = 1$, $v (S_2 \geq S_3) = 1$, $v (S_3 \geq S_4) = 1$, $v (S_3 \geq S_1) = 1$, $v (S_4 \geq S_1) = 1$, $v (S_4 \geq S_3) = 1$

And so for the matrixes p_1, p_2, p_3 and p_4:

P_1: $v (s_1 \geq S_2) = 1$, $v (s_2 \geq S_1) = 1$, p_2: $v (s_1 \geq S_2) = 0.4574$, $v (s_2 \geq S_1) = 1$, p_3: $v (s_1 \geq S_2) = 1$, $v (s_2 \geq S_1) = 1$

P_4: $v (s_1 \geq S_2) = 1$, $v (s_2 \geq S_1) = 1$

q:

$V (s_1 \geq S_2, S_3, S_4) = \min \{v (s_1 \geq S_2), V (s_1 \geq S_3), v (s_1 \geq S_4)\} = 1$

$V (s_2 \geq S_1, S_3, S_4) = 0.444$, $v (s_3 \geq S_2, S_1, S_4) = 0.1902$, $v (s_4 \geq S_2, S_3, S_1) = 1$

$\acute{W} = (1, 0.444, 0.1902, 1)$

P_1: P_2:

$\acute{W} = (1, 1)$ $\acute{W} = (0.457, 1)$

P_3:P_4:

$\acute{W} = (1, 1)$ $\acute{W} = (1, 1)$

Normalizing by average method

q $\Longrightarrow$ w= (1.5184, 0.6742, 0.2888, 1.5184)

P_1 $\Longrightarrow$ w= (0.5, 0.5), p_2 $\Longrightarrow$ w= (0.313, 0.687)

P_3 $\Longrightarrow$ w= (0.5, 0.5), p_4 $\Longrightarrow$ w= (0.5, 0.5)

Calculating the total weight of the options:

The first design: $1.5184 \square 0.5 + 0.6742 \square 0.313 + 0.2888 \square 0.5 + 1.5184 \square 0.5 = 1.8738$

The second design: 1 .5184🔲0.5+0.6742🔲0.687+0.2888🔲0.5+1.5184🔲0.5=2.1255

Step four- Selecting the best design:

According to the results obtained in the previous step, the second design is selected as the winning design. Its detailed design has been done by the engineering designers and shown in Figure 5.
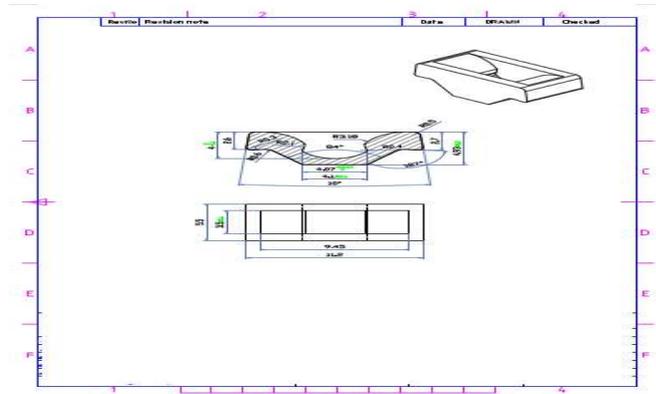
Figure 5. The final part design

The second phase- Selecting the best supplier using value engineering and target costing:

Step one- Determining the target selling price of disk and clutch plate

According to the data from SUPCO on the previous purchase prices of disc and clutch plate system, the target selling price is estimated. It was revealed that disc and clutch plate has been purchased from different suppliers with the following prices (the numbers are in Rials):

385500, 360432, 361500 and 390000

The studies have shown that the manufacturing companies are often considering about 17 to 20 percent of profit to their products. So taking into account the former purchase prices and at least 20 percent of the expected profit, the selling price is considered 374400 Rials for clutch plate.

Step two-Achieving the target cost:

Given the price of 374400 Rials and reducing by 20 percent as profits the target cost will be 288,062 Rials. According to the previous allocation pattern, 171741 Rialsis for clutch plate and 116321 Rials is for disc out of this amount.

Step three- Parts multiplexing (including new added part)

Table 4. Multiplexed prices to disk parts

Clutch disk	Consumption rate	Real amount in Rials
Facing lining	1	54945
Facing rivet	12	576
Hub	1	22490
Drive washer	1	11750
Disc(metalicplaye)	1	30081
Guide washer	1	8056
Guide washer	1	8056
Spering	2	2879
Spering	2	3116

Spering	2	2167
Toothed washer	1	4998
Toothed washer(pre)	1	1523
Flexibel washer	1	2224
Flexibel washer(pre)	1	2007
Spering(pre)	2	3608
Spering centering tampon	1	1672
Flexibel tampon	2	5680
Spaser	1	2206
Stop pin	1	467
Sum	-	168507
Assembling and overhead costs	-	3234
Total sum	-	171741

Table 4. Multiplexed prices to clutch plate parts

Clutch plate	Consumption rate	Real amount in Rials
Cover	1	31644
Pressure plate	1	28500
Diaphragm spring	1	40000
Fulcrum ring	1	5484
Drive strap	9	1152
Cover rivet	3	264
Plate rivet	3	1605
Balance rivet	1	33
Assembling and overhead costs	-	4639
Total sum	-	116321

Therefore, the target cost of each new added part is 2840 Rials.

Considering the target cost of new part, and offering it to four former suppliers, two suppliers agreed to supply the part. Now let us evaluate the suppliers by value engineering.

Step four- Evaluating suppliers by value engineering:

Two suppliers A and B have announced to supply the part. Taking into account the value index of each supplier based on the factors considered, this step deals with the selection of best supplier.

Value= $\frac{function}{cost}$

Generally, the evaluation criteria of suppliers' value are based on the priorities of the organization and its strategy including product delivery time, quality, prestige, and manufacturing similar products.

So in this step, the value index of each of the suppliers A and B is calculated. Value index of quality, delivery time, prestige, and manufacturing similar products is shown respectively with the following variables:

V_q ، V_D ، V_P ، V_M

With regard to the costs imposed to the organization resulting from failing to meet any of the above mentioned criteria, in calculating the value index, the costs of that index and the value of the performance of the criterion are calculated as the criterion performance from the perspective of the organization. Based on earlier records and the information available about these two suppliers:

In the case of supplier A:

$$v_{Q_A} = \frac{0.8}{500} = 0.0016 \quad , v_{D_A} = \frac{0.7}{200} = 0.003$$
$$V_{M_A} = \frac{0.6}{500} = 0.0012 \quad , \quad v_{P_A} = \frac{0.6}{400} = 0.0015$$

And in the case of supplier B:

$$v_{Q_B} = \frac{0.8}{300} = 0.0026, \quad v_{D_B} = \frac{0.7}{200} = 0.003$$
$$V_{P_B} = \frac{0.6}{200} = 0.003, \quad v_{M_B} = \frac{0.6}{400} = 0.0015$$

As can be seen, in all items the value index of supplier B is equal or more than the value index of supplier A. So it is selected as the best supplier.

5. Conclusion

The prospect of Iran's automotive industry is presence in international markets and competing with foreign manufacturers; a requirement that after several years of activity in supportive markets and exclusive circumstance can be regarded as a major challenge for the automotive industry in Iran. The new conditions demand changes in many strategies and mental and operational models in the industry. Despite some apparent similarities, based on the findings the contents of current models of suppliers selection is different from those of competitive markets and do not have the requisite effectiveness. In this context, the need is felt to design domestic and more practical models based on basic criteria of automotive companies, the standards of production on a global scale, and the strategy partnership criteria for selecting the global strategy supplier.

Also due to the increase of customers' knowledge and change in their demands and to survive in the market and problems caused by redesigning which entails extra expenses and long time, changes are periodically forced to initial product to meet customer needs. Selecting the desired part based on innovative design which does not has any contradiction with other components of the system is necessary so that it could lead to an ideal design by resolving the contradictions. So, this study proposes a two-phase model in which in the first phase a combination of TRIZ and fuzzy AHP approaches was used to resolve the problems of selecting the desired part for replacement in product with respect to the contradictions resulting from it. In the second phase, by integrating the two complementary processes of target costing and value engineering an appropriate supplier is selected in an efficient way with regard to the profit margin and without quality loss.

The main achievement of this research is a new model of product configuration change. Moreover, a case of clutch system in SUPCO has been used to approve the applicability of the proposed approach. In this study, the best choice is the use of fuzzy AHP. After determining the total cost of target product and initial screening of suppliers based on that, the index values are calculated for each supplier according to the criteria of the organization. Thus, the best suppliers with the highest value to the organization, has been selected.

For further studies, other parameters can be added to the process of selecting the best design. For example: using fuzzy value relationship to determine the value of each supplier, surveying the costs of suppliers' services based on their performance, and using efficient assessment methods to select the best supplier in the final step.

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