A Two-Level Decision Support System For Supplier Diversification

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***Abstract*— In this study, we provide a two-level decision support system for the constitution of supplier pool and order quantity decision for each of the suppliers selected from a predetermined candidate list. The candidate suppliers are the current vendors in the market. The proposed decision support tool integrates a knowledge-based expert system and a genetic algorithm to consider both qualitative and quantitative criteria in supplier selection and order quantity decision. The expert system decreases the candidate suppliers to the most preferred ones according to quality, delivery and management core dimensions. Genetic algorithm then allocates order quantities to each supplier considering quantity discounts, preference factors and capacity constraints. A real-life case study at a steel structures manufacturing company demonstrates an application of the proposed support system.**

Keywords- expert systems; genetic algorithms; decision support systems; supply chain management; supplier selection

I. INTRODUCTION

Procurement expenses constitute a major component of the operating expenditures of the firms. Thus, supplier selection has become one of the key issues in supply chain management. Furthermore, choosing the right vendors would result in improved coordination with suppliers. In practice, the contemporary approach is to work with fewer but more fulfilling suppliers to build long term relationships with each of them. With the increasing diversity of suppliers, transaction costs, monitoring costs, supply chain strategic and operational risks, competition are increased, whereas supplier innovation and responsiveness are decreased [1-4]. However, firms benefit from the risk pooling effect with the increased number of suppliers.

Apparently, building a manageable supplier base is a multi-criteria decision making problem which requires the analysis of both quantitative and qualitative factors such as price, delivery leadtime and quality, and managerial issues (feedback, contingency planning, etc.). Consideration of quantity discounts also adds a new level of complexity to the supplier selection problem. That is, the decision maker must determine the order quantities for each supplier under several conflicting factors. In this context, the need for an effective decision support system is apparent.

In the literature, a vast number of studies focus on the supplier selection issue. One group of studies relies on the inventory management perspective. In such studies, delivery leadtime, quality, supplier capacity, and other factors are embedded into inventory control models. The other group of studies mainly concentrates on developing decision support systems (such as expert systems, data envelopment analysis) based on qualitative factors. In this study, we combine these two approaches and propose a two-level decision model consisting of a knowledge-based expert system and a genetic algorithm. The model is composed of two main stages: In the first stage, a knowledge- based expert system is used to discover the suppliers --with their preference factors-- that we can order for a certain type of product. The second stage aims at determining the order quantity allocated to each of the selected suppliers with the use of a genetic algorithm.

This paper is structured as follows. Section 2 presents a review of some of the related literature. Section 3 introduces the proposed methodology in an overall perspective. Sections 4 and 5 present the knowledge-based expert system and the genetic algorithm respectively. A case study is carried out in Section 6. The final section summarizes the paper and presents the conclusion.

II. LITERATURE REVIEW

In the area of supply base management numerous methods have been used for supplier evaluation and selection. We refer the reader to the recent survey of [5]. The research analyzes prevalently applied approaches and provides evidence that the multi-criteria decision making methods are better than the traditional cost-based approach.

With its practical usefulness, a majority of the studies are based on data envelopment analysis [6]. Mainly, the methodology seeks for relatively efficient suppliers based on multiple inputs and outputs. It relies on the assumption that more efficient suppliers are more effective. AHP (Analytical Hierarchy Process) is another popular method used widely in the literature [7]. It should be noted that, due to the number of evaluations required, for problems with a large number of alternatives or criteria, the use of this technique is unwieldy. The use of intelligent systems, such as case-based reasoning, neural networks and expert systems form another group of decision making tools [8-11].

Most studies in the literature have addressed the selection problem solely. Some articles considering the order quantity allocation to the selected suppliers under

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multiple sourcing strategies. Degraeve and Roodhooft [12] followed a mathematical programming approach using activity-based costing for supplier selection. Karpak et al. [13] and Kumar et al. [14] used goal programming (GP) models to select suppliers and allocate orders under supplier's capacity constraints. Ghodsypour and O'Brien [15] proposed a mixed integer nonlinear programming model to minimize the total cost of logistics, including net price, storage, transportation and ordering costs.

In [16][17][18][19], integrated AHP and GP models are used. Relative performances of suppliers found from the AHP model was used as inputs to the GP model to find the optimal supplier base. Both quantitative and qualitative factors could be used for supplier evaluation, but the unit price of a product is assumed constant for different order quantities.

Xia and Wu [20] used AHP for searching potential suppliers and then used the multi-objective mixed integer programming to determine the number of suppliers to employ and the order quantity allocated to these suppliers. Mendoza and Ventura [21] also used AHP in the first phase to reduce the number of suppliers. At the second phase they implemented a mixed integer non-linear programming method to determine the optimal order quantites. Demirtas and Ustun [22] have used analytic network process (ANP) in the first step and for quantity allocation they followed the similar method used in [20].

In the studies of [23][24], fuzzy multi-objective programming models were developed for supplier selection and order quantity allocation. Their later work also considered price discounts. Chen [25] used the fuzzy set theory to select suppliers under supplier base limitations.

Eventually, while many studies in the literature address the quantity discounts in the economic order quantity subject, a little attention has been paid to the case in the supplier selection and order quantity allocation problem. This paper proposes a two-level approach to seek for the most appropriate supplier base by using the expert system and the genetic algorithm with quantity discount considerations.

III. THE PROPOSED METHODOLOGY

Supplier selection and order quantity allocation is a multi-step process which requires the evaluation of suppliers by quantitative and qualitative measures dependent on the product type and various constraints. The methodology proposed in this study follows a two-step architecture illustrated in Figure1.

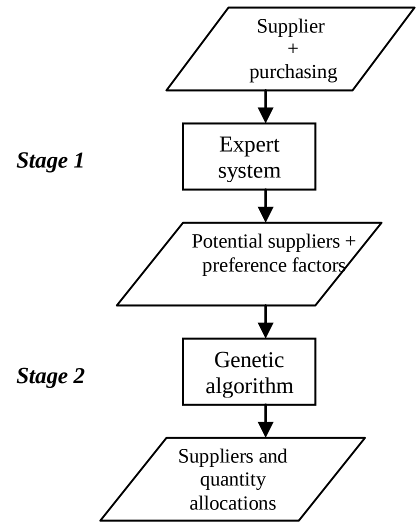

Figure 1. Main flowchart.

The first stage uses a knowledge- based expert system to select potential suppliers under quality, delivery and management dimensions. At the end of this step, a list of candidate suppliers with their preference factors is provided as an output to the second step. Using this data, the second stage searches throughout the solution space under supplier capacity constraints and price discounts to determine the optimal supplier base. Finally, at the end of this phase, optimal suppliers and their order quantity allocations are specified.

IV. STAGE I .THE KNOWLEDGE-BASED EXPERT SYSTEM

A. *Criteria determination and evaluation*

Dickson [26] listed 23 factors to consider for supplier evaluation and selection. Recently, Ho et al. [27] reviewed the literature to discover the criterion used by the decision makers. Studies identify more than hundreds of measures with quality, delivery, cost, manufacturing capability and service as being the most popular ones and some recently recognized criterions such as environmental standards. In general, the evaluation and selection process differs according to the purchased product type. Therefore, in the developed model, initial determinant in the system is the product's category, which may be either strategic or non-critical.

The criteria in this work were determined based on related literature and by interviews with the purchasing managers of a medium-sized company in the steel structure construction business. It should be noted that these criterions are subject to discussion and they may be defined in a different way for companies in different industries. Figure 2 shows the decision map for the strategic products.

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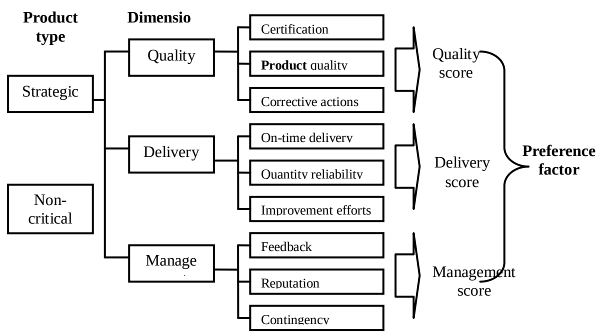

Figure 2: Decision map for strategic products

Additional details for the decision attributes and their values for strategic products are given in Table I.

TABLE I. DECISION ATTRIBUTES AND THEIR VALUES

Strategic product	
Does the supplier have the quality system certifications required?	No / Yes
At what level does the supplier meet the requirements for quality?	U / M / S / V / E
At what level does the supplier show vigorous and successful corrective actions?	U / M / S / V / E
Does the supplier comply with the delivery schedule?	U / M / S / V / E
Does the supplier comply with the delivery quantity?	U / M / S / V / E
What is the level of supplier's efforts for delivery recovery?	U / M / S / V / E
How is the supplier's communication skills and feedback?	U / M / S / V / E
How is the supplier's reputation and position in the industry?	U / M / S / V / E
At what level does the supplier have satisfactory contingency plans to ensure business continuity?	U / M / S / V / E

Key: U=Unsatisfactory, M= Marginal, S= Satisfactory, V= Very Good, E= Excellent

B. Expert system architecture

A knowledge-based expert system developed for determining the potential suppliers and their preference factors is composed of the following elements: User and expert interfaces, knowledge base, material requirements planning module and the inference engine. The user and the material requirements planning module together provide information related to the product to be purchased and the available suppliers. The knowledge base contains the problem specific information obtained from purchasing experts. The facts and rules (based on production rules semantics) are stored in the knowledge base are generally in the structure provided in Table II.

TABLE II. DECISION ATTRIBUTES AND THEIR VALUES

Rule id: ST_Q_5			
IF	certification	IS	Yes
AND IF	product quality	IS	Very good
AND IF	corrective actions	IS	Satisfactory
THEN	quality score	IS	Very good
Rule id: ST_D _12			
IF	on-time delivery	IS	Very good
AND IF	quantity reliability	IS	Excellent
AND IF	improvement efforts	IS	Excellent
THEN	delivery score	IS	Excellent
Rule id: ST_M _9			
IF	feedback	IS	Satisfactory
AND IF	reputation	IS	Very good
AND IF	contingency planning	IS	Satisfactory
THEN	management score	IS	Satisfactory
Rule id: ST_P _9			
IF	quality score	IS	Very good
AND IF	delivery score	IS	Excellent
AND IF	management score	IS	Satisfactory
THEN	preference factor	IS	Very good

Example rules given above are used for strategic products. Through rule ST_Q_5, the system determines the supplier's quality score as very good, if it is certified, its product quality is high and its corrective action management is satisfactory. According to the next rule, (ST_D _12), if a company's on-time delivery is rated very good, quantity reliability and improvement efforts are excellent then its delivery score is excellent. Rule ST_M _9 states that if supplier feedback is satisfactory, reputation is very good and contingency planning is satisfactory then the management score is satisfactory. The scores for the three main dimensions are then evaluated together to obtain the preference factor in terms of "Unsatisfactory; Marginal; Satisfactory; Very Good; Excellent". For instance, through rule ST_P _9, preference factor is rated as very good for a supplier with very good quality, excellent delivery and satisfactory management.

V. STAGE II

Previous phase determined the potential suppliers along with their preference scores. This stage allocates order quantities to each of these suppliers under supply constraints and price discounts. To search throughout the large solution space, a genetic algorithm, which is known as an effective method for solving complex optimization problems, was employed.

A. Chromosome representation

Each chromosome is designed in a way to represent a feasible solution with suppliers and their quantity allocations. As illustrated in Figure 3, each gene of a chromosome is designed to stand for the quantity allocation (q_i) for each supplier placed in a fixed position.

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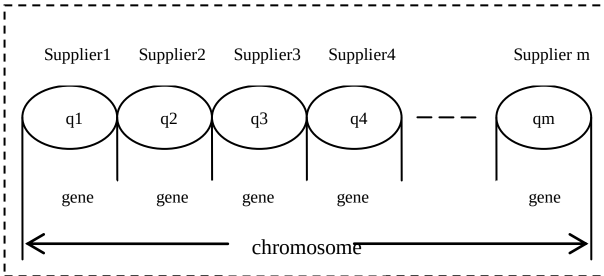

Figure 3: Chromosome representation

B. Genetic operators

In order to maintain the genetic diversity for evolution, selection, crossover and mutation operators are utilized. The selection process selects two individuals or parents for crossover. Rank selection technique is used for this purpose. Once the parents are selected offspring are created by the use of the crossover operator. With the aim of ensuring the variety of the individuals so as to prevent local optimum solutions, mutation operator is induced. Figure 4 demonstrates the two-point crossover and the mutation operators used in this study. To preserve the best individuals in an attempt to shelter the population, elitist strategy is adapted when creating the new population.

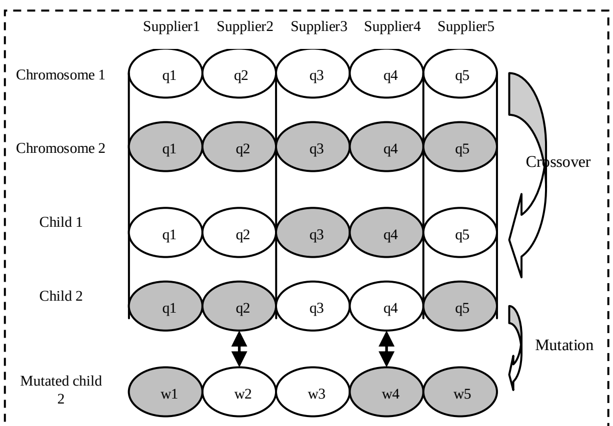

Figure 4: Crossover and mutation operators

C. Fitness function

Fitness value of a chromosome reveals its value compared to other individuals in terms of the defined objective. In this model, the fitness function is an arrangement of the measures unit and fixed purchasing prices, and preferences. Furthermore, diversity the total number of suppliers in the supplier set formed by the expert-system.

$$\min Z = F(diversity, price, preference)$$

The solution is reached through simultaneous minimization of those measures. Preference factor for each supplier is derived from the first stage expert system outputs. Unit price policies for different quantity ranges are prearranged for each supplier.

q_i quantity allocated to supplier i
x_i preference factor of supplier i
SC_i capacity of the i*th* supplier
D total demand
$P_i(q_i)$ unit price for supplier i if the order quantity is q_i
K_i fixed ordering cost for supplier i (setup cost)

We consider a single-buy model with deterministic demand. One may consider this model as a make-to-order model with known demand, say D, for a specific component. That is, the total quantity allocated to the suppliers should be defined as $\sum_i^n q_i = D$, where *n* is the total number of suppliers in the preferred list generated by the expert-system. Further, with a supplier capacity of SC_i, quantity must also be limited by $q_i \le SC_i$.

Preference factors derived from the expert system are converted to numeric values through one to five, with five being the least preferred and one the most preferred score. We then use the preference factors of the suppliers as the weights of their costs. Then the objective function is

$$\underset{q_1,\dots,q_n}{min}\ Z = \sum_i^n x_i (q_i P_i(q_i) + K_i 1(q_i > 0))$$

where $1(q_i > 0)$ is an indicator function; it returns 1 if $q_i > 0$ and 0 otherwise.

VI. CASE STUDY

The proposed method was coded in Microsoft Visual C++ with .NET Framework under Windows Vista. The model was then applied to a mid-size steel structures manufacturing company. The case selected for testing purposes was a strategic product with 12 potential suppliers. Some suppliers could meet the qualifications entirely and some partially. The input data related to the performance criteria in the model are given in Table III.

The solution procedure followed the structure outlined in Figure 1. The initial determinant is the product category. As the user selects the strategic product option, the expert system will follow the decision-tree structure depicted in Figure 2. The output preference factors for each supplier are shown in Table IV.

Since the maximum number of suppliers is limited by the company, the suppliers with the top preference scores are taken as input to the second phase of the model. The supply capacities, setup costs and price levels for different quantities for those suppliers are shown in Table V. Total demand of the product is given as 100 units.

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TABLE III. SUPPLIER DATA

		s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12
Quality	Certification	Y	N	N	Y	Y	Y	Y	N	Y	Y	N	N
	Product quality	V	S	M	E	V	S	S	V	U	M	S	V
	Corrective action mgmt	S	M	U	E	V	S	V	E	M	M	S	V
Delivery	On-time delivery	V	S	M	E	V	S	M	M	V	V	S	M
	Quantity reliability	V	M	U	E	V	S	U	U	S	V	V	M
	Improvement efforts	E	M	S	S	V	E	E	M	S	V	E	S
Management	Feedback	M	S	S	V	V	S	M	U	S	V	E	S
	Reputation	E	M	U	E	V	V	V	M	V	S	M	V
	Business continuity	V	U	U	V	S	S	M	M	V	S	M	S

TABLE IV. SUPPLIER PREFERENCE VALUES

	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12
Quality	V	M	U	E	V	S	V	S	M	M	M	M
Delivery	E	M	M	V	V	S	M	M	S	V	V	M
Management	V	M	U	E	V	S	M	M	S	S	M	S
Overall	E	M	U	E	V	S	M	M	M	S	M	M

TABLE V. SUPPLY CAPACITIES AND PRICE LEVELS FOR SUPPLIERS

Supplier	Quantity	Price	Capacity	Setup cost
s1	$q<25$	22	80	1
	$25 \le q<50$	17		
	$q \ge 50$	11		
s4	$q < 15$	20	70	1
	$15 \le q< 40$	16		
	$q \ge 40$	11		
s5	$q \le 20$	20	70	4
	$20 \le q<50$	15		
	$q \ge 50$	10		
s6	$q \le 30$	19	90	3
	$30 \le q<60$	14		
	$q \ge 60$	10		
s10	$q \le 20$	22	60	3
	$20 \le q<30$	14		
	$q \ge 30$	10		

Parameters and attributes related to the genetic algorithm are as follows:

- The population size is set to 50
- Rank selection is used for choosing the candidates for breeding.
- Two-point crossover is implemented.
- Crossover and mutation probabilities are set to 0.9 and 0.2 accordingly.
- Elitist strategy is implemented.
- Maximum number of iterations is set as 250.

Genetic algorithm was run with the above parameters and the best solution found in ten runs is shown in Table VI. The supplier base is composed of two suppliers: Supplier 1 and Supplier 4. Supplier 1 scored “Very good” in quality, “Excellent” in delivery and “Very Good” in management, whereas Supplier 4 scored “Excellent” in quality, “Very Good” in delivery and “Excellent” in management aspects. The first supplier is assigned an order of 60% of demand (60 units). With this amount, the order size is above the second price breakpoint and the company can benefit from the price advantage. Remaining demand (40 units) is allocated to Supplier 4, where the third price level policy may again be adapted.

TABLE VI. BEST SOLUTION OUTPUT

Total demand	Fitness		Quantity	Price
100	13.224	Supplier 1	60	11
		Supplier 4	40	11
		Supplier 5	0	0
		Supplier 6	0	0
		Supplier 10	0	0

Within the genetic optimization stage, the solution fitness scores at each iteration were analyzed. Figure 5 and 6 demonstrate how the individuals persistently converged to better solutions, consistent with the genetic algorithms nature. While the first graph belongs to the population average progress, the second graph shows the evolution process of the best chromosome for ten runs.

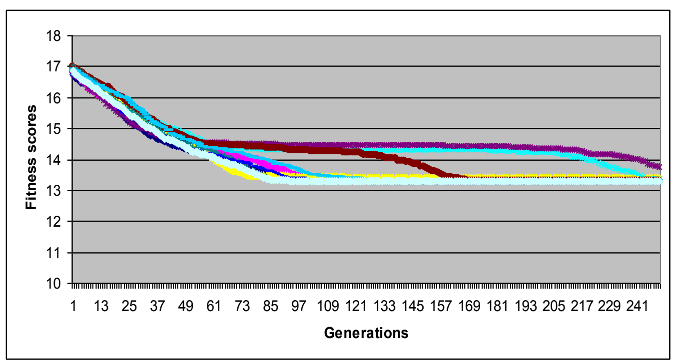

Figure 5: Fitness evolution of population average

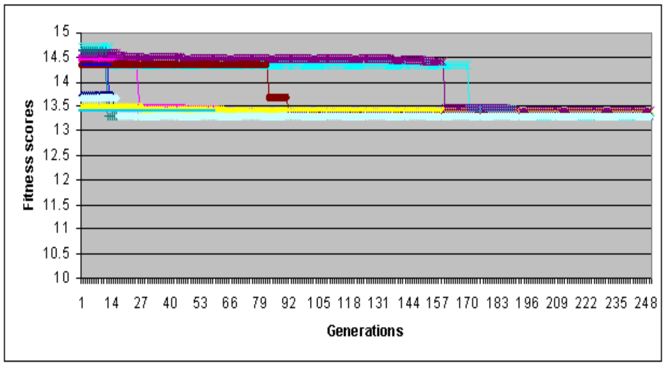

Figure 6: Fitness evolution of the best solution

Examination of the solutions proved that all solutions are feasible in terms of supplier capacities, demand and price polices. Criterion relating to quality, delivery, management, and price were considered simultaneously in decision of the final selection. The model showed strong tendency towards choosing the most appropriate suppliers in terms of quality, delivery and management as far as it would be economically reasonable. Furthermore, solutions also tempted to work with fewer but more reliable suppliers. These results verify the efficiency of the fitness function explained previously.

It should be noted that heuristic algorithm solutions do not guarantee an optimal result. Nevertheless, reaching a result close to the optimal solution, to some extent, is essential. To test the algorithms performance in this perspective, best and worst solutions throughout the experimental runs were collected. These two values may imply the upper and the lower bounds of the feasible solution space.

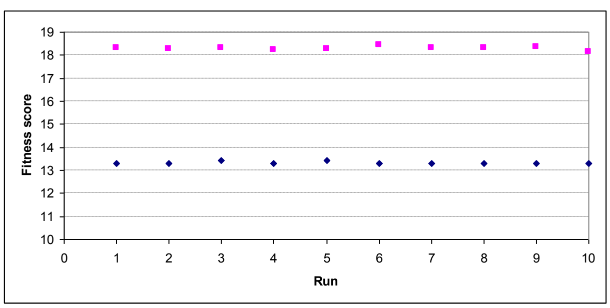

Figure 8: Solutions dispersion

In Figure 8, dispersion of the best and the worst scores in ten runs are illustrated. It can be observed that, best solutions are scattered within the top 2% of the feasible solution space. With these facts, it can be concluded that the developed genetic algorithm conforms to the fundamental requirement of a heuristic and the developed method can be employed as an efficient decision support tool in order to help purchasing managers.

VII. CONCLUSION

This paper proposes a new model integrating the expert system and the genetic algorithm to build the most appropriate supplier base. With the knowledge-based expert system potential suppliers are chosen with respect to quality, delivery and management dimensions and preference factors are assigned to each supplier. In the second phase order quantities are allocated to each supplier considering quantity discounts, preference factors and setup costs. A real-life case study at a steel structures manufacturing company illustrates the applicability of the proposed methodology.

As a future research, the model can be extended to tackle multi-product orders. Then, the model can be used for group decision making for a complete supplier base optimization.

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