AN INTEGRATED APPLICATION OF ANALYTIC HIERARCHY PROCESS AND GOAL PROGRAMMING TO SUPPLIER SELECTION

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ABSTRACT

Supplier selection decisions are frequently multi-objective in nature. That is, they are evaluated by more than one criterion. This paper presents an integrated application of goal programming and analytic hierarchy process in order to solve supplier selection problem of a TV manufacturing company. The problem is multi-item multiple sourcing in nature. The model determines the best two suppliers for each material, and also simultaneously allocates purchase orders among them by minimizing the deviations from performance and cost targets. It can be seen as a mixed application of preemptive and nonpreemptive goal programming. The weights assigned to the nonpreemptive goals were found out by applying the analytic hierarchy process. This model was solved on LINGO optimization software by utilizing the sequential goal programming solution method.

ÖZET

Tedarikçi seçme kararlari genellikle çok amaçli bir yapi arz eder. Yani bu kararlar birden fazla kritere göre degerlendirilmelidir. Bu çalismada bir televizyon üretim isletmesinin tedarikçi seçimi problemiyle ilgili olarak, amaç programlama ve analitik hiyerarsi sürecinin entegre bir uygulamasi sunulmaktadir. Problem çok sayida malzeme ve tedarikçiyi kapsamaktadir. Gelistirilen model her malzeme için en iyi iki tedarikçiyi belirleyerek bunlara açilacak siparis büyüklüklerini saptar. Model öncelikli ve agirlikli amaç programlamanin karma bir uygulamasi olarak görülebilir. Amaçlara atanan agirliklar analitik hiyerarsi sürecinden faydalanilarak bulunmustur. Bu model ardisik amaç programlama çözüm yöntemini kullanarak LINGO yaziliminda çözülmüstür.

1. Introduction

One of the most important responsibilities of a purchasing organization is the selection and management of suppliers that are competent and uniquely qualified to fulfill the buying firm's needs. Staying abreast of the large number of potential suppliers in the marketplace, and their respective capabilities and potential, it can be a difficult and time-consuming task if it is done well (Dobler & Burt, 1996).

Supplier selection refers to the selection of suppliers and the determination of appropriate order quantities to be placed with them. Such decisions may greatly affect a firm's ability to compete in the global market as they frequently account for a large portion of a product's production cost. Many companies purchase thousands of items from thousands of suppliers. Purchased materials account for 30 to 60 percent of sales and more than 50 percent of the cost of goods sold in most manufacturing firms (Smith, 1989). In today's competitive operating environment it is impossible to successfully produce low-cost, high-quality products without satisfactory suppliers.

Supplier selection decisions are complicated by the fact that various criteria must be considered in the decision making process. Quality, delivery, price, and service are known as the most crucial criteria. Frequently, the relevant criteria are in conflict. For example, the supplier with the lowest price may not have the best quality or delivery performance of the various suppliers under consideration. The firm must analyze the tradeoffs among the relevant criteria when making its supplier decisions. Consequently, it can be said that the supplier selection problem is often an inherently multi-objective one.

In this paper, an integrated goal programming and analytic hierarchy process model is presented in order to solve supplier selection problem of a TV manufacturing company.

2. Literature Survey On Supplier Selection and Order Allocation

In the literature, there are two types of supplier selection problem. In the first kind of supplier selection, one supplier can satisfy all the 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 the buyer's requirements, more than one supplier has to be selected (Multiple Sourcing). In these circumstances management needs to make two basic decisions. The management must decide which suppliers it should contact and it must determine the appropriate order quantity for each supplier selected.

In the literature various methods have been proposed for single sourcing supplier selection. Mazurak, Rao, and Scotton (1985) developed a vendor evaluation/selection system using linear weighting model in a spreadsheet environment. Gregory (1986) proposed the use of a matrix approach in supplier selection. Houshyar and Lyth (1992) presented a systematic procedure for use by procurement managers in making supplier selection decisions. Al-Faraj, Alidi, and Al-Zayer (1993) utilized the analytic hierarchy process for vendor selection in a spreadsheet system. A research made by Barbarosoglu and Yazgac (1997) presented an application of the analytic hierarchy process to the supplier selection problem. In addition to these methods, different methods have been introduced in the literature, such as Categorical Approach and Cost Ratio Approach (Timmerman, 1986), Probabilistic Linear Weighting (Soukup, 1987), Multiple Regression Analysis (Chapman & Carter, 1990), Expert System (Vokurka, Choobineh & Vadi, 1996), Human Judgment Models (Patton III, 1996), Discrete Choice Analysis (Verma & Pullman, 1998), Control Charts (Muralidharan, Anantharaman, Pugazhendhi & Deshmukh, 1999), Principal Component Analysis (Petroni & Braglia, 2000).

In spite of the importance of multiple sourcing only a few articles have addressed this problem. Weber, Current, and Benton (1991), who presented a review of 74 articles that discussed the supplier selection problem since 1966, stated that only ten articles applied mathematical programming to vendor selection. Since their review some other articles have used this technique. In the study of Chaudhry, Forst, and Zydiak (1991) an integer goal programming model is developed to solve a vendor selection problem under consideration of quality, lead-time, price, and service goals. Weber and Current (1993) presented a multi objective approach to generate various vendor selection options, which demonstrate the efficient trade offs among the relevant criteria. Akinc (1993) proposed a decision support approach to selecting vendors under the conflicting criteria of minimizing the annual material costs, reducing the number of suppliers and maximizing suppliers' delivery and quality performances. The approach of Current and Weber (1994) is based on the application of facility location modeling constructs to vendor selection problems. Rosenthal, Zydiak, and Chaudhry (1995) developed a mixed integer linear program that finds the purchasing strategy for the buyer that minimizes the total purchase cost. Kasilingam and Lee (1996) proposed a mixed integer programming model to the vendor selection problem. The model considers the stochastic nature of demand. Ghodsypour and O'Brien (1998) developed a decision support system integrating the analytic hierarchy process and linear programming to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them such that the total value of purchasing becomes maximum. Weber, Current, and Desai (1998) extended the study of Weber et al. (1993) by demonstrating three methods which can be used by purchasers to negotiate with vendors which have not been selected by the multi objective model in order to become part of the solution set. Degraeve and Roodhooft (1998) introduced a multi-period mathematical programming model using activity based costing information to evaluate sourcing strategies on the basis of the different costs associated with the purchasing decision. Aladag (1999) developed a two-phase methodology employing first an aspiration level interactive method to select suppliers, and then a goal programming model including three different objectives in a preemptive structure in order to determine order quantities to be assigned to each selected supplier. Karpak, Kumcu, and Kasuganti (1999) presented a vendor selection problem of a hydraulic pump manufacturing company. They utilized a visual interactive goal programming model to identify appropriate vendors and allocate purchase orders among them while minimizing product acquisition costs and maximizing total product quality and delivery reliability.

3. Goal Programming

Goal Programming is a multi objective programming technique. It can be thought of as an extension of Linear Programming that allows simultaneous satisfaction of several conflicting objectives while obtaining a solution that is optimal with respect to the decision maker's specification of goal priorities.

In the typical real world situation, goals set by the decision maker are achievable only at the expense of other goals, which are often incompatible. Since it may be impossible for a decision maker to meet all of the decided goals, he/she attempts to find a solution that comes as close as possible to reaching all goals. Thus, there is a need to establish a hierarchy of importance among these incompatible goals. This hierarchy ensures that before the less important goals are considered, the more important goals must be satisfied. The hierarchy can be established by providing either ordinal or cardinal ranking of the goals in terms of their importance to the organization.

In cardinal ranking cases, importance parameters or weights are assigned to the given goals. Then, all of them are expressed in a composite objective function; the problem is solved as a single-objective problem. In these types of problems, determining the weights is the most important concern. This approach of goal programming is called Nonpreemptive Goal Programming. This method can be used if all the goals are defined using some common units for example, in terms of money units (Murty, 1995). If the goals are not commensurable, normalization procedure is needed in this case. The most intuitive and simplest way for normalizing the goals is to express them in percentages rather than in absolute values.

Ordinal ranking requires ranking of the goals in order of priority, known as preemptive priorities. This method is named as Preemptive Goal Programming. In this approach, the most important goal which is in priority level one is satisfied using the standard linear programming, after that the second priority level is considered, then the third and so on.

4. Analytic Hierarchy Process

Analytic Hierarchy Process was first developed by Thomas L. Saaty (1980). This approach allows users to assess the relative weight of multiple criteria (or multiple alternatives against a given criterion) by using pairwise comparison between each pair of criteria. Pairwise comparisons can be made verbally, numerically or graphically. Each comparison is then transformed to a numerical value. It is a powerful technique when quantitative ratings are unavailable. By using this approach the decision maker can be able to incorporate both objective and subjective considerations in the decision analysis.

Four steps are used to solve a problem with the analytic hierarchy process methodology:

1. Build a decision "hierarchy" by breaking the general problem into individual criteria. (User/Analyst modeling phrase)
2. Gather relational data for the decision criteria and alternatives and encode preferences using the analytic hierarchy process relational scale. (User/Analyst pair-wise comparison input)
3. Estimate the relative priorities (weights) of the decision criteria and alternatives.
4. Perform a composition of priorities for the criteria that gives the rank of the alternatives (usually lowest level of hierarchy) relative to the top-most objective (Analytic Hierarchy Process software or a spreadsheet).

5. Description Of The Problem

The company investigated operates in the electronics sector, and produces more than 20 types of television. Company manages all of the business operations using SAP R/3, which is an Enterprise Resource Planning system. The company requires many kinds of material at large amounts. Generally materials are classified into raw materials and finished components provided from internal and external markets, and semi products supplied from subcontractors. There are lots of suppliers that they are willing to supply such an organization. That is to say for a specific item, many different suppliers being alternative to each other are available from abroad and domestic markets. According to a survey made by the Department Of Central Purchasing, there exist over 7,000 kinds of material with 272 approved suppliers and much more than that are awaiting for approval. From this point of view it can be pointed out that management and evaluation of all these suppliers is a very hard, complex, and comprehensive duty.

Problems that are faced in the supply and production can be defined as below:

- Lateness of the materials that are ordered.
- Rejection of the lots, which those are not meeting the technical and quality specifications set by the company.
- Appearance of low quality or broken parts in the production.

In order to overcome these problems, the management believes that the necessity of an effective supplier evaluation and selection system. Company's most important goal is to establish a supplier evaluation system based on tangible criteria, and thus they want to use the outputs of this system for supplier selection and order allocation decisions. Performing such a system also allows management to reduce the supplier base. The company desires to determine the best two suppliers for each material and allocate orders among them.

6. The Proposed Approach

This study shows an application of the goal programming and analytic hierarchy process in an integrated fashion, in order to solve a multi-item multiple sourcing supplier selection problem. Such a model can be useful for future order allocation decisions while benefiting from past performance data.

The integrated model determines the best two suppliers for each material, and also simultaneously places satisfying order quantities among them. It includes two basic objectives in a preemptive structure to address these considerations: quality, delivery, cost, capacity, and amount of past business.

The methodology used in this study comprises modeling and solution phases, sequentially. Therefore the steps of the methodology are summarized as follows:

A. Modeling Phase
   1. Define supplier selection criteria,
   2. Collect necessary data,
   3. Calculate performance measures,
   4. Identify main and sub goals,
   5. Determine target values for the goals,
   6. Determine weights of the sub goals,
   7. Express the notation used in the mathematical model,
   8. List the assumptions,
   9. Formulate the goals,
   10. Formulate constraints,
   11. Generate alternative achievement functions,

B. Solution Phase
   12. Solve the model,
   13. Obtain the results and interpret them.

6.1. Definition Of The Supplier Selection Criteria

In order to determine preferences of the company about the supplier selection criteria, three meetings were organized with participation of the purchasing specialists. According to these meetings seven important criteria were defined to address quality, delivery, cost, capacity, and past business considerations. The main and sub criteria are shown in Table 1.

Table 1. Company's supplier selection criteria

Main Criteria	Sub Criteria
1. Quality	1.1. Percentage of units rejected (POUR)
	1.2. Percentage of lots rejected (POLR)
2. Delivery	2.1. Percentage of units delivered late (POUDL)
	2.2. Percentage of lots delivered late (POLDL)
3. Cost	3.1. Past landed cost index (PLCI)
4. Capacity	4.1. Capacity utilization ratio (CUR)
5. Past Business	5.1. Measure of past business (MOPB)

6.2. Data Collection

To collect necessary data, ABC analysis was performed in order to determine the materials that are going to be included in the model. The reason for use this analysis is that these selected materials, which generate a large majority of the material costs, make the largest impact on the company's overall purchasing performance. After doing this analysis, the class A materials were chosen to be focused in the model. However, as discussed before, the company's main objective is to reduce the current supplier base by working with two predetermined suppliers for each material that can be purchased from at least two suppliers (multiple sourcing). It is not necessary to consider the materials that have only one supplier. In this respect, instead of all of the class A materials, just 72 materials were involved into the model. These selected items account for approximately 63 percent of the total purchasing value.

The data required to construct the model can be categorized mainly as follows: 1- List of the respected suppliers and their capacities. 2- Performance data of the suppliers. 3- Purchase requirements for the relevant materials.

List of the respected suppliers and their capacities. Totally 86 different suppliers are available for supplying these 72 materials. The required data for them are commonly material information (name and code), commodity information (name and code), number of the suppliers for each material, supplier information (title, geographical location, yearly capacity, and average monthly capacity).

Performance data of the suppliers. The necessary data to calculate the performance measures defined earlier was gathered from SAP. Because SAP was established in 1999, it was impossible to obtain the former data before 1999. So, only one-year performance data, entered into SAP between 1999 and 2000, was used to calculate the measures. The data needed are quantity of units received, quantity of units rejected, number of lots received, number of lots rejected, quantity of units delivered late, number of lots delivered late, minimum past landed cost, average past landed cost, yearly capacity of the supplier, and total quantity received from all suppliers.

Unit landed cost is the total cost of ownership of a unit material, and includes transportation, insurance, import and customs costs. The unit landed cost is computed by adding these costs onto the net unit price. The purchasing expert does this whenever a new lot is received. The minimum past landed cost is the lowest cost made up, in all orders under consideration of all vendors supplying the same material. The average past landed cost is a weighted average of the unit landed costs, and was found out for each supplier by the following equation:

$$\text{Avg. Past Landed Cost} = \sum (\text{Quantity Received} * \text{Unit Landed Cost}) / \sum \text{Quantity Received}$$

Purchase requirements for the relevant materials. Another crucial data for the model was monthly material requirements. SAP generates net purchase requirements by excluding the stocks from the gross material requirements. The net requirements arisen for January, February, and March in 2000 were used in this study. Using this data and past performance measures in the proposed model, it can be possible to designate order quantities that should be opened on the respected three months.

6.3. Calculation Of The Performance Measures

In this section, formulations developed to measure the performance criteria are presented.

$$POUR = \frac{\text{Units rejected}}{\text{Units received}}$$

$$POLR = \frac{\text{Lots rejected}}{\text{Lots received}}$$

$$POUDL = \frac{\text{Units delivered late}}{\text{Units received}}$$

$$POLDL = \frac{\text{Lots delivered late}}{\text{Lots received}}$$

$$PLCI = \frac{\text{Min. Past Landed Cost}}{\text{Avg. Past Landed Cost}}$$

$$CUR = \frac{\text{Units received}}{\text{Yearly capacity of the supplier}}$$

$$MOPB = \frac{\text{Units received from the relevant supplier}}{\text{Total quantity received from all suppliers}}$$

6.4. Identification Of The Goals

There are two general objectives considered in the mathematical model. The first objective is a composite goal including seven different sub goals to address the predefined supplier performance criteria, and minimizes the weighted sum of all the deviations between the targets and their aspiration levels. The second objective is more simply one. This goal minimizes the total of the undesirable deviations between the target landed costs and their achieving levels for all materials.

6.5. Determination Of The Target Values

For each material, it is necessary to determine the target values to be satisfied on the basis of each criterion. These values demonstrate the expected performance levels from the suppliers, and must be determined by the company. Normally, the ideal values of the measures are the maximum values that could be possible for them. For example, this value is zero for the POUR, while it is 1.0 for the PLCI. However, with this setting of the targets, the objectives defined before cannot be satisfied completely as the company wants to work with two suppliers for each material. Under this consideration a different setting scheme must be built.

To do that, an interview was made with the managers for determination of the target values, and they expressed that they expect the each performance target as a weighted average of the best two suppliers, which is calculated by the following equation for each material:

Target Value = 0.70*Measure of the best supplier + 0.30*Measure of the second best supplier

On the other hand, it can be found out the target landed cost for a given material by putting the last landed costs of the best two suppliers into the above formulation instead of the performance measures.

6.6. Assignment Of The Weights To The Sub Goals

Another crucial step in the modeling phase is to assign weights to the sub goals. As each supplier criterion does not have the same importance for the company, it is necessary to express the relative importance among them. According to the preferences of the managers it can be said that the quality measures are the most important measures overall, although the PLCI is the most important criterion individually. The weights assigned to the criteria are presented in Table 2.

Table 2. Company's criteria weighting scheme

Main Criterion	Overall Weight	Sub Criterion	Individual Weight
1. Quality	0.35	1.1. POUR	0.19
		1.2. POLR	0.16
2. Delivery	0.30	2.1. POUDL	0.15
		2.2. POLDL	0.15
3. Cost	0.25	3.1. PLCI	0.25
4. Capacity	0.05	4.1. CUR	0.05
5. Past Business	0.05	5.1. MOPB	0.05
Total	**1.00**		**1.00**

By setting these weights on the undesirable deviations, the composite objective function can be formulated.

6.7. Notation

Notation used in the model is given in Appendix.

6.8. Assumptions

Some assumptions were made while mathematical model of the problem was being developed. They are as follows:

1. The planning period is three-month.
2. The material requirements, and average monthly capacities of the suppliers are constant during the planning period.
3. It is assumed that the early deliveries do not affect the landed costs.
4. There is no budget constraint to obtain the orders.

6.9. Formulation Of The Goals

The first objective function aims to minimize the weighted sum of all the deviations occurred from the differences between the desired and achieved levels of the sub goals. Because all performance measures and target values was measured in percentages, there is no need for normalization of the goals. The sub goals were formulated as soft constraints in the model, as shown below:

Sub Goal 1: Minimize the amount of units rejected.

$$\sum_{i=1}^{I} POUR_{ij} * QO_{ijt} + NPOUR_{jt} - PPOUR_{jt} = TPOUR_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

Sub Goal 2: Minimize the number of lots rejected.

$$\sum_{i=1}^{I} POLR_{ij} * QO_{ijt} + NPOLR_{jt} - PPOLR_{jt} = TPOLR_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j=1, …, J; and t=1, …, T.

Sub Goal 3: Minimize the amount of units delivered late.

$$\sum_{i=1}^{I} POUDL_{ij} * QO_{ijt} + NPOUDL_{jt} - PPOUDL_{jt} = TPOUDL_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j=1, …, J; and t=1, …, T.

Sub Goal 4: Minimize the amount of lots delivered late.

$$\sum_{i=1}^{I} POLDL_{ij} * QO_{ijt} + NPOLDL_{jt} - PPOLDL_{jt} = TPOLDL_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

Sub Goal 5: Maximize the multiplication of the order quantity and the past landed cost index.

$$\sum_{i=1}^{I} PLCI_{ij} * QO_{ijt} + NPLCI_{jt} - PPLCI_{jt} = TPLCI_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

Sub Goal 6: Maximize the multiplication of the order quantity and the capacity utilization ratio.

$$\sum_{i=1}^{I} CUR_{ij} * QO_{ijt} + NCUR_{jt} - PCUR_{jt} = TCUR_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

Sub Goal 7: Maximize the multiplication of the order quantity and the measure of past business.

$$\sum_{i=1}^{I} MOPB_{ij} * QO_{ijt} + NMOPB_{jt} - PMOPB_{jt} = TMOPB_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

As can be seen, there exist some conflicts among the above goals due to the different optimization structures. The first four of sub goals are expressed in a minimization form, and they aim at minimizing the order quantity as far as possible. However, the succeeding three goals, which are to be maximized, tries to maximize the order quantity. Therefore, in order to satisfy the first four goals the positive deviations from the target levels should be minimized, while the negative deviations should be minimized for the last three goals. Under these considerations the objective function takes the following form:

$$\text{Min}\left\{WPOUR * \sum_{j=1}^{J}\sum_{t=1}^{T} PPOUR_{jt} + WPOLR * \sum_{j=1}^{J}\sum_{t=1}^{T} PPOLR_{jt} + WPOUDL * \sum_{j=1}^{J}\sum_{t=1}^{T} PPOUDL_{jt} + \right.$$

$$WPOLDL * \sum_{j=1}^{J}\sum_{t=1}^{T} PPOLDL_{jt} + WPLCI * \sum_{j=1}^{J}\sum_{t=1}^{T} NPLCI_{jt} + WCUR * \sum_{j=1}^{J}\sum_{t=1}^{T} NCUR_{jt} +$$

$$\left. WMOPB * \sum_{j=1}^{J}\sum_{t=1}^{T} NMOPB_{jt} \right\}$$

The second objective tries to assure that the material cost do not exceed the landed cost. The goal equation can be formalized as follows:

$$\sum_{i=1}^{I} LLC_{ij} * QO_{ijt} + NLC_{jt} - PLC_{jt} = TLC_{j} * \sum_{i=1}^{I} QO_{ijt}$$

for j = 1, …, J; and t = 1, …, T.

To satisfy this goal the positive deviations should be minimized as the following:

$$\text{Min}\left\{\sum_{j=1}^{J}\sum_{t=1}^{T} PLC_{jt}\right\}$$

6.10. Formulation Of The Constraints

Demand Constraint: The sum of the assigned order quantities to the selected suppliers should not be less than the required quantity by the company.

$$\sum_{i=1}^{I} QO_{ijt} \geq RQ_{jt}$$ for j = 1, …, J; and t = 1, …, T.

Capacity Constraint: The quantity ordered from the selected supplier should be equal or less than its average monthly capacity.

$$QO_{ijt} \leq AMC_{ij} * X_{ij}$$ for i = 1, ..., I; j = 1, …, J; and t = 1, …, T.

Number Of Suppliers To Be Employed: The Company wants to employ with two suppliers for each material. This constraint can be expressed as follows:

$$\sum_{i=1}^{I} X_{ij} = NOS$$ for j = 1, …, J; and t = 1, …, T.

6.11. Generation Of The Alternative Achievement Functions

The first task for the formulation of the achievement function is to give priority each of the objectives. However, it is possible to generate different sets of priorities. Changes in the priority ranking in the achievement function can have a major impact on the optimal solution. By reordering the priority ranking, the management can make tradeoff decisions and decide which solution to select as 'best'. Therefore, instead of using only one priority scheme, all alternative priority-ranking structures were used to provide alternative solutions to the management. In the model, due to the consideration of two main objectives to be satisfied, two different achievement functions can be constructed by changing the priorities of the objectives.

In the first, it is assumed that the most important objective is minimizing the weighted sum of all the undesirable deviations from the sub goals, and the second important objective is to minimize the deviations over the target landed costs. If the first priority is displayed by P_1 and the second is by P_2, the achievement function (Z) takes the following form:

$$MIN\ \mathrm{Z} = \mathrm{P}_1 \left\{ WPOUR * \sum_{j=1}^{J} \sum_{t=1}^{T} PPOUR_{jt} + WPOLR * \sum_{j=1}^{J} \sum_{t=1}^{T} PPOLR_{jt} + WPOUDL * \sum_{j=1}^{J} \sum_{t=1}^{T} PPOUDL_{jt} + \right.$$

$$WPOLDL * \sum_{j=1}^{J} \sum_{t=1}^{T} PPOLDL_{jt} + WPLCI * \sum_{j=1}^{J} \sum_{t=1}^{T} NPLCI_{jt} + WCUR * \sum_{j=1}^{J} \sum_{t=1}^{T} NCUR_{jt} +$$

$$\left. WMOPB * \sum_{j=1}^{J} \sum_{t=1}^{T} NMOPB_{jt} \right\},\ \mathrm{P}_2 \left\{ \sum_{j=1}^{J} \sum_{t=1}^{T} PLC_{jt} \right\}$$

The second achievement function assumes that minimization of the deviations over the target landed costs is the most important objective with the priority of P_1, while minimizing the weighted sum of all the undesirable deviations from the sub goals is the second important shown by the P_2.

On the other hand, setting different weighting structures on the sub goals that are built on the supplier selection criteria can generate different satisfying solutions for the problem. By changing the relative importance among the criteria, various weights can be obtained. According to the surveys in the literature, the most important criteria for supplier selection are delivery, quality, and cost. Because the weights determined by the company regard the past landed cost index as the most important criterion, two other weighting schemes can be implemented by considering the delivery and quality criteria as the most important one separately. In this study, the Expert Choice package, which is based on the Analytic Hierarchy Process, was used to determine the weights.

In the Expert Choice, first a hierarchy, in which the delivery criteria took precedence over the other individual criteria, was structured. Pairwise comparisons were made to determine the precedence. For instance, it was assumed that the POUDL is 3 times more important than the POUR, 7 times more important than the PLCI, and it is as important as the POLDL. The pairwise comparisons matrix is presented as below:

	POLDL	**POUR**	**POLR**	**PLCI**	**CUR**	**MOPB**
POUDL	1	3	5	7	9	9
POLDL		3	5	7	9	9
POUR			2	4	6	6
POLR				2	4	4
PLCI					2	2
CUR						1

According to these comparisons, the Expert Choice displayed the inconsistency ratio as 0.02. Since this value is less than 0.1, there is no evidence of lack consistency in the comparison judgments. The final weights are given as follows:

POUDL	**POLDL**	**POUR**	**POLR**	**PLCI**	**CUR**	**MOPB**
0.332	0.332	0.149	0.085	0.047	0.028	0.028

Secondly, pairwise comparisons taking the quality measures as the most important criteria were made. They are expressed in the following matrix:

	POLR	POUDL	POLDL	PLCI	CUR	MOPB
POUR	2	5	5	7	9	9
POLR		4	4	6	8	8
POUDL			1	3	5	5
POLDL				3	5	5
PLCI					3	3
CUR						1

For this structure, the inconsistency ratio is 0.02, and the resulting weights are as below:

POUDL	POLDL	POUR	POLR	PLCI	CUR	MOPB
0.108	0.108	0.394	0.285	0.053	0.026	0.026

Consequently, using two different priority schemes and three different weighting structures, totally six different alternatives can be produced. They are:

Alternative Model 1

P_1: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the company’s weights.

P_2: Minimization of the deviations over the target landed costs.

Alternative Model 2

P_1: Minimization of the deviations over the target landed costs.

P_2: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the company’s weights.

Alternative Model 3

P_1: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the weights under precedence of the delivery criteria.

P_2: Minimization of the deviations over the target landed costs.

Alternative Model 4

P_1: Minimization of the deviations over the target landed costs.

P_2: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the weights under precedence of the delivery criteria.

Alternative Model 5

P_1: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the weights under precedence of the quality criteria.

P_2: Minimization of the deviations over the target landed costs.

Alternative Model 6

P_1: Minimization of the deviations over the target landed costs.

P_2: Minimization of the weighted sum of all the undesirable deviations from the sub goals by applying the weights under precedence of the quality criteria.

The problem was solved separately for these alternatives.

6.12. Solution Of The Model

In this research, the Industrial LINGO Release 3.1 software was used to solve the model. LINGO is known as a mathematical programming language, and allows users to solve linear and also nonlinear models. The sequential goal programming solution method was utilized in this software to get the optimum results for different achievement functions.

It should be noted that, two other modeling issues were considered in the solution phase. The first issue is related to modifications of the target values. If the model is solved against the target values determined by the company, some of the undesirable deviations are found out as higher than zero, so the related goals are not satisfied. It means that the selected suppliers cannot meet the targets of the company. In order to overcome this matter, necessary modifications must be actualized on the targets. In this study, they were implemented by increasing the target value by the value of positive deviation obtained in the minimization goals, and by decreasing the target value by the value of negative deviation for maximization goals. Thus, the first priority goals were satisfied against the final targets. It should be pointed out that the modifications were made only for the first priority objective. After the first priority objective was satisfied, the second priority objective was added into the model.

The second issue refers to additional constraints made in the alternative model 2, 4, and 6. If a supplier is overall better than other suppliers for a given material in the direction of both performance measures and landed costs, monthly orders are placed completely to this supplier. As stated before, the company wants to work with exactly two suppliers for each material. To ensure that some additional constraints were attached to the model as formulized below:

$$\sum_{t=1}^{T} QO_{ijt} \geq MAB_{ij} * X_{ij}$$

These constraints ensure that in the planning period a minimum amount of units (MAB) will be received from the selected supplier. These values were obtained by asking to the management according to the following equation:

MAB = min [MPQ ; TTMC]

MPQ is the minimum-purchasing quota applied to a supplier during the contract period, and TTMC is the total three-month capacity of a supplier. The MPQ is 10%, and means that for this model, the company will purchase 10 percent of the three-month material requirements from the given supplier.

6.13. Results

After each alternative model was solved, the resulting order quantities assigned to each selected supplier through the January, February, and March were obtained. If the objectives are shortly named as performance objective and cost objective, the performance objective is fully satisfied while the cost objective is overachieved in the first alternative model. The cost objective is exceeded by $3,494,362. The objective values are summarized in Table 3.

Table 3. Objective values of the models

Alternative	Performance Objective	Cost Objective
Model 1	0	3,494,362
Model 2	4,207,621	0
Model 3	0	5,240,737
Model 4	4,098,422	0
Model 5	0	3,700,300
Model 6	4,516,399	0

Gray cells show the values of first priority objectives. Accordingly, the first priority objectives are fully achieved for all models, but the second priority objectives are not satisfied.

Each alternative model can be evaluated in such a way but in order to compare the models easily, Table 4 was prepared. This table illustrates the results of the alternative models in terms of total units rejected, total units delivered late, total landed cost, total number of suppliers, and number of suppliers not selected.

Table 4. Evaluation of the results

Alternative	Total Units Rejected	Total Units Delivered Late	Total Landed Cost ($)	Total Number of Suppliers	Number of Suppliers Not Selected
Model 1	10,395,998	10,743,240	156,294,997	60	26
Model 2	10,667,265	10,879,296	152,506,536	60	26
Model 3	10,127,000	7,950,165	158,041,374	61	25
Model 4	10,661,980	10,540,999	152,857,411	63	23
Model 5	5,857,686	13,851,644	156,500,931	56	30
Model 6	10,222,695	11,429,786	152,825,541	58	28

According to this table, the model 2, 4, and 6 generates lower-cost plans about $152 million, since they keep the cost objective as the first priority. But these models produce higher number of units rejected and units delivered late than other models do. The model 1 reflects the company's objective preferences, and it can be counted as an inefficient plan because of the higher levels of measures. It has more 77%

nonconforming items, 35% more late deliveries, and 2% worse landed cost than do the best solutions for those measures. The model 5 minimizes the total number of units rejected. However, this minimization causes increase in the cost and the number of units delivered late. The model 3 presents a minimum number of units delivered late, but with a maximum total landed cost. As can be seen simultaneous optimization of all goals is impossible, since there exist some tradeoffs between them. In this study, instead, satisfying solutions were obtained from different points of views. Hence, the management of the company can choose the proper one it prefers for implementation. The tradeoffs among the measures are demonstrated in Figure 1 and Figure 2.

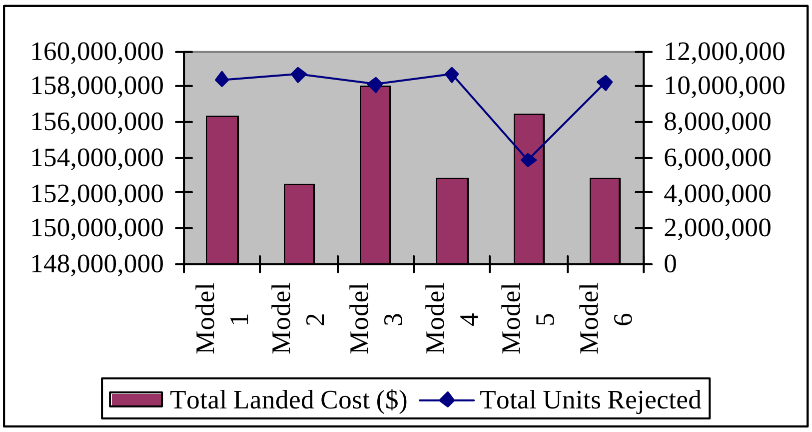

Figure 1. Comparison of the results in terms of total landed cost and total units rejected

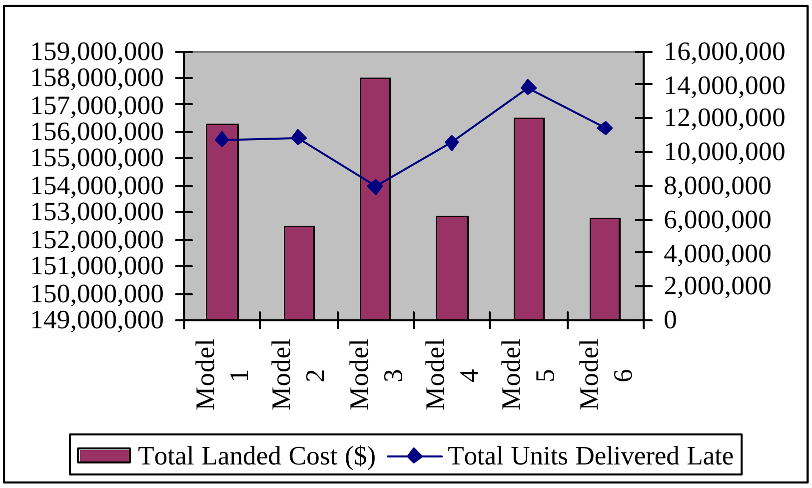

Figure 2. Comparison of the results in terms of total landed cost and total units delivered late

On the other hand, the models can be assessed in terms of total number of suppliers the company should be worked with. The above models, at the same time, reduce the current supplier base. As remember, the company worked with 86 different suppliers for all of the 72 materials in 1999. On average, these models decrease the number of suppliers by 30%. The model 5 minimizes this number with the 56 selected suppliers.

7. Conclusion

In this paper an integrated model of goal programming and analytic hierarchy process was developed for the supplier selection problem of a TV manufacturing company. The described model determines the best two suppliers for each material, and also simultaneously allocates purchase orders among them with the consideration of two main conflicting objectives. The performance measures or criteria used to evaluate suppliers are tangible, and calculated according to the proper formulations developed in the modeling phase.

This model was solved for all of the alternative priority rankings of the objectives, and against the different weighs set to the sub goals with respect to the performance targets. In this way, alternative order allocation plans were generated and presented to the management of the company. Since this model selects only the best two suppliers for each material included in the study, the overall supplier base is reduced from 86 to 60 on average.

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Appendix

Notation used in the model is given as follows:

Decision Variables

QO_{ijt} : Quantity ordered from supplier i for item j on month t.

X_{ij} : Binary integer variable (1 if supplier i is selected for item j; 0, otherwise).

Parameters and Constants

i : 1, ..., I (supplier)

j : 1, ..., J (item)

t : 1, ..., T (month)

$POUR_{ij}$: Percentage of units rejected for item j from supplier i.

$POLR_{ij}$: Percentage of lots rejected for item j from supplier i.

$POUDL_{ij}$: Percentage of units delivered late for item j from supplier i.

$POLDL_{ij}$: Percentage of lots delivered late for item j from supplier i.

$PLCI_{ij}$: Past landed cost index for item j of supplier i.

CUR_{ij} : Capacity utilization ratio of supplier i for item j.

$MOPB_{ij}$: Measure of past business for item j from supplier i.

LLC_{ij} : Last landed cost for item j of supplier i.

$TPOUR_{j}$: Target percentage value of the POUR for item j.

$TPOLR_{j}$: Target percentage value of the POLR for item j.

$TPOUDL_{j}$: Target percentage value of the POUDL for item j.

$TPOLDL_{j}$: Target percentage value of the POLDL for item j.

$TPLCI_{j}$: Target percentage value of the PLCI for item j.

$TCUR_{j}$: Target percentage value of the CUR for item j.

$TMOPB_{j}$: Target percentage value of the MOPB for item j.

TLC_{j} : Target landed cost for item j.

$NPOUR_{jt}$: Negative deviation from the $TPOUR_j$ on month t.

$PPOUR_{jt}$: Positive deviation from the $TPOUR_j$ on month t.

$NPOLR_{jt}$: Negative deviation from the $TPOLR_j$ on month t.

$PPOLR_{jt}$: Positive deviation from the $TPOLR_j$ on month t.

$NPOUDL_{jt}$: Negative deviation from the $TPOUDL_j$ on month t.

$PPOUDL_{jt}$: Positive deviation from the $TPOUDL_j$ on month t.

$NPOLDL_{jt}$: Negative deviation from the $TPOLDL_j$ on month t.

$PPOLDL_{jt}$: Positive deviation from the $TPOLDL_j$ on month t.

$NPLCI_{jt}$: Negative deviation from the $TPLCI_j$ on month t.

$PPLCI_{jt}$: Positive deviation from the $TPLCI_j$ on month t.

$NCUR_{jt}$: Negative deviation from the $TCUR_j$ on month t.

$PCUR_{jt}$: Positive deviation from the $TCUR_j$ on month t.

$NMOPB_{jt}$: Negative deviation from the $TMOPB_j$ on month t.

$PMOPB_{jt}$: Positive deviation from the $TMOPB_j$ on month t.

NLC_{jt} : Negative deviation from the TLC_j on month t.

PLC_{jt} : Positive deviation from the TLC_j on month t.

$WPOUR$: Weight assigned to the POUR goal.

$WPOLR$: Weight assigned to the POLR goal.

$WPOUDL$: Weight assigned to the POUDL goal.

$WPOLDL$: Weight assigned to the POLDL goal.

$WPLCI$: Weight assigned to the PLCI goal.

$WCUR$: Weight assigned to the CUR goal.

$WMOPB$: Weight assigned to the MOPB goal.

NOS : Number of suppliers to be selected.

RQ_{jt} : Required quantity for item j on month t.

AMC_{ij} : Average monthly capacity of supplier i for item j.

MAB_{ij} : Minimum amount of business to be given to supplier i for item j.