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Equipment Supplier Selection under Multiple Criteria

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Abstract
During the design and construction phase one significant factor for the project's successful outcome, is the selection of the appropriate construction equipment supplier. It is important to choose the best supplier wisely, as his performance could potentially affect the project schedule and final cost. This paper, aims at providing a standardized approach in selecting the best supplier, through the use of an appropriate mathematical function. The synthesis of the specific function is based on research conducted through a prototype questionnaire survey. The survey aimed at defining weights for a predefined set of criteria, concerning the selection of equipment suppliers. After the completion of the survey, the data was statistically analyzed. The application employed was the SPSS. The various statistical results were compared and the criteria weights were estimated. The research findings led to the construction of a final function which attributes scores to each of the construction equipment suppliers and indicates the best choice for the project under consideration.

Keywords
Construction, Suppliers selection, Equipment, Statistical analysis

1. Introduction

Purchasers in an organization buy many different types of items and services. The procedures used in completing a total transaction normally vary among the different types of purchases. Procurement is defined, in a narrow sense, as the act of buying goods and services for a firm or, from a broader perspective, as the activity of obtaining goods and services for the firm. Procurement process is divided into five stages: identification of suppliers, supplier selection, recognition of needs, ordering, and evaluation of supplier. In these stages, selection of the right supplier is the key to obtain: the desired level of quality, timeliness, price, the necessary level of technical support, and the desired level of service (Choi and Chang, 2006).

The steps taken to insure that the choice of suppliers minimizes cost risk are part of cost control. Supplier selection includes more than just bid evaluation and is one of the most crucial activities performed by organizations because of its strategic importance (Bhutta and Huq, 2002). Supplier selection is a multi-objective problem involving both quantitative and qualitative criteria (Bayazit *et al.*, 2006). A majority of the research deals with qualitative supplier evaluation schemes (Choi and Chang, 2006).

At the same time many companies engaged in construction activities cannot successfully compete in isolation. Rather, companies interact to exploit each other's talents and services in order to maximize company profitability. Suppliers and contractors co-exist in a precarious but essential business relationship (Nicholas and Edwards, 1998).

A construction manager presented with the task of selecting equipment for a new contract cannot always enlist those items already in the fleet since the particular characteristics of the new job may call for a new purchase (Chan and Harris, 1989). Therefore, a symbiotic business relationship exists between suppliers, construction contractors and managers. Specifically, contractors must continually purchase materials on credit to complete projects, whilst suppliers exist on the profits made from selling such (Nicholas and Edwards, 1998).

Construction suppliers provide an invaluable source of indirect financial resources for many contractors (Nicholas and Edwards, 1998). Similarly, contractors capitalize upon this relationship, by obtaining the necessary equipment required for projects, they are contracted to complete (Nicholas *et al*., 1999).

Moreover, equipment operators need to be involved in project planning at early phases in order to provide input about equipment operations that is unavailable anywhere else. Operators need to help develop equipment requirements since they are the ultimate users. Furthermore, suppliers frequently have more technical expertise than the customer, and can offer valuable assistance in specifying customer requirements. Supplier input during early design stages can be crucial in helping to control costs. A supplier can focus attention on design parameters that may be "wants" as opposed to "needs", and can thereby insure that the customer gets high value (Querns, 1997).

It is important for the purchaser to take into consideration the required amount of time for the manufacture of the equipment. It is equally important to study the schedule, so that the equipment can be delivered on time. Suitable arrangements should be made with the vendor, to arrange for delivery when it is convenient for the purchaser (Ward, 1992).

Through literature review a number of criteria were highlighted, depending on the frequency of their reference. The next stage considered the definition of weights for the predefined set of criteria. In order to do so, a prototype questionnaire was created, and a corrsponding survey was conducted. The survey took place among project managers in Greek construction companies. The data collected was analysed through the SPSS application. The analysis' results were used as input to the simos method in order to attribute weights to the selected criteria.

The second section presents in detail the abovementioned research methodology. Section three highlights the criteria for equipment supplier selection which were presented in the questionnaire survey, followed by construction of the optimal mathematical model in section four. Finally, section five of the paper, presents the research conclusions and the future work.

2. Research Methodology

There are several decision – making and problem – solving systems in use today that can be applied to equipment – engineering – procurement – construction (EPC) projects. These systems include mathematical modeling as a base for building operations research models. When the equipment is complex, costly, or involves significant risk, such models may be useful (Querns, 1997).

Model formulation is mostly a function of the user's ability to analyze and understand the problem, and of the ability to translate verbal descriptions of the problem into mathematical symbols and relationships. Model building then, requires identification of the objective function and definition of the variables that affect decisions. The objective function is the measure of effectiveness represented in terms of control variables. Solutions to models take several forms. Among them are graphical, algebraic, and those using differential calculus (Querns, 1997).

The procedure followed in order to build the final equation for selecting the best construction equipment supplier is based on the following steps:

- Literature review for equipment supplier selection criteria

- Dominant criteria are selected for assessment in the questionnaire survey
- Definition of criteria hierarchy
- Weight estimation and assignment for each criterion
- Formation of final mathematical equation for equipment supplier selection

This approach can be graphically presented in figure 1:

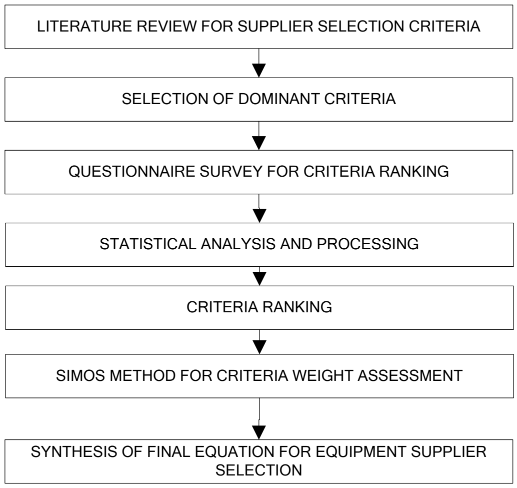

Figure 1: Proposed Approach for the Formation of the Final Equation for Supplier Selection

3. Definition of Criteria for Equipment Supplier Selection

Thorough literature review identified a number of criteria, for the selection of the best supplier, for the project under consideration. Definition of the final criteria to be incorporated in the questionnaire survey was based on the frequency of their reference in the literature. The final criteria are the following:

- Supplier's financial stability
- Potential longevity of the collaboration between supplier and firm
- Supplier's workload
- Availability of experienced supplier's personnel
- Long term support
- Expertise of suppliers personnel
- Equipment cost
- Experience with the type of equipment being purchased

The research involved project managers of Greek construction firms and fifty responses were acquired. Project managers were asked to rank the criteria, assigning successive numbers, ranging from 1 to 8, with one being the most significant and eight indicating the less important. Each time a number is appointed to a certain criterion, it is then deducted from the available set of numbers. It was obvious that through this procedure criteria acquiring minimum points are the most significant ones, and vice versa.

By summing up the total points for each of the criteria available, the order of significance becomes apparent. Moreover, through the application of SPSS, and it's "Descriptive Statistics" module, the mean, median, mode values are estimated. Table 1 presents the total points assigned to each of the criteria and their respective value differences and table 2 presents the SPSS outcomes:

Table 1: Precise Points Attributed to Each Criterion and Order of Significance

SUPPLIER SELECTION CRITERIA, RESPECTIVE SCORES AND VALUE DIFFERENCES		
SELECTION CRITERIA	SCORES	ΔS
Experience with the type of equipment being purchased	82	-
Equipment Cost	104	22
Expertise of suppliers personnel	132	28
Long term support	174	42
Availability of experienced supplier's personnel	177	3
Supplier's workload	210	33
Potential longevity of the collaboration between supplier and firm	227	17
Supplier's financial stability	229	2

Table 2: Mean, Median and Mode Value for each Criterion

	Equipment Cost	Experience with the type of equipment being purchased	Supplier's financial stability	Supplier's workload	Expertise of suppliers personnel	Potential longevity of the collaboration	Long term support	Availability of experienced supplier's personnel
Mean	2.44	2.40	5.85	5.12	3.42	5.85	4.77	4.88
Median	2.00	2.00	6.00	5.00	3.00	6.00	5.00	5.00
Mode	1	1	8	6	3	8	7	4

In conclusion the final list of the criteria in descending order of significance is the following:

- Experience with the type of equipment being purchased
- Equipment Cost
- Expertise of suppliers personnel
- Long term support
- Availability of experienced supplier's personnel
- Supplier's workload
- Potential longevity of the collaboration between supplier and firm
- Supplier's financial stability

4. Formation of Mathematical Model for Material Supplier Selection

With the hierarchy of the criteria defined it is time to evaluate the weights of each of the criteria. Several methods have been developed for assessing weighting factors. Some of these methods include: (a) The eigenvector method used in the Analytical Hierarchy Process, or AHP, (b) Linear Programming for Multi-dimensional Analysis of Preferences, or LINMAP (Hwang *et al*., 1998), (c) the Simos method, (d) the revised Simos method (Shanian *et al*., 2008).

The Simos method has been applied to a wide range of decision – making problems. It is based on a "card playing" procedure in which different criteria are classified in different levels (also called subsets) by the decision maker, followed by the ranking and weighting of levels. The method is simple and practical. However, it can occasionally process some criteria that have the same importance in an uncontrolled manner. Furthermore, similar to the AHP method, there is no reference made to criteria scales and therefore certain combinations of weights may be excluded (Shanian *et al*., 2008).

The revised Simos method is similar to its original version in that it allows the decision maker to convert directly the priorities to weights. However, as compared to the original version, the revised Simos method has some advantages in terms of: (1) collecting a new kind of information, (2) processing information to obtain non-normalized weights, (3) minimizing the rounding off errors during the calculation of normalized weights. Note that the normalization step is done so that the summation of the final weights becomes a hundred (Shanian *et al*., 2008).

4.1 Criteria Weight Estimation Using the Simos Method

The procedure of criteria classification according to the Simos method is based on a set of cards. It includes one card for each criterion and identical white cards. White cards have no conceptual meaning, and their only purpose is to increase the distance between the criteria cards.

The first step is to select those criteria that are least important and have the same weight. As soon as these cards are out of the way, the next less important criteria are selected, until all of them are chosen. In the meantime, in order to increase the distance between the created classes, it is possible to place between the criteria cards a number of white ones.

The weight estimation, summing up to 100, is based on the following procedure:

- Number of cards: For every class created (classes of white cards are also included) the constituent cards are recorded and their sum is estimated
- Position / Rank: Every card is attributed with a position number 1,2,3,….. beginning at the end of the hierarchy until the head of the classification is reached. The position of the last card is obviously equal to the total number of the cards.
- Not normalized weights: Class weight is defined by the sum of the classes' positions divided by the number of the classes' constituent cards
- Normalized weights - rounding: The non normalized weights are divided by the sum of the positions, where the positions of the white cards are not counted, and multiplied by 100. The weights are then rounded to the closest integer.

The number of white cards that are placed between the criteria cards, are equal in number to the distance which is calculated at the hierarchical ranking of the questionnaire research (Table 1). The methodology applied provided the final weights of the criteria. Table 3 presents analytically the required estimations and its stages:

Table 3: Criteria Weight Estimation for Equipment Supplier Selection

CLASSES	NUMBER OF CARDS	ROUNDING	PLACES / POSITIONS	NOT NORMALIZED WEIGHT	NORMALIZED WEIGHT	ROUNDING
Supplier's financial stability	**1**	1	1	0.15503876	0.16	0.16
WHITE	**2**	(2,3)				
Potential longevity of the collaboration between supplier and firm	**1**	4	4	0.620155039	0.62	0.62
WHITE	**27**	(5,..32)				
Supplier's workload	**1**	33	33	5.11627907	5.12	5.12
WHITE	**24**	(34,..58)				
Availability of experienced supplier's personnel	**1**	59	59	9.147286822	9.15	9.15
WHITE	**7**	(60,..,67)				
Long term support	**1**	68	68	10.54263566	10.54	10.54
WHITE	**61**	(69,..130)				
Expertise of suppliers personnel	**1**	131	131	20.31007752	20.31	20.31
WHITE	**39**	(132,..,171)				
Equipment Cost	**1**	172	172	26.66666667	26.67	26.67
WHITE	**4**	(173,..,176)				
Experience with the type of equipment being purchased	**1**	177	177	27.44186047	27.44	27.44
TOTAL	**172**	645				100.01

The results are summarized in Table 4:

Table 4: Criteria's Weights for the Selection of Equipment Suppliers

Supplier's financial stability	0.16
Potential longevity of the collaboration between supplier and firm	0.62
Supplier's workload	5.12
Availability of experienced supplier's personnel	9.15
Long term support	10.54
Expertise of suppliers personnel	20.31
Equipment Cost	26.67
Experience with the type of equipment being purchased	27.44

4.2 Optimal Mathematical Model

It is now possible to create the proper equation for the evaluation and selection of construction equipment suppliers. In order to define the mathematical function for the selection of the optimal construction material supplier, the criteria must be transformed into variables. The next table presents the criteria and their corresponding variables:

Table 5: Criteria, Weights and Corresponding Variables

Supplier's financial stability	0.16	a
Potential longevity of the collaboration between supplier and firm	0.62	b
Supplier's workload	5.12	c
Availability of experienced supplier's personnel	9.15	d
Long term support	10.54	e
Expertise of suppliers personnel	20.31	f
Equipment Cost	26.67	g
Experience with the type of equipment being purchased	27.44	h

The variable W is the final sum of the points attributed to a supplier. The equation will have the following form:

$$W = 0.16\,a + 0.62\,b + 5.12\,c + 9.15\,d + 10.54\,e + 20.31\,f + 26.67\,g + 27.44\,h$$

5. Conclusions and Future Work

The aim of this paper was to deliver an easy and at the same time reliable approach for selecting the best equipment supplier for the project under consideration. The solution employs the form of a mathematical equation, which makes it extremely simple to apply and come up with a solution. The creation of the final function is based on the findings of a qustionnaire survey conducted among project managers in the Greek construction industry.

It is concluded from the abovementioned calculations that the most significant criteria are "Experience with the type of equipment being purchased" and "Equipment Cost" and among the least significant ones are "Potential longevity of the collaboration between supplier and firm" and the "Supplier's financial stability".

As far as the future work is concerned, the model will be applied to corresponding real – life situations and the results will be used to validate the model and even produce appropriate calibrations to the existing one in order to increase its efficiency and consistency.

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