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AN INTEGRATED SUPPLIER SELECTION AND ORDER ALLOCATION APPROACH IN A BATTERY COMPANY

*Gülçimen ALYANAK, Özgür ARMANERİ**

Department of Industrial Engineering, Dokuz Eylül University, Buca, İzmir,
gulcimenalyanak@yahoo.com; ozgur.armaneri@deu.edu.tr

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ABSTRACT

Firms should work with suppliers in order to provide direct and indirect materials and components. Thus, purchasing decision is very important in a firm. The question of "who to buy from and how much" is simply the supplier selection problem that every firm faces. In this problem, there is more than one concern that the decision maker needs to deal with. Hence, supplier selection is a multi-criteria problem which includes both tangible and intangible factors. When capacity constraints exist, this problem becomes more complicated as, in these circumstances, purchasers should decide about two issues: "which suppliers are the best" and "how much should be purchased from each selected supplier". The aim of this study is to solve the supplier selection and order allocation problem of a battery company. In the scope of the study, an integrated approach based on analytical hierarchy process and goal programming is proposed to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them.

Keywords: Supplier selection, multi-criteria decision making, analytical hierarchy process, goal programming.

BİR AKÜ FİRMASINDA BÜTÜNLEŞİK TEDARİKÇİ SEÇİMİ VE SİPARİŞ MİKTARI BELİRLEME YAKLAŞIMI

ÖZET

Firmalar, ihtiyaç duydukları dolaylı ve dolaysız malzemeleri ve bileşenleri temin edebilmek için tedarikçilerle çalışmak zorundadır. Bu yüzden satın alma kararları firmalar için çok önemlidir. Hangi firmadan ne kadar malzeme alınacağı sorusu, her firmanın karşılaştığı temel tedarikçi seçimi problemidir. Bu problemlerde karar vericinin göz önüne alması gereken birden çok faktör vardır. Tedarikçi seçimi nitel ve nicel faktörleri içeren çok kriterli bir karar verme problemidir. Kapasite kısıtı olduğu zaman, tedarikçi seçimi problemi daha karmaşık hale gelir. Bu durumda, satın almacı hangi tedarikçi daha iyi olduğu ve her seçilen tedarikçiden ne kadar alınmalı problemleri hakkında karar vermek zorundadır. Bu çalışmanın amacı, bir akü üretim firmasında tedarikçi seçimi ve sipariş miktarlarının belirlenmesi problemini çözmektir. Çalışma kapsamında, nicel ve nitel faktörleri göz önüne alarak en iyi tedarikçiyi seçmek ve buna göre optimum sipariş miktarlarını belirlemek için analitik hiyerarşi sürecini ve hedef programlamayı temel alan bir yaklaşım önerilmiştir.

Anahtar Kelimeler: Tedarikçi seçimi, çok değişkenli karar verme, analitik hiyerarşi prosesi, hedef programlama.

* Corresponding Author

1. INTRODUCTION

Many definitions of the concept of supply chain have been provided in the literature. Broadly the "supply chain management (SCM)" term is defined as the integration of activities to procure materials, transform them into intermediate goods and final products, and deliver to customers. SCM have been one of the fastest growing areas of management (Heizer and Render, 2001; Benyoucef et al., 2003). A supply chain is referred as an integrated system which synchronizes a series of inter-related business processes in order to: 1) acquire raw materials and parts, 2) transform these raw materials and parts into finished products, 3) distribute these products to either retailers or customers, 4) facilitate information exchange among various business entities (Min and Zhou, 2002; Selim et al., 2004). The supply chain consists of all links from the suppliers to the customers of a product.

Supplier management is one of the key issues of SCM because the cost of raw materials and component parts constitutes the main cost of a product, such that in some cases it may account for up to 70% and most of the firms have to spend considerable amount of their sales revenues on purchasing. In high technology firms, purchased materials and services represent up to 80% of total product cost. Thus the purchasing department can play a key role in an organization's efficiency and effectiveness because it has a direct effect on cost reduction, profitability and flexibility of a company. Selecting the right suppliers significantly reduces the purchasing cost and improves the corporate competitiveness (Ghodsypour and O'Brien, 2001).

On the other hand, supplier selection problem involves trade-offs among multiple criteria that involve both quantitative and qualitative factors, which may also be conflicting (Weber et al., 1991; Ghodsypour and O'Brien, 1998). In other words, buyer-supplier relationships based on only the price factor may not be appropriate in SCM. Considerations have been given also to the other important strategic and operational factors such as quality, delivery, flexibility, and etc. Supplier selection decisions must include strategic and operational factors as well as tangible and intangible factors in the analysis (Pearson and Ellram, 1995; Sarkis and Talluri, 2002). Hence, supplier selection problem can be modeled and solved by means of utilizing multi-criteria decision analysis (Lambert et al., 1997; Weber et al., 1998). Ashayeri and Rongen (1997), Min and Melachrinoudis (1999), and Nozick and Turnquist (2001) are some of the important studies in this area.

The aim of this study is to solve the supplier selection and order allocation problem of a battery company. In this study, an integrated approach is proposed to consider both tangible and intangible factors in choosing the best suppliers and define the optimum quantities among selected suppliers to minimize the deviation from the goals. The priorities are calculated for each supplier by using Analytic Hierarchy Process (AHP). By considering capacity constraints, a goal programming (GP) model is built to minimize the deviation from demand, budget, defect rate and total value of purchasing. The developed models are solved by Lingo and Expert Choice software.

The paper is organized as follows; after giving a brief description of the SCM and describing the scopes of the study in the first section, supplier selection is discussed in section two. In section three, general information on AHP and GP is provided. The proposed approach and its real-life application were explained in chapter four. Finally, chapter five gives the results obtained and recommendations about the study.

2. SUPPLIER SELECTION CONCEPT

SCM is a key strategic factor for increasing organizational effectiveness and for better achieving organizational goals such as enhanced competitiveness, better customer care and increased profitability. Supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these products to customers. One important factor of the supply chain is the supplier selection in the purchasing process. Supplier selection is a broad comparison of suppliers using a common set of criteria and measures. The objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost. Supplier selection is of great importance because selecting the right suppliers significantly reduces the purchasing costs and improves corporate competitiveness.

Supplier selection is a multi-criteria problem which includes both tangible and intangible factors. In order to select the best suppliers it is necessary to make a trade off between these tangible and intangible factors some of which may be conflicting (Ghodsypour and O'Brien, 1998). However, the level of the detail used for examining the potential suppliers may vary depending on a firm's needs. The overall goal is to identify high-potential suppliers (Kahraman et al., 2003). In other words, two different aspects characterize the supplier selection problem; the first aspect is the determination of the number of the suppliers, and the second aspect is the selection of the best suppliers among the existing alternatives (Benyoucef et al., 2003).

The evaluation of vendors is a complicated decision problem. In this process, some of the components are quantitative whereas others are subjective. As the competition in the marketplace increases, there exists a large search space for decision makers, and also there are a multitude of factors/attributes involved in a selection process which are often conflicting and sometimes complementary (Mohanty and Deshmukh, 2001).

The question of 'who to buy from and how much to buy' is simply the *Supplier Selection Problem.* At this point two situations can be considered for a firm. In the first kind of supplier selection, one supplier can satisfy all buyer's needs (Single Sourcing) and the management needs to make only one decision, which supplier is the best, whereas in the second type of supplier selection, as no supplier can satisfy all buyer's requirements, more than one supplier has to be selected (Multiple Sourcing). In these circumstances management needs to make two decisions: which suppliers are the best, and how much should be purchased from each selected supplier (Ghodsypour and O'Brien, 1998)?

In addition to the categorization of materials into direct and indirect, all purchased products may also be categorized based on their value/cost ratio and how critical they are. Most indirect materials are included in *general items.* The goal of purchasing in this case should be to lower the cost of acquisition or transaction cost. Direct materials can be further classified into bulk purchase, critical, and strategic items. For most *bulk purchase* items, such as packaging materials suppliers will tend to have the same selling price (Chopra and Meindl, 2004).

It is thus important for purchasing to make a distinction between suppliers based on the services they provide and their performance. Auctions are likely to be most effective for bulk purchase items. *Critical items* include components with long lead times and specialty chemicals. The key sourcing objective for critical items is not low price but to ensure availability. *Plug* is a good instance for critical item in the battery production company. Because of the foreign suppliers, its lead time is long. In this study, plug supplier selection will be discussed.

Electronics for an auto manufacturer is a good example for *strategic items.* In this case, the buyer and supplier relationship will be long term. Thus, supplier should be evaluated based on the lifetime cost/value of the relationship. Lead is a good instance for strategic item in a battery company.

Dobler and Burt (1996) explain supplier selection procedure in six steps. These steps are; develop and maintain a viable supplier base; address the appropriate strategic and tactical issues; ensure the potential suppliers are carefully evaluated and that they have the potential to be satisfactory supply partners; decide whether to use competitive bidding or negotiation as the basis of source selection; select the appropriate source and manage the selected supplier to ensure timely delivery of the required quality at the right price.

In this study, first four steps have been already done and approved suppliers list for plug is prepared. As mentioned, the aim of study is selection the most appropriate source for the company. After determining the criteria, approved suppliers are carefully evaluated by AHP. Then approved suppliers are managed to ensure timely deliveries of right quantity at the required quality.

Several factors affect suppliers' performance. For instance, Ghodsypour and O'Brien (1998) identified three main criteria and six sub criteria for supplier selection including cost, quality (defect rate, process capability), and service (on-time delivery, ease of communication, response to changes and process flexibility). Gencer and Gürpınar (2007) implemented their supplier selection model in an electronic company and identified 45 sub criteria under three main criteria.

As mentioned, supplier selection problem includes both tangible and intangible criteria, some of which may conflict. For example, the supplier with the lowest price may not have the best quality or delivery performance of the various suppliers under consideration. It can be said that the supplier selection is often an inherently multi-criteria/multi-objective decision making process.

3. ANALYTICAL HIERARCHY PROCESS AND GOAL PROGRAMMING

Model of the supplier selection should enable the management to make a trade off between several tangible and intangible factors. AHP is a technique that uses pair wise comparison and reduces dependency of the system on human judgment. Both weight of criteria and rank of suppliers are determined by one systematic approach. The technique also takes into consideration the qualitative criteria (Handfield et al., 2002).

The suppliers' capacity constraints and the buyers' aggregate quality and service limitations makes the problem complicated. If the best supplier meets the all constraints, then we need to allocate order. GP is a tool for solving this kind of problems. In the following sections, AHP and GP will be described briefly.

3.1 Analytic Hierarchy Process

Thomas L. Saaty's AHP (1980) provides a powerful tool that can be used to make decisions involving multiple objectives (Winston, 1993). It is a robust technique that allows managers to determine preferences of criteria for selection purposes, quantify those preferences, and then aggregate them across diverse criteria. It is a relatively easy technique to understand and apply.

The strength of the AHP lies in its ability to structure a complex, multi-person and multi-attribute

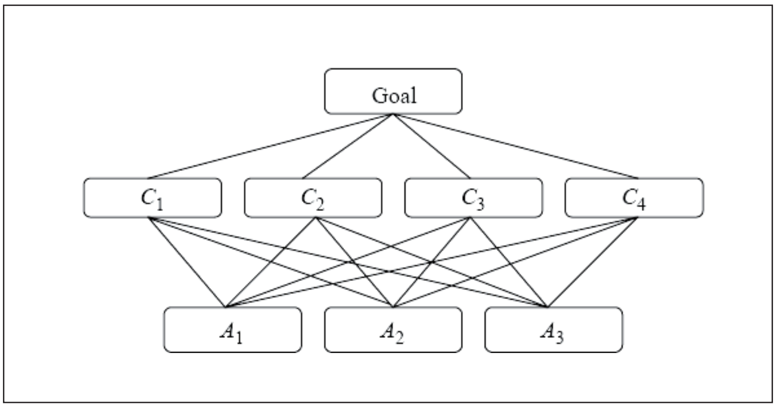

Figure 1. A Simple AHP Model (Ramanathan, 2006)

problem hierarchically, and then to investigate each level of the hierarchy separately, combining the results as the analysis progresses (Liu and Hai, 2005).

It has been applied in decision making in many areas such as finance, marketing, energy resource planning, microcomputer selection, sociology, architecture, political science etc. Most of the time, AHP is used in the choice phase of decision making. In fact the duty of AHP is to combine quantitative factors to evaluate all the objectives (Saaty, 1994).

A simple AHP model can be seen in Figure 1 that has three levels; goal, criteria and alternatives. Four criteria are represented as *C1, C2, C3* and *C4*; three alternatives are represented as *A1, A2* and *A3.* Though the simple model with three levels shown in Figure 1 is the most common AHP model, more complex models containing more than three levels are also used in the literature. For example, criteria can be divided further into sub-criteria and these sub-criteria can be divided into sub-sub-criteria. Finally alternatives take place in the last level of the hierarchy (Ramanathan and Ganesh, 1994; Ramanathan, 2006).

The methodology of AHP is discussed as (Winston, 1993); identify the objectives and the alternatives; generate the pair wise comparison matrix; create the weights of the objectives; check for consistency, and find the overall score of an alternative.

3.2 Goal Programming

Decision makers usually face problems where they have to deal with many conflicting objectives such as supplier selection problems. Thus, the decision maker needs a multiple-objective programming technique. GP is the one of them. It was first introduced by Charnes and Cooper in 1961. In the following years, GP was applied in many different areas such as hospital administration, media solutions, production planning etc.

GP realizes many objectives at the same time and tries to work them out together. Most of time, all objectives cannot be satisfied together and conflict with each other. GP tries to achieve all objectives taking into account their priorities. Objectives are given priorities by the decision maker according to their importance. The aim of GP is achieving all objectives while taking their priorities into account.

GP is a specific application of linear programming (LP). When some constraints in a LP model have no feasible solution, GP allows the model to release the constraints and finds a feasible solution.

In a GP model, constraints are turned into goals and the objective is to minimize both positive and negative deviations from the goals. This can simply be represented mathematically as follows;

$$\text{Minimize} \quad z = \sum_{i=1}^{n} (u_i + v_i)$$

$$\text{Subject to} \quad \sum_{j=1}^{m} (a_{ij} x_j) + u_i - v_i = b_i. \quad i = 1, \ldots, \text{n} \qquad (1)$$

$$\text{All variables} \geq 0$$

where z is the objective function; u_i is negative deviation from goal *i; v_i* is positive deviation from goal *i; m* is number of decision variables; *n* is number of goals; a_{ij} is technological coefficient of the j^{th} decision variable x_j in goal *i*, and b_i is target level of i^{th} goal.

In this formulation, only the goal constraints are shown. These are also called soft constraints. Number of products to be produced, the desired profit etc. can be examples of this type of constraints. Deviations from the target values may occur and they are reflected to the objective function. In addition to this formulation, the system constraints are called as hard constraints. These are not shown in (1). They are the constraints that cannot be violated and have to be settled before the goal constraints. In model (1), all positive and negative deviations from the target values are considered in the objective function and penalized equally. However, in real life cases the situation is more complex. According to the objective, only the positive or the negative deviations can be desirable.

In non-preemptive (weighted) GP model, weights are assigned to the deviations from the target values. By this way the relative importance of the goals are identified. AHP is an effective way to calculate the weights of the objectives. The mathematical model becomes as follows;

$$\text{Minimize} \quad z=\sum_{i=1}^{n}(c_{1i}u_i+c_{2i}v_i)$$

$$\text{Subject to} \quad \sum_{j=1}^{m}(a_{ij}x_j)+u_i-v_i=b_i\,. \quad i=1,\ \ldots,\ n \qquad (2)$$

$$\text{All variables} \geq 0$$

where c_{1i} is numerical coefficient assigned to negative deviations, and c_{2i} is numerical coefficient assigned to positive deviations.

In preemptive GP, priorities are assigned to each of the goal defined. The most desirable objective of the organization is given the highest priority (p_1), and the least desirable objective is given the smallest priority (p_n). The goals are worked in the order of priority and satisfied fully without disturbing the previous goals. This procedure can be implemented by setting up a separate objective function for each priority. Then each of the linear programming models are solved sequentially (Winston, 1993).

This can be represented mathematically as follows;

$$\text{Minimize} \quad z=\sum_{i=1}^{n}(p_iu_i)$$

$$\text{Subject to} \quad \sum_{j=1}^{m}(a_{ij}x_j)+u_i=b_i. \quad i=1,\ \ldots,\ \text{n} \qquad (3)$$

$$\text{All variables} \geq 0$$

where p_i is the priority of the i^{th} goal.

4. THE PROPOSED APPROACH

In this study, an integrated approach based on AHP and GP is proposed to solve the supplier selection and order allocation problem of a battery company. The integrated approach determines the best two suppliers, and also simultaneously places satisfying order quantities to the selected suppliers.

The model includes two main phases. In the first phase, the criteria are settled to evaluate the suppliers and AHP is used to figure out the weights of the factors. In the second phase, a GP model is developed to select the vendors and allocate the orders among them. Expert Choice software package is used to solve the AHP and Lingo software package is used to solve the GP model. The steps of the proposed approach are summarized as follows:

Phase 1:

(1) Determine the goal and supplier selection criteria,
(2) Define the approved suppliers,
(3) Collect the last year's data from the database,
(4) Make the pair wise comparisons by Expert Choice software,
(5) Solve the model and determine the weights of each supplier by Expert Choice software.

Phase 2:

(1) Express the notation used in the mathematical model,
(2) Formulate the goals,
(3) Formulate constraints,
(4) Solve the model by Lingo software package,
(5) Obtain the results and interpret them.

5. APPLICATION OF THE PROPOSED APPROACH: A REAL-LIFE CASE STUDY

Traditionally, suppliers are selected according to their ability to meet the quality requirements and their price. After implementing advanced concepts in material management, quality management, logistics and achieving JIT objectives, a company needs to work with specialized suppliers in producing the right quality product. Therefore, the supplier selection process is a multi-objective decision of strategic importance to companies, encompassing many tangible and intangible factors in a hierarchical manner. Few supplier strategies imply that a buyer wants to have a long-term relationship and the cooperation of a few dedicated suppliers. Using few suppliers can create value to the buyer and yield both lower transaction and production costs. Cooperation between buyer and supplier is the starting point to establish a successful supply chain management. The next level needs coordination and collaboration between buyer and suppliers (Zaim et al., 2003).

The considered battery company has four plug suppliers at approved supplier list. Aim of this study is to work with fewer suppliers and to build long-term relationship. This strategy has many advantages for the firm as follows;

(1) By giving orders with large amounts in one order can reduce monthly total landed cost instead of procuring from many different suppliers.

(2) Having material procurement from a supplier at large amount will increases the good communication and cooperation between the company and the supplier and when a problem occurs, supplier will be willing to solve the problem immediately.

(3) Dealing with a few suppliers will reduce the work load and thus increase the efficiency of the procurement department.

(4) During the contract stage, higher discounts can be offered by the suppliers due to the high annual purchasing quantity.

Phase 1:

The main goal of the supplier selection problem is selecting the best supplier that meets the requirements or criteria of the company. The studies carried out in the first phase are as follows;

1. The Supplier Selection Criteria: Five main criteria and 20 sub criteria are determined according to firm's strategy and expectation from the supplier. These criteria are discussed below;

(1) General Information of the Supplier;

(1.1) *Long term relationship & mutual trust:* A strong and successful buyer/supplier relationship can occur at long term relationships.

(1.2*) The number of working years in the sector and professionalism:* It is regarding how long the supplier operates in the sector and its reputation in the sector.

(1.3) *Financial status and viability of the supplier:* Financial strength can be a good indicator of the supplier's long-term stability.

(1.4) *The number of employees:* It is also an indicator for the capacity of the supplier.

(1.5) *Education status and expertise of the employees:* This includes the knowledge, accuracy, attitude and reliability of the contact people in the supplier firm.

(1.6) *Ease of communication:* The capability of the supplier to be reached by every communication means.

(2) Quality;

(2.1) *Defect rate:* Defect rate is one of the most important criteria. When defective product is rejected, it takes time to replace it. Also missing material causes break in line, the break in the production line.

(2.2) *Certificate point:* It is calculated in Table 1 as following;

Table 1. Calculation of the Certificate Point

ISO 9001:2000 Certificate	Exist	15
	Preparation for ISO is started	8
	No Certificate-no preparation	0
Conformity Certificate	Exist	10
	No	0
External failure	Exist	15
	No	0

Conformity Certificate is given by quality department of the supplier. By this certificate, supplier confirms that referenced products have been manufactured with the approved material and according to (or complying with) the actual procedures, specifications, requirements, and piece drawings. *External failure* occurs when any type of defective item is received by the end user.

(2.3) *Application of the Quality System:* This criterion includes good use of statistical methods to monitor and control the processes.

(3) Cost;

(3.1) *Unit Cost:* It is the price of a plug.

(3.2) *Landed Cost:* The total cost of a landed shipment including freight, insurance, and other costs up to the place of the delivery point which is customer's warehouse. Turkish plug suppliers' landed costs include only freight. Italian plug suppliers' landed costs include seven kinds of other expenses besides freight. These are insurance cost, storage cost, local transportation cost, custom clearance cost, KKDF (source usage support fund), and VAT.

(4) Service;

(4.1) *On-time delivery:* On-time delivery is one of the most important criteria in the supplier selection. On-time delivery performance of a supplier is calculated according the difference between the actual and the planned delivery dates.

(4.2) *Appropriateness of the quantity:* Appropriateness of the quantity performance of a supplier is calculated according the difference between the actual and the planned quantities. Less or more than the ordered quantity is dissatisfactory.

(4.3) *Lead time:* Lead time is the period of time between the initiation of any process of production and the completion of that process. The supplier lead time is the duration between the placement and receival of orders.

(4.4) *Response to changes:* This means tolerating the amount of variation in order quantity and variation in delivery date. This allows flexibility in production planning of the firm.

(4.5) *Minimum lot size:* It prevents the firm from purchasing material more than the requirement amount.

(4.6) *Follow-up:* The supplier firm should keep the customer informed about their production and delivery status.

(5) Production capability of the supplier;

(5.1) *Machine and equipment:* Using High-Technology in production.

(5.2) *Technical support and design capability:* Provides consistently high-quality products, promotes successful development efforts, and designs the future's product.

(5.3) *Continuous improvement programs (Production system of the supplier):* The supplier employs continuous improvement programs and tools like Kaizen, Six Sigma, TPM, 5S.

2. Suppliers in Approved Suppliers List: The firm has *four plug suppliers* at approved supplier list. Two of them are Turkish suppliers and others are Italian suppliers.

3. Pair wise Comparison: Pair wise comparisons in between criteria are made according to company's strategy. Firstly, pair wise comparisons in between five main criteria are made. Using these pair wise comparisons, the weights of main criteria are determined as in Table 2.

Table 2. Weight of Main Criteria

Main Criteria	Weight
General information of the supplier	5.9
Quality	29.4
Cost	29.4
Service	29.4
Production capability of the supplier	5.9

11 criteria are intangible and 9 criteria are tangible. Data of tangible criteria directly enter into the model. Tangible and intangible criteria in AHP are given Figure 2. Pair wise comparisons in between sub criteria under their main criteria are made. Then pair wise comparisons in between suppliers are made according to the suppliers' performance regarding to relevant criterion. Comparison matrix including all direct and pair wise comparisons of suppliers is presented in Table 3.

4. The Solution of AHP: The main goal is to select the best supplier that meets the requirements and criteria's of the company. In order to calculate the final score of each supplier the weights of criteria, sub criteria and suppliers' rating are combined, and the results are shown in Figure 3.

Covering Objectives / Formulas	Type
General information of the sup \ Long Term Relationship & Mutual Trust	Pairwise
General information of the sup \ The number of working years in this sector and professionalism	Pairwise
General information of the sup \ Financial status and viability of the supplier	Pairwise
General information of the sup \ The number of employees	DIRECT
General information of the sup \ Education status and expertise of the employees	Pairwise
General information of the sup \ Ease of communication	Pairwise
Quality \ Quality point	DIRECT
Quality \ Defect Rate	DIRECT
Quality \ Application of the Quality System	Pairwise
Cost \ Unit Cost	DIRECT
Cost \ Landed Cost	DIRECT
Service \ On-Time Delivery	DIRECT
Service \ Appropriateness of the quantity	DIRECT
Service \ Lead Time	DIRECT
Service \ Response to changes	Pairwise
Service \ Minimum Lot Size	DIRECT
Service \ Follow up	Pairwise
Production capability of the s \ Machine and equipment	Pairwise
Production capability of the s \ Technical support and design capability	Pairwise
Production capability of the s \ Continuous improvement programs (Production system of the supplier)	Pairwise

Figure 2. Tangible and Intangible Criteria of Supplier Selection

Table 3. Comparison Matrix of Supplier Selection by Using AHP

Main Criteria	Sub Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4
General information of the supplier	Long Term Relationship & Mutual Trust	0.570	0.128	1.000	0.283
	The number of working years in the sector and professionalism	0.208	0.098	1	0.464
	Financial status and viability of the supplier	0.383	0.15	1	0.383
	The number of employees	0.56	0.31	1	0.75
	Education status and expertise of the employees	0.391	0.174	1	1
	Ease of communication	1	1	0.333	0.333
Quality	Defect rate	1	0.375	1	1
	Certificate point	0.92	0.42	0.92	1
	Application of the Quality System	0.323	0.145	1	0.706
Cost	Unit Cost	0.9	1	0.83	0.95
	Landed Cost	0.29	1	0.06	0.06
Service	On-Time Delivery	1	0.79	0.84	0.95
	Appropriateness of the quantity	0.89	0.79	0.95	1
	Lead Time	1	0.57	0.13	0.19
	Response to changes	1	1	0.174	0.391
	Minimum Lot Size	0.83	1	0.5	0.5
	Follow-up	1	0.229	0.295	1
Production capability of the supplier	Machine and equipment	0.364	0.119	1	0.687
	Technical support and design capability	0.281	0.103	0.631	1
	Continuous improvement programs (Production system of the supplier)	0.171	0.094	1	0.514

Each supplier score represents the estimated total benefits to be obtained from selecting this supplier. Based on this study, Supplier 1 received the highest ranking with a score of 0.265. Also these alternative weights will be used in GP. Application of this will be discussed in the following section. Detailed synthesis of the model including all sub criteria are shown in Table 4.

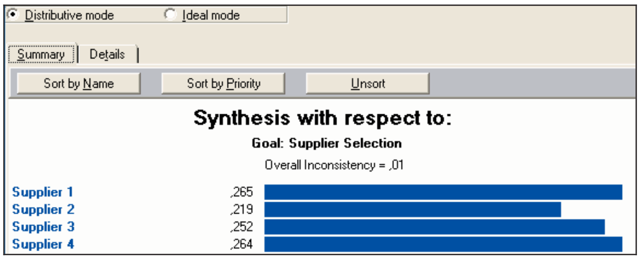

Figure 3. Suppliers' Final Rating

Table 4. Detailed Synthesis of the Model

Level 1	Level 2	Supplier 1	Supplier 2	Supplier 3	Supplier 4
General information of the supplier (L:1.000) (L:0.059)	Long Term Relationship & Mutual Trust (L:1.000) (L:0.118)	0.002	0	0.003	0.001
	The number of working years in the sector and professionalism (L:0.126)	0.001	0	0.004	0.002
	Financial status and viability of the supplier (L: 0.412)	0.005	0.002	0.013	0.005
	The number of employees (L: 0.048)	0.001	0	0.001	0.001
	Education status and expertise of the employees (L:0.071)	0.001	0	0.002	0.002
	Ease of communication (L: 0.225)	0.005	0.005	0.002	0.002
Quality (L: 0.294)	Quality point (L: 0.172)	0.015	0.006	0.015	0.015
	Defect Rate (L: 0.726)	0.06	0.028	0.06	0.065
	Application of the Quality System (L:0.102)	0.004	0.002	0.014	0.01
Cost (L: 0.294)	Unit Cost (L: 1.000) (L: 0.833)	0.06	0.067	0.055	0.063
	Landed Cost (L: 0.167)	0.01	0.035	0.002	0.002
Service (L: 0.294)	On-Time Delivery (L: 1.000) (L: 0.411)	0.034	0.027	0.028	0.032
	Appropriateness of the quantity (L:0.266)	0.019	0.017	0.02	0.022
	Lead Time (L: 0.095)	0.015	0.008	0.002	0.003
	Response to changes (L: 0.115)	0.013	0.013	0.002	0.005
	Minimum Lot Size (L: 0.041)	0.004	0.004	0.002	0.002
	Follow up (L: 0.072)	0.008	0.002	0.002	0.008
Production capability of the supplier (L:0.059)	Machine and equipment (L: 1.000) (L:0.200)	0.002	0.001	0.005	0.004
	Technical support and design capability (L:0.600)	0.005	0.002	0.011	0.018
	Continuous improvement programs (Production system of the supplier) (L:0.200)	0.001	0.001	0.007	0.003

Phase 2:

After weights of the suppliers are determined by AHP, in order to best order quantities, GP is developed.

1. Mathematical Model of the GP:

Notations;

- w_i :Normal weights of the i^{th} supplier obtained from AHP
- c_i :Capacity of the i^{th} supplier
- u_i :Unit cost for the i^{th} supplier
- o_i :Order cost for the i^{th} supplier
- q_i :Defect rate of the i^{th} supplier
- X_i :Order quantity for the i^{th} supplier
- Y_i :Binary integer (0-if the order is given to the i^{th} supplier, 1-if the order is not given to the i^{th} supplier)
- d :Demand for a month
- T :Theoretical upper bound.
- $MaxQ$:acceptable total defect rate
- *budget*:the firm's budget allocated for plug
- n :number of suppliers
- dn_1 :Negative deviation from the defect rate goal
- dp_1 :Positive deviation from the defect rate goal
- dn_2 :Negative deviation from the budget goal
- dp_2 :Positive deviation from the budget goal
- dn_3 :Negative deviation from the theoretical upper bound goal
- dp_3 :Positive deviation from the theoretical upper bound goal

Objective Function;

$$\text{Min } z = dn_1 + dn_2 + 2^* dn_3$$

Goal Constraints;

The objective is to minimize the weighted sum of all the deviations from desired levels of sub goals. The sub goals were formulated as a soft constraint in the model, these are given below;

- *Quality Constraint:* Since *MaxQ* is the buyer's maximum acceptable defect rate and q_i is the defect rate of the i^{th} supplier, the quality constraint can be shown as;

$$\sum_{i=1}^{n} X_i * q_i + dn_1 - dp_1 = d * MaxQ$$

- *Budget Constraint:* Sum of the unit cost and order cost of plug should not be exceed the budget.

$$\sum_{i=1}^{n} X_i * u_i + \sum_{i=1}^{4} Y_i * o_i + dn_2 - dp_2 = Budget$$

- *Theoretical Upper Bound:* As w_i denote the normal weights of the i^{th} supplier obtained from AHP. This constaint; make the suppliers' order quantity higher which gets higher value from AHP.

$$\sum_{i=1}^{n} X_i * w_i + dn_3 - dp_3 = T$$

System Constraints;

- *Demand Constraint:* As the sum of the assigned order quantities to four suppliers should meet the buyer's demand, it can be stated that;

$$\sum_{i=1}^{n} X_i = d$$

- *Capacity constraint:* As supplier *i* can provide up to C_i units of the product and its order quantity (X_i) should be equal or less than its capacity, these constraints are;

$$X_i \le C_i * Y_i \quad i = 1, \ldots, n$$

- *Number of Supplier to be employed:* Company wants to limit the number of suppliers to be employed. This constraints shows the below;

$$\sum_{i=1}^{n} Y_i = 2$$

- *Binary Constraints:* Y_i is binary variables.

  $Y_i = 1$ If supplier *i* is chosen

  $Y_i = 0$ Otherwise

- *Integer Constraints:* Order quantities are integer variables;

  X_i= Integer Value.

2. Solution of the GP: The mathematical models of the GP are written in Lingo Optimization Software and solved by this. After GP is solved, 290,000 units are allocated to the first supplier and 510,000 units are allocated to the fourth supplier. There is no purchase from Supplier 2 and Supplier 3. Data and result of the model is presented at Table 5.

Table 5. Result of GP

	Unit Cost (EUR)	Order Cost(EUR)	w	Capacity	Defect rate (ppm)	Order Quantity
Supplier1	0.21	350	0.265	450	60	290,000
Supplier2	0.19	100	0.219	250	130	0
Supplier3	0.23	1750	0.252	800	60	0
Supplier4	0.2	1750	0.264	600	55	510,000

Target Value		
Max Q	Monthly Demand	Budget
60	800	165

3. Results and Comparison with the Current System: For the proposed approach, overall 20 sub criteria are determined under five main criteria. For the company, cost, service and quality criteria have the same importance and they are strongly (by Saaty's 1-9 scales) more important than general information and production capability criteria.

On-time delivery performance of a supplier is calculated according the difference between incoming and ordered delivery date. Buyer wants to supply the material when it will be used in the production, not before or not after. Delays causes break in-line and inefficiency in production. Delivery before the production deadline is also not satisfactory for customer. Because this increases the inventory holding cost. In the battery company, main raw material of battery is lead. It is very expensive and its price is changing according to LME (London Metal Exchange). In addition to this, large storage place is needed for lead. Thus, early delivery from the deadline is not acceptable in lead supply. On the other hand, inventory holding cost of plug is not high. Storage cost of plug is low, 50,000 units of plugs are placed in one palette. In addition, plug is not expensive material like lead. Hence tardiness is only considered in calculation of plug's on time delivery performance in this study.

In the company, plugs are used in final line of the production. After this final line, batteries are sent to the shipping area. Thus, break in line and tardiness at this stage, directly affects the shipping date of the batteries. Cost of break in line of one operator for 1 hour is €4.5. Eight operators work in final line. Hence, if one-hour break in line occurs in the final line, it costs €36. The monthly demand of plug is 800,000 units. Six plugs are used in one battery. The Monthly number of battery production is 133,333 units. In the current system, performance of the on time delivery is 84.53%. Thus, 15.5% of the delivery is not done on time. Hence, 20,625 units of battery have material problems because of the missing plug in production. One lot is 500 units. Production planning department prevents 75% of break in line which causes because of missing plug. Approximately, 10 breaks in line occur per month because of the missing plugs. When a break in line occurs, it takes two hours. So cost of break in line is calculated €743 monthly in current system. In same way, €393 is calculated for Scenario 1. Monthly this scenario's is €350 and annual saving is calculated €4,194.

The cost, which is mentioned above, occurs from the result of the inefficiency in production. Break in line also causes lost of opportunity cost. 50% of the break in line can't be compensated and customer order couldn't be finished until shipping date. Thus, shipping must be made with missing quantity. In this circumstance, lost of opportunity cost is occurred. Revenue of the company and margin of the profit is confidential data. In this study we assume that annual revenue of the company is €90,000,000 and margin of the profit is 10%. According to this, daily profit is calculated as €30,000. When 50% of the break in line can't be compensated, lost of opportunity cost is €14,224 in one month. Shipping with missing quantity also makes the customers dissatisfied. It affects the company badly in long term. According these calculations, break in line cost of current system and the proposed model are presented in Table 6. Monthly comparisons between proposed approach and current system are shown in Table 7.

4. Other Scenarios and Their Impact on Optimum Solution: In proposed approach, cost, service and quality criteria have same importance and they are strongly (by Saaty's 1-9 scales) more important than general information and production capability criteria. This proposed approach is defined as Scenario 1. The main goal of this study is selecting the best supplier that meets the requirements and criteria's of the company. The best supplier can be changed according to the importance of the criteria which depend on company's strategy and policy. As an example, in most industries, the raw materials cost constitutes the main cost of a product. In high technology firms, purchased materials and services represent up to 80% of total product cost. Thus, cost is the important criterion of the supplier selection problem in many companies. In Scenario 2, cost

Table 6. Break in Line Cost of Current System and the Proposed Approach

Criteria	Current System	The Proposed Approach
On-Time Delivery (%)	84.53	91.81
Not On-Time Delivery (%)	15.47	8.19
Cost of inefficiency in production (€)	743	393
Opportunity cost (€)	14,244	7,529
Total break in line cost (€)	14,967	7,922
Saving (monthly) (€)	**7,045**	
Saving (annual) (€)	**84,539**	

Table 7. The Comparison Between Current System and Proposed Approach (monthly)

	Current System	Proposed Approach	Explanation
Order Quantity of Supplier1	225,000	290,000	
Order Quantity of Supplier2	150,000	0	
Order Quantity of Supplier3	250,000	0	
Order Quantity of Supplier4	175,000	510,000	
Total Cost of Purchasing	170,350	165,000	€5350 saving
Total Defect Rate	57.6	45.5	12.2 PPM decreasing
On-Time Delivery (%)	84.53	91.81	7.28% increasing
Appropriateness of the quantity (%)	86.88	91.38	4.50% increasing
Cost of Break-in line	14,967	7,922	€7,045 saving
Total Cost	185,317	172,922	€12,395 saving

criterion is twice times important than service and quality criteria. As a result, six different scenarios have been developed by changing the weights of the main criteria. Then, based on these scenarios, suppliers' final weights for each scenario are calculated. For each scenario, priorities of the main criteria are given in Table 8, and weights of each supplier are given Table 9.

Sensitivity analysis identifies the impact of changes in the priority of criteria on the suppliers' performance and order quantities. This is performed by using Expert Choice software. Performance Sensitivity and dynamic sensitivity of each scenario is shown in Tables 10 to 15, respectively.

Comparison in between six scenarios and current system is illustrated in Table 16. Figure 4 shows graphical illustration of comparison of current system with each scenario with respect to order quantity of the each supplier.

Table 8. Priorities of the Main Criteria For Each Scenario

Scenario	General information	Quality	Cost	Service	Production capability
1	0.059	0.294	0.294	0.294	0.059
2	0.045	0.226	**0.458**	0.226	0.045
3	0.045	**0.458**	0.226	0.226	0.045
4	0.045	0.226	0.226	**0.458**	0.045
5	**0.148**	0.266	0.266	0.266	0.053
6	0.053	0.266	0.266	0.266	**0.148**

Table 9. Weights of Each Supplier For Each Scenario

Scenario	Supplier1	Supplier2	Supplier3	Supplier4
1	**0.265**	0.219	0.252	0.264
2	**0.258**	0.248	0.239	0.255
3	0.266	0.196	0.264	**0.274**
4	**0.276**	0.225	0.239	0.260
5	0.262	0.212	**0.268**	0.258
6	0.252	0.204	0.265	**0.279**

Table 10. Sensitivity Analysis of Scenario 1

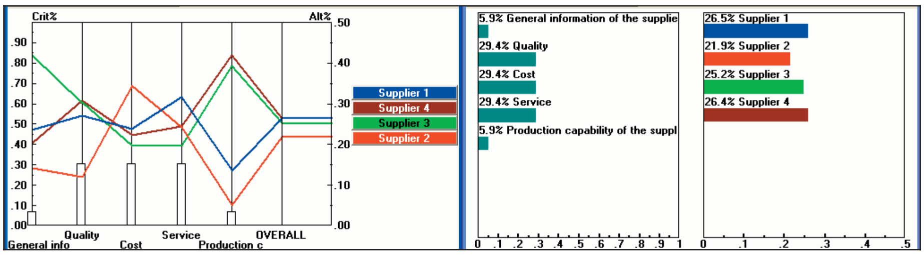

Table 11. Sensitivity Analysis of Scenario 2

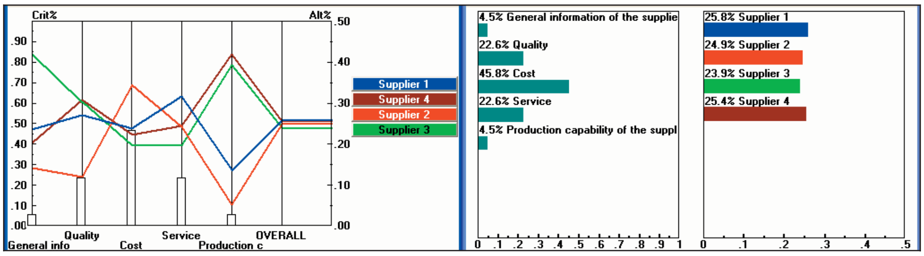

Table 12. Sensitivity Analysis of Scenario 3

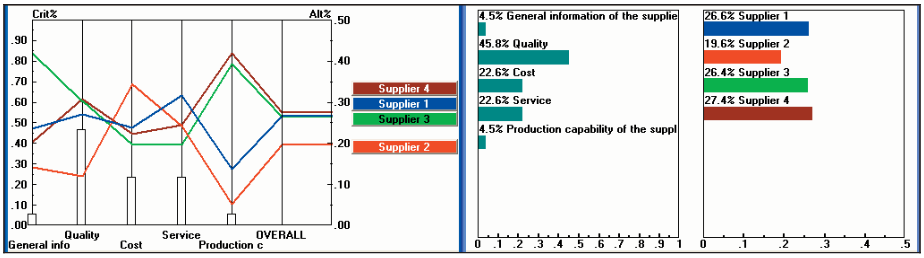

Table 13. Sensitivity Analysis of Scenario 4

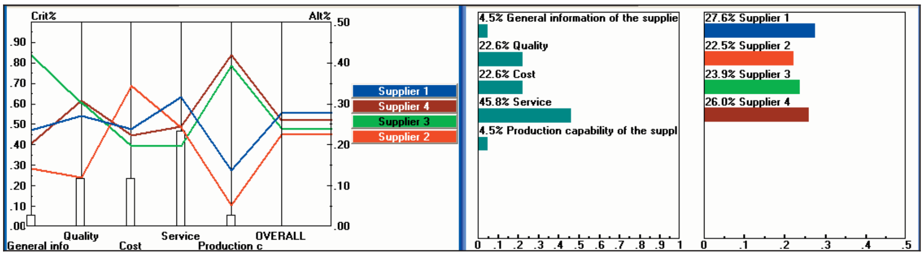

Table 14. Sensitivity Analysis of Scenario 5

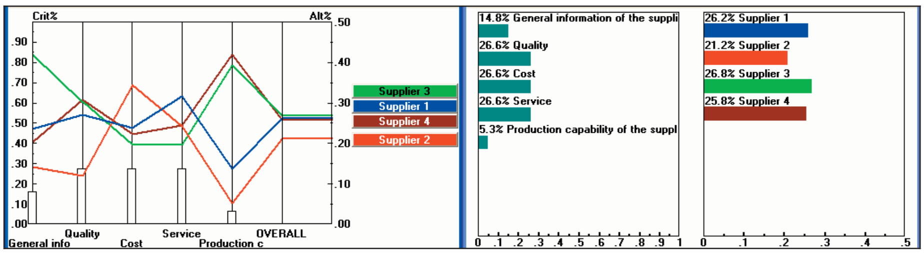

Table 15. Sensitivity Analysis of Scenario 6

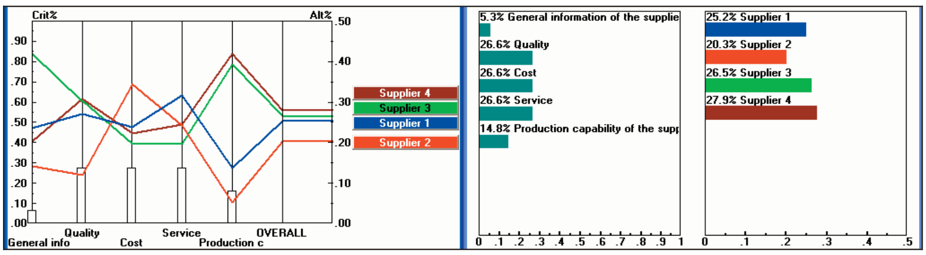

Table 16. Comparison in Between Six Scenarios and Current System

	Current System	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Order Quantity of Supplier 1	225,000	290,000	290,000	200,000	400,000	290,000	0
Order Quantity of Supplier 2	150,000	0	0	0	0	0	0
Order Quantity of Supplier 3	250,000	0	0	0	0	0	200,000
Order Quantity of Supplier 4	175,000	510,000	510,000	600,000	400,000	510,000	600,000
Total Cost of Purchasing	170,350	165,000	165,000	164,100	166,100	165,000	169,500
Total Defect Rate	57.6	45.5	45.5	45.0	46.0	45.5	45.0
On-Time Delivery (%)	84.53	91.81	91.81	91.25	92.50	91.81	87.50
Appropriateness of the quantity (%)	86.88	91.38	91.38	92.50	90.00	91.38	93.75
Cost of Break-in line	14,967	7,922	7,922	8,466	7,257	7,922	12,094
Total Cost	185,317	172,922	172,922	172,566	173,357	172,922	181,594

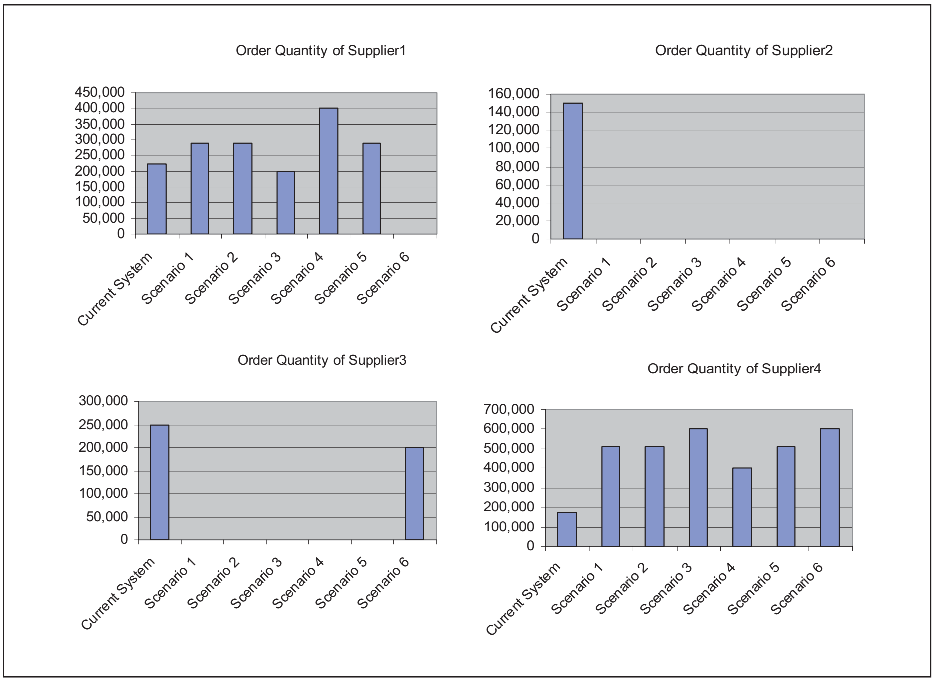

Figure 4. Comparison of Current System With Each Scenario With Respect to Order Quantity

6. CONCLUSION

In most industries the cost of raw materials and component parts constitutes the main cost of a product. Selecting the right suppliers significantly reduces the purchasing cost and improves corporate competitiveness, which is why many experts believe that the supplier selection is the most important activity of a purchasing department (Ghodsypour and O'Brien, 2001).

In single sourcing, the decision maker needs to make only one decision, which supplier is the best. Usually in real life, no supplier can satisfy all the buyer's requirements, more than one supplier has to be selected. This circumstance defined as multiple sourcing and the decision maker needs to make two decisions: which suppliers are the best, and how much should be purchased from each selected supplier? Also, supplier selection is a multi-criteria problem which the decision maker needs to deal with more than one concern. It involves trade-offs among multiple criteria that involve both quantitative and qualitative factors, which may also be conflicting (Ghodsypour and O'Brien, 1998). It should be systematically considered. The objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost.

This study proposes an integrated approach based on AHP and GP for solving supplier selection and order allocation problem of one of the battery company. Then, the proposed integrated approach has been implemented in the real-life case. In current system, battery company has four plug suppliers at approved supplier list. Aim of this study was to work with fewer suppliers and to build long-term relationship. The best two suppliers from the company's approved suppliers were determined by using the proposed approach. It was also determined satisfying order quantities among them, simultaneously. The integrated approach includes two main phase. In the first phase, the criteria are settled to evaluate the suppliers and AHP is used to figure out the weights of the factors. The AHP model is developed and solved in Expert Choice. In the second phase, a GP is developed to select the two suppliers and allocate the orders among them. The GP is developed and solved in Lingo.

As a result of implementing the proposed approach, 290,000 units were allocated to Supplier 1 and 510,000 units are allocated to Supplier 4. There is no purchase from Supplier 2 and Supplier 3. Then, total cost of purchasing, which is included unit cost and landed cost, is decreased €5,350. Total Defect Rate is decreased 12.2 ppm. On-time delivery percentage is increased 7.28%. Appropriateness of the quantity percentage is increased 4.50%. Cost of break-in line is decreased €7,045, and total cost is decreased €12,395.

Working with fewer suppliers and building long-term relationship have many advantages, besides the above mentioned ones. Having large amount material procurement from one supplier will increases the good communication and cooperation between the company and the supplier and when a problem occurs, supplier will be willing to solve the problem immediately. This will affect the service performance of the supplier. At the contract stage, more discounts can be taken by a high annual purchasing volume. Dealing with a few suppliers will reduce the work load and thus increase the efficiency of the procurement department.

In proposed approach, cost, service and quality criteria have same importance and they are strongly (by Saaty's 1-9 scales) more important than general information and production capability criteria. However, the best supplier can be changed according to the importance of the criteria which depend on company's strategy and policy. Because of that reason, six different scenarios were developed by changing the weight of the main criteria, and the results were obtained. Then, sensitivity analysis was performed in order to identify the impact of changes in the priority of criteria on the suppliers' performance and order quantities.

The advantages of this proposed approach are summarized as follows;

(1) Both tangible and intangible factors can be included.
(2) Using pair wise comparison reduces dependency of the system on human judgment.
(3) Both weight of criteria and rank of suppliers are determined by one systematic approach.
(4) Corporate strategies can be reflected in purchasing activities.
(5) Analysis of several "what-if" scenarios is facilitated, for example; what happens if the

weight of some criteria changes or another supplier joins the system, or another criterion is added or omitted.

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