A DECISION SUPPORT SYSTEM FOR SUPPLIER EVALUATION AND ORDER ALLOCATION

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ABSTRACT

A DECISION SUPPORT SYSTEM FOR SUPPLIER EVALUATION AND ORDER ALLOCATION

This study focuses on the improvement of supplier evaluation and order allocation decisions for one of the leaders of the white-goods manufacturers in Turkey. A decision support system (DSS) is developed to increase the quality and speed of decision making. In the current purchasing system, the decision maker evaluates the supplier candidates informally and after tough negotiations quota diversification is established. In the proposed system, a tool is developed to evaluate the suppliers with qualitative and quantitative criteria and allocate annual quota so as to optimize a set of purchasing goals.

KISA ÖZET

TEDARİKÇİ DEĞERLENDİRMESİ VE KOTA DAĞILIMI İÇİN BİR KARAR DESTEK SİSTEMİ

Bu çalışma Türkiye'deki lider beyaz eşya üreticilerinden birinin tedarikçi değerlendirme ve kota dağılım kararlarını iyileştirmeye yönetliktir. Karar verme sürecinin kalitesini ve hızını arttırmak üzere bir karar destek sistemi geliştirilmiştir. Mevcut satınalma sisteminde, karar verici tedarikçi adaylarını öznel olarak değerlendirmekte ve kota dağılımından önce her bir adayla sıkı pazarlık sürecine girmektedir. Önerilen sistemde, hem tedarikçileri nicel ve nitel kriterlere bağlı olarak değerlendirilen, hem de bir takım satınalma hedeflerini en iyi şekilde sağlayarak kota dağılımı yapan bir yazılım geliştirilmiştir.

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DEDICATION

To the honorable memory of Prof. İ. Reşat Özkan.

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FORMULAS

ABBREVIATIONS

AHP: Analytic Hierarchy Process
ANP: Analytic Network Process
DEA: Data Envelopment Analysis
DSS: Decision Support System
ERP: Enterprise Resource Planning
GP: Goal Programming
GUI: Graphical User Interface
IT: Information Technologies
LP: Linear Programming
LGP: Lexicographic Goal Programming
MRP: Materials Resource Planning
PGP: Preemptive Goal Programming
PPM: Parts Per Million

CHAPTER 1

INTRODUCTION

Successful supply chain management requires an effective and efficient sourcing strategy to eliminate the uncertainties in both supply and demand. In general, supply distributions result with delays, fluctuations in lead times and unexpected costs. Eventually the firms lose market presence and reputation in their sector.

With the increase of the purchasing costs as compared to the overall costs, the purchasing function and the purchasing decisions have gained a significant importance at each firm. On average, a typical manufacturing company spends 60% of its total turnover in purchasing materials, goods and services acquired from external suppliers (Bayrak et al., 2007). Furthermore, the complexity of purchasing decisions has also increased because more people are involved in decision making. Besides, cost of poor decisions are higher and agility is a must for proactive business (Boer et al., 2001). Thus purchasing decisions might have significant effects on lowering costs and increasing profits.

Purchasing processes are analyzed in 2 stages. First the selection of suppliers formally stated as pre-qualification of suitable suppliers is performed. Second stage is the order allocation where the annual order quota for each supplier is determined. The methods used in the first step are categorical methods, data envelopment analysis (DEA), cluster analysis, analytic hierarchy process (AHP) and analytic network process (ANP), etc. In the second stage, simple linear weighting method, i.e., assigning weights to suppliers or complex methodologies like mathematical programming models, statistical models and artificial intelligence are used for order allocation (Burke et al., 2001).

Earliest works on supplier evaluation and order allocation go back to Dickson's 23 factors weighted by four companies in 1966 and Baffa and Jackson's goal programming (GP) model for purchase planning in 1983. Since then, there have been many studies on purchasing decisions that can mainly be grouped as single and combined models. Single models use only one method for supplier selection and order allocation, whereas combined models integrate two methods for this purpose (Ha & Krishnan, 2007).

In this thesis study, the supplier evaluation and order allocation system of one of Turkey's biggest white-goods manufacturers is analyzed through interviews with the Purchasing Department of the company. The existing system is discussed with the managers, the process and the data flows are analyzed. At the end of the analysis, a Decision Support System environment is constructed based on the existing performance evaluation criteria and the needs of the Purchasing Department for better supplier evaluation and order allocation decisions.

The study focuses on the supplier evaluation through the pair-wise comparison of a selected set of criteria, sub-criteria and alternatives respectively and then allocating the yearly demand to the alternative suppliers in the form of annual quotas. The Decision Support System proposed in this model enables the decision maker to evaluate the suppliers on a common basis and diversify the annual order quota based on concrete targets and constraints.

The supplier evaluation model and the order allocation model are integrated with an easy to use graphical user interface (GUI) to provide a Decision Support System environment for the Purchasing Department manager. Furthermore, sensitivity analysis is possible with the graphs to see the results of the different order allocation scenarios for better decision making.

The organization of the thesis is as follows: In Chapter 2, background information on the Analytical Hierarchy Process and Goal Programming are given. In Chapter 3, a review of the related recent literature is provided with the detailed explanation of the four papers that inspired this thesis study. In Chapter 4, the existing supplier evaluation and order allocation system of the company is described. The development of the supplier evaluation and order allocation models is explained in detail. Chapter 5 consists of the illustration of the Decision Support System environment with a numeric application provided by the company. Finally in Chapter 6, the conclusions drawn from this study and the possible future work are emphasized.

CHAPTER 2

BACKGROUND

Analytic Hierarchy Process

Introduction

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making methodology developed by Thomas Saaty in 1986 while directing research projects in US Arms Control and Disarmament Agency. It was created after finding the reality that there existed no simple, easy to implement method to make complex decisions. Since its development, AHP has been used widely in many decision problems not only in the Defense domain but in business, government, social studies, R&D, etc. for its simplicity and power (Bhushan & Rai, 2004).

AHP enables the decision makers to design the decision making process in a hierarchical structure, demonstrating the relationship between the goal, criteria and the alternatives. AHP consists of few elements like hierarchical structure of the complex problem, pair-wise comparisons of the sub-criteria, criteria and alternatives, expert evaluations, weighing the pairs and checking the consistency of the evaluations (Adamcsek, 2008).

Incorporating the decision makers' objective and subjective thoughts to the decision making process and putting both the tangible and intangible factors for criteria and sub-criteria are the two prominent features of AHP. Its fundamental scale of absolute numbers for weighing the pairs have been proven and validated by experts to capture the individual judgments with all the facets of factors. Therefore, the results of the hundreds of applications are justified by the decision makers (Forman & Gass, 2001).

Theoretical Foundation

The theoretical foundation of AHP is based on four axioms (Adamcsek, 2008):

1. Reciprocal Axiom: The method is two sided; meaning if A has an importance level of 5 compared to B, then B has an importance level of 1/5 compared to A.

$$a_{ij} = 1 / a_{ji} \tag{1}$$

2. Homogeneous Axiom: This axiom assumes that the criteria compared are not too divergent from each other: A criterion cannot be infinitely better than the other.

$$aij \neq \infty \tag{2}$$

3. Synthesis Axiom: Stating this axiom, it is accepted that evaluation or priorities of sub-criteria in one hierarchy of the AHP is independent from lower levels of the

hierarchy. This axiom ensures the formulation of the hierarchic structure.

4. Expectation Axiom: This is an axiom introduced later on by Saaty which means that the output priorities of the AHP model should not be radically divergent from the former knowledge that the decision maker has.

The first axiom points out that there exists pair-wise comparison in between the elements, whereas the homogeneous and synthesis axioms state the problem will be formulated as a hierarchy. The last axiom expresses the need of rational judgment where the decision maker puts in all the knowledge for pair-wise comparison.

The Analytic Process

The analytic process of AHP is constructed with the following steps (Albayrak, 2004):

1. Problem Definition: In this step, the decision problem is defined and it is decided whether the problem is suitable to be solved by AHP or not. It should be verified that the elements incorporated at the AHP model can be compared quantitatively.
2. System Observation: AHP decomposes a complex multi-criteria decision problem into a hierarchy of goal, criteria, sub-criteria and alternatives. In order to define criteria and sub-criteria and to form the hierarchy, each and every element of the system and the relationship in between them should be well known.
3. Decomposition of the Decision Problem: The decision problem is separated into a hierarchy of goal, criteria, sub-criteria and alternatives. This step is the most significant and productive part of the methodology in which the decision makers

structure the decision problem according to their priorities. Any mistake or understatement at this stage might cause incorrect formulation and will not reflect the real decision problem. Hierarchy signifies the tree like design at the top of which lays the goal. Under the goal, the main criteria for decisions are positioned and under each criterion its sub-criteria are placed. At the bottom, the alternatives are placed.

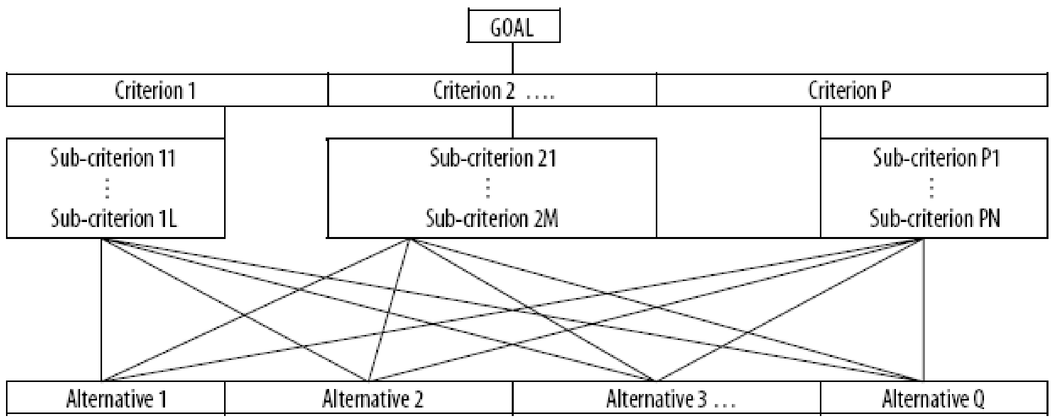

Figure 1. Generic hierarchic structure (Bhushan & Rai, 2004).

4. Priority Assessment: Subsequent to the decomposition of the decision problem, the comparative priorities of the elements at the same level are set. At this point Saaty's fundamental scale of absolute numbers is used to make pair-wise comparison.

Table 1. Fundamental Scale for Comparison of Alternatives (Bhushan & Rai, 2004).

Option	*Numerical value(s)*
Equal	1
Marginally strong	3
Strong	5
Very strong	7
Extremely strong	9
Intermediate values to reflect fuzzy inputs	2, 4, 6, 8
Reflecting dominance of second alternative compared with the first	Reciprocals

When the pair-wise comparison is reliably made, then, either with a software program such as Expert Choice or using mathematical calculation the relative weights of elements are computed.

5. Synthesis: At the bottom of the AHP structure lays the alternatives for the decision problem. Similar to priority assessment of sub-criteria, the weights are scaled up to the criteria and the comparison of the alternatives for each criterion is made to calculate the final ratings of the alternatives.
6. Evaluation and the Result: At the end of the synthesis an indicator called The consistency index is calculated to make sure that the overall comparison is persistent. It is used to measure how consistent the judgments have been relative to large samples of purely random judgments. In other words, if criteria A is preferred to criteria B and criteria B is preferred to criteria C, then in a consistent behavior, criteria A is preferred to criteria C. Inconsistent behavior is an indicator that the decisions are not given on a logical basis, or in other terms, evaluation is random.

   In literature, the consistency index is accepted to be 10% the maximum. If the indicator is less than 10% the calculation is consistent. If not then firstly the pair-wise comparisons should be checked, and as a last solution the AHP hierarchy should be restructured.

<u>Synthesis of Priority Assessment</u> (Saaty, 1985)

First the matrix of weight ratios is checked for its consistency. This matrix can be defined as $W = [w_{ij}]_{qxq}$:

$$\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \cdots & \frac{w_1}{w_q} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \cdots & \frac{w_2}{w_q} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \frac{w_q}{w_1} & \frac{w_q}{w_2} & \frac{w_q}{w_3} & \cdots & \frac{w_q}{w_q} \end{pmatrix}$$

Figure 2. Matrix of weight ratios (Adamscek, 2008)

A matrix W is consistent if its components satisfy these equalities $w_{ij} = w_{ji}^{-1}$, $w_{ij} = w_{ik}w_{kj}$ for any i, j and k.

Then using Saaty's assumptions the eigenvector solution is applied to convert the matrix of weight ratio into ranking of the alternatives. The sum of the rows are calculated and normalized, and as a result, a vector of $N = [n]_{qx1}$ is computed. The original matrix W is raised to its powers until the difference between the two consecutive normalized matrixes is smaller than a preset value. The resulting vector defines the results of the evaluation. The calculation of the ratings is moved up in the hierarchy from the sub-criteria to the criteria and from the criteria to the alternatives.

In the last step the consistency index is calculated to check the findings. If this indicator is less than 10% the calculation is consistent, if not then firstly the pair-wise comparisons should be checked and as a last solution AHP hierarchy should be restructured.

Pitfalls and Contributions of AHP

As a widely used tool for decision making AHP has been discussed in literature as consisting of the following pitfalls and contributions (Kuruüzüm & Atsan, 2001):

Pitfalls

- The rank of reversal is a problem in AHP methodology. If a new element is added or subtracted from the model, then the synthesis step should be revised and ratings of the alternatives are updated.
- AHP is an evaluation tool in which the decision makers reflect subjective thoughts as quantitative comparisons. As a result of this subjective attribute, the results of the methodology can never be stated as "totally valid".
- As the number of levels or the elements in each hierarchy increase, the number of pair-wise comparison increases drastically. For that reason, it will take more time to construct and evaluate the model compared to less structured decision making methods.

Contributions

- AHP methodology is an easy decision making tool which enables the decision maker to decide on the best alternatives for a target.
- It has a structure/process which eases complex problems.
- AHP leverages the decision makers' understanding of the problem decision and its elements.
- It includes the decision makers' objective and subjective thoughts in the decision making process and puts both the tangible and intangible factors into the model.

- The sensitivity analysis can be conducted to validate the final results.
- AHP is a decision making tool which can also be used in group decision making.

Applications of AHP

Since its development in 1986, AHP has been applied to many decision-making problems (Forman & Gass, 2001):

- Choice – selecting one or more alternatives from a set of possibilities
- Evaluation – ranking the set of alternatives
- Resource Allocation – preferring the best alternatives with respect to the constraints of the problem
- Benchmarking – comparing processes or systems with other processes or systems
- Quality Management

Choice: Xerox is using AHP for R&D decisions on portfolio management, technology implementation and engineering design selection. British Columbia Ferry Corporation in Canada employs AHP to select products, suppliers and consultants. Management Reorganization at Edgewood applied AHP to select the new management structure for its directorate. NASA worked on this methodology to evaluate alternatives as a power source for the first lunar outpost.

Evaluation: The University of Santiago of Chile applied AHP to help develop research proposals in 1993. The Royal Institute of Technology in Stockholm chose to use AHP to screen working fluids for heat engines. Rockwell International utilized the method in its Computer Aided Systems Engineering Tool Set to provide a common product development framework. General Motors' car designers made use of AHP to evaluate design alternatives and perform risk management. U.S. Navy Submarines Executive Office uses AHP to derive the critical elements in selecting the equipment for the submarines.

Resource Allocation: Woods Hole Fisheries applied AHP to evaluate and prioritize the existing elements of the research program. Scarborough Public Utilities increased the value of their company and attracted more customers through AHP. Air Force Medical Services reallocated their resources for better service with this methodology. The Korea Telecommunication Authority used AHP to prioritize, forecast and allocate resources. The Savannah River multi-site remediation portfolio was managed by AHP.

Benchmarking: IMB Rochester Minnesota's computer integrated manufacturing process team used AHP for benchmarking their production priorities to optimize their processes. Square D Company benchmarked their internal processes with other companies with this selection method. Carlson Travel Network identified and prioritized 44 critical requirements for a more successful business center with AHP.

Quality Management: The Stainless and Magnetic Steel Division of the ILVA firm used AHP to evaluate customers on the performance of its divisions; customers were asked to compare ILVA's service and product quality with the rivals. Latrobe Steel Company applied AHP in its continuous quality improvement program.

As seen from the examples above, AHP applications have spread to the domains of healthcare, defense, project management, forecasting, marketing, new product development, price assignment, policy evaluation, social sciences, etc. Since its foundation it has been applied to many decision problems and evolved into a commonly used tool by decision makers.

Goal Programming

The very basic form of optimization algorithms consist of only one objective, in most cases: maximizing the profit, maximizing the amount of products sold or minimizing the cost. In real life however, the situation is quite different where several goals exits and the decision maker has to sacrifice extreme profits or minimized cost but reach the targeted values. A manufacturer does not only aim to maximize the profit, but also tries to maximize the market share, likes to keep the investments within the capital-spending budget, aims to have a minimum cash reserve and a steady workforce growth. As a result, the concepts of linear programming are expanded to meet the multi-objective conditions for optimum levels and this approach is called goal programming. The goal programming method is preferred due to the fact that it holds flexibility in accommodating multiple goals while allowing a trade-off in between the targets. This is established by letting some of the goals be partially met and the goal programming model consists of the following elements:

1. Decision Variables: The variables for which the optimum solution is to be found.

2. Parameters: The elements which will be submitted as input values for coefficients, constants and goal deviations (Y_j^+ , Y_j^-).
3. Goal Targets: The multi-objective targets in the model.
4. Regular Constraints: The constraints required for the model other than the goal constraints.
5. Goal Deviation Constraints: The constraints which state the goals as equalities and include the goal deviations from the goal targets as the negative and positive deviation quantities.
6. Omnibus Objective Function: Omnibus target function which includes the goal deviations and their coefficients as the cost of unit deviation on either negative or positive terms. In GP, the objective is to minimize omnibus target function.

A general form of goal programming model can be given as:

Minimize: $Z = \sum_{i=1}^{m} w_i^+ d_i^+ + w_i^- d_i^-$

subject to: $\sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = b_i$, for $i = 1,...,m$

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \text{, for } i = m+1, m+2,..., m+k$$

$$d_i^+,\ d_i^- \text{, for } i = 1,...,m$$

$$x_j \geq 0 \text{, for } j = 1,...,n \qquad (3)$$

Where d_i^+ is named the positive deviation variable and d_i^- is called the negative deviation variable from the goal target levels. w_i^+ and w_i^- are nonnegative coefficients which represent the relative weights assigned to the positive and negative deviation variables. There exist $m+k$ constraints in which m are goal deviation constraints and k are regular constraints. The objective is to minimize the cost of deviations from the goal target levels.

CHAPTER 3

LITERATURE SURVEY

In this thesis study, a comprehensive set of integrated supplier evaluation and order allocation models are reviewed. Initially four papers that basically inspired this thesis study are introduced and discussed in more detail. These papers belong to Ghodsypour & O'Brien (1998), Çebi & Bayraktar (2003) and Wang et al. (2004 and 2005). In the following part of the literature survey, a comparative study is conducted for the other relevant literature.

Ghodsypour and O'Brien's (1998) study consists of an integrated AHP-Linear Programming (LP) model to consider both the tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them. The integrated model is a single objective and single supply item model, where the customer supplies only one type of product from all of the possible suppliers. It is aimed to maximize the total value of purchasing which is defined as supplying most of the supply item from the most preferred suppliers. In this paper, the AHP model is constructed with the following main criteria: Cost, Quality (defects and process capability) and Service (on time delivery, response to changes and process flexibility). As a result of this evaluation the supplier ratings are calculated.

Then the LP model is structured with the objective of maximizing the total value of purchasing where the aim is to allocate maximum quantities to the most preferred suppliers. The ratings calculated the previous stage are used in the objective function as coefficients. Constraints of the linear programming model are related to the supplier's production capacity, total demand of the buyer, aggregate capacity of all the suppliers and the quality requirement for production. It is a simple model. However, the effect of the defective supply items on the total demand is neglected.

The second study belongs to Çebi & Bayraktar, conducted in 2003 for a company producing dry mixed food and drink products in Istanbul. The model is based on AHP and Lexicographic Goal Programming (LGP) integrated to solve the supplier selection and order allocation problem. The problem is a multi-supplier and multi-supply item problem in which orders for 8 supply items are given to 13 suppliers in total and one supplier can deliver more than one type of material. The AHP model is developed with the aid of the previous work on this issue and the main criteria are defined as Logistical issues (lead time, supply lots, flexibility and delivery conditions), Technological issues (capacity, involvement, improvement efforts and problem solving), Business issues (reputation, financial strength and management) and issues related to Relationship (communication, past experience and sales competence). Cost, quality and delivery issues which come up in almost all of the AHP models are excluded in this work in order to avoid redundancy. These criteria are evaluated at the objective functions in the LGP model.

The LGP model is constructed with four objectives which are maximizing the non-defective items, minimizing the quantity of supplies delivered late, minimizing the cost of the supplies and maximizing the supplier ratings. Supplier ratings calculated with the AHP model are the inputs of the utility objective function. Constraints of the LGP are the buyer's demand, minimum and maximum order quantities negotiated with the suppliers, minimum number of suppliers to work with and a constraint for order allocation between long & short term suppliers.

Wang. et al. have several studies in supplier selection. The model developed in Wang et al. (2004) has combined AHP and Preemptive Goal Programming (PGP) to solve the supplier selection and order allocation problem. The AHP process matches product characteristics with supplier characteristics to qualitatively determine supply chain strategy. PGP mathematically determines the optimal order quantity from the selected suppliers. The supplier evaluation criteria are Delivery Reliability (delivery performance, fill rate, order fulfillment lead time and perfect order fulfillment), Flexibility and Responsiveness (supply chain response time and production flexibility), and Cost (total logistics management cost, value-added productivity, warranty cost or returns processing cost). The AHP ratings of the supplies are given according to the type of supply chain the supply item belongs to; lean, agile or leagile (lean and agile).

The PGP model has two goals, the first one is to maximize the total value of purchasing and the second goal is to minimize the total cost. The ratings from the AHP model are used in the first objective function. There exist supplier capacity constraints and demand constraints for the manufacturer. The PGP does not include the delivery performance of the supplier, perfect order fulfillment rate or minimum and maximum order quantities. The model is quite simple and has few constraints to take into account.

In 2005, Wang et al. have improved the previous study further to calculate the overall supply chain effectiveness. After computing the order quantities via integrated AHP-PGP model, each supply item's effectiveness is calculated. Then by using the relative importance of each item in every product, the effectiveness of the product is determined. According to the weight of importance of each product manufactured, the supplier's effectiveness is calculated. Lastly, assuming that the distribution channel's effectiveness is known the overall effectiveness of the supply chain is estimated.

Although the calculation of the distribution channel is not explained in detail and the fact that this calculation should differ vastly from the calculation of the supplier effectiveness, this study has a unique contribution to the supplier evaluation and order allocation problem. It defines the notion of supply chain effectiveness with a single numerical value which can be used to compare different supply chain scenarios and gives insight on how to improve the supply chain performance.

Apart from these inspiring studies, more than 100 studies which use AHP methodology, mathematical models and/or other models to solve the supplier evaluation and order allocation problem were scanned. Out of the total 150, eighty-one are worth pointing out in this context. These studies are categorized into two: Related Studies where Analytical Hierarcy Process and/or Mathematical Programming Models are used (Table 1) and Other Studies on Supplier Evaluation and Order Allocation (Table 2). These related studies are listed according to the model they compromise and the problem covered.

Table 2. Related Studies where Analytical Hierarcy Process and/or Mathematical Programming Models are used

Author	Supplier Evaluation	Order Allocation
Kokangul & Susuz (2008)	Analytic Hierarchy Process	Multi Objective Non Linear Integer Programming
Aguezzoul & Ladet (2007)		Mixed Non Linear Programming
Ha & Krishnan (2007)	Analytic Hierarchy Process, Data Envelopment Analysis and Neural Network Integrated Model	
Özgen et al. (2007)	Analytic Hierarchy Process	Multi Objective Probabilistic Linear Programming
Pehlivan (2007)	Analytic Hierarchy Process	Weighted Goal Programming
Sevkli et al. (2007)	Analytic Hierarchy Process	Weighted Fuzzy Linear Programming
Bei et al. (2006)	Analytic Hierarchy Process	
Choi & Chang (2006)		Single Objective Preemptive Programming
Liao & Rittscher (2006)		Non Linear Mixed Integer Programming
Perçin (2006)	Analytic Hierarchy Process	Preemptive Goal Programming
Bayazit & Karpak (2005)	Analytic Hierarchy Process	
Liu & Wu (2005)	Analytic Hierarchy Process and Data Envelopment Analysis	
Yang & Chen (2005)	Analytic Hierarchy Process	
Çerçioğlu et al. (2004)	Dempster-Shefer Analytic Hierarchy Process	
Cakravastia & Takahashi (2004)		Multi Objective Non Linear Programming
Wang et al. (2004 & 2005)	Analytic Hierarchy Process	Preemptive Goal Programming
Benyoucef et al. (2003)	Analytic Hierarchy Process	Linear Integer Programming
Çebi & Bayraktar (2003)	Analytic Hierarchy Process	Lexicographic Goal Programming
Dağdeviren & Eren (2001)	Analytic Hierarchy Process	0-1 Goal Programming
Ghodsypour & O'Brien (2001)		Non Linear Mixed Integer Programming
Lee et al. (2001)	Analytic Hierarchy Process	

Table 2. continued

Author	Supplier Evaluation	Order Allocation
Muralidharan et al. (2001)	Analytic Hierarchy Process	
Tam & Tummala (2001)	Analytic Hierarchy Process	
Degraeve & Roodhooft (1999)		Mixed Integer Linear Programming
Ghodsypour & O'Brien (1998)	Analytic Hierarchy Process	Linear Programming

It should be noted that these studies are very recent; the oldest one is from 1999, and all of the models developed within these studies strive to find the optimum solution for the supplier selection and order allocation problem. Ha & Krishnan (2007), Bei et al. (2006), Bayazit & Karpak (2005), Liu & Wu (2005), Çerçioğlu et al. (2004), Lee et al. (2001), Muralidharan et al. (2001) and Tam & Tummala (2001) utilize the Analytic Hierarchy Process model only to evaluate the supplier base and then propose to allocate the entire order quota to the most preferred supplier. On the other hand, Kokangul & Susuz (2008), Özgen et al. (2007), Pehlivan (2007), Perçin (2006), Yang & Chen (2005), Benyoucef et al. (2003) and Dağdeviren & Eren (2001) employ integrated models where AHP is the first stage to evaluate the suppliers according to the company policies and criteria. Later on, the company & supplier constraints and the AHP ratings are considered, the mathematical programming models are solved. The remaining six studies besides the four inspiring papers again consist of single models and mathematical programming methods are used straight away to diversify the order quota.

The other studies mentioned in Table 3 vary in their methodology and the purpose of fulfillment. Some of them compare the performance of two or more models. Some of them use an extended form of AHP, the Fuzzy AHP. However, finding the optimum solution for the supplier evaluation and order allocation problem is the common attribute in all of these studies.

Table 3. Other Studies on Supplier Evaluation and Order Allocation

Author	Supplier Evaluation	Order Allocation	Literature Review/ Comparison
Demirtaş & Üstün (2008)	Analytic Network Process	Multi Objective Mixed Integer Linear Programming	
Ho (2008)			Integrated Analytic Hierarchy Process and Its Applications
Ng (2008)	Weighted Linear Program		
Aissaoui et al. (2007)			Supplier Selection and Order Lot Sizing
Araz & Ozkarahan (2007)	PROMSORT		
Araz et al. (2007)	PROMETHEE		
Bayrak et al. (2007)	Fuzzy Set Theory		
Burke et al. (2007)			Single vs. Multiple Supplier Strategies
Chan & Kumar (2007)	Fuzzy Analytic Hierarchy Process		
Demirtaş & Üstün (2007)	Analytic Network Process	Goal Programming	
Gencer & Gürpınar (2007)	Analytic Network Process		
Ha & Krishnan (2007)	Analytic Hierarchy Process, Data Envelopment Analysis and Neural Network Integrated Model		
Liao & Rittscher (2007)	Mutli Objective Model with Genetic Algorithm		
Liu (2007)	ELECTRE II		
Ma & Guo (2007)	Linear Optimization Hierarchy Process		
Pang (2007)	Fuzzy Analytic Hierarchy Process		
Sevkli et al. (2007)	Data Envelopment Analytic Hierarchy Process		
Sucky (2007)	Stochastic Dynamic Model Based on Hierarchical Planning Approach		
Tan et al. (2007)	Analytic Network Process		
Akman & Alkan (2006)	Fuzzy Analytic Hierarchy Process		

Table 3. continued.

Author	Supplier Evaluation	Order Allocation	Literature Review/ Comparison
Bayazit (2006)	Analytic Network Process		
Chen & Lee (2006)	Analytic Network Process		
Dağdeviren et al. (2006)	Analytic Network Process		
Ertugrul & Karakasoglu (2006)	Fuzzy Analytic Hierarchy Process		
Faez et al. (2006)	Fuzzy Case Based Reasoning	Mixed Integer Programming	
Onal (2006)	Fuzzy Analytic Hierarchy Process		
Shyur & Shih (2006)	Analytic Network Process and TOPSIS		
Sonmez (2006)			A Review and Critique of Supplier Selection Process & Practices
Vaidya & Kumar (2006)			Analytic Hierarchy Process: Overview of Applications
Basnet & Leung (2005)			Comparing Enumerative Search Algorithm and Heuristic Algorithm
Dağdeviren et al. (2005)	Analytic Network Process		
Genevois et al. (2005)	Fuzzy Analytic Hierarchy Process		
Güner et al. (2005)	Fuzzy Analytic Hierarchy Process and Fuzzy Information Axiom		
Hwang et al. (2005)			Analytic Hierarchy Process vs. Fuzzy Set Ranking
Liu & Hai (2005)	Voting Analytic Hierarchy Process		
Ozfirat et al. (2005)	PROMETHEE	Fuzzy GP	
Sun et al. (2005)	Support Vendor Machine		
Uyanık (2005)			TOPSIS vs. Analytic Hierarchy Process
Kumar et al. (2004)		Fuzzy Goal Programming	
Sato (2004)			Multiple Choice vs Analytic Hierarchy Process
Akhavi & Hayes (2003)			Analytic Hierarchy Process vs. Multi Rank Ordering
Chan (2003)	Interactive Selection Model		

Table 3. continued.

Author	Supplier Evaluation	Order Allocation	Literature Review/ Comparison
Dulmin & Mininno (2003)	Multi Criteria Decision Aid Method		
Erol & Ferrel (2003)	Multi Objective Model with Fuzzy Quality Function		
Choy et al. (2002)	Case Based Reasoning and Neural Network		
Sarkis & Talluri (2002)	Analytic Network Process		
Boer et al. (2001)			Review of Methods Supporting Supplier Selection
Bhutta & Huq (2001)			Total Cost of Ownership vs. Analytic Hierarchy Process
Kuruüzüm & Atsan (2001)			Analytic Hierarchy Process and Its Applications on Management
Kwong et al. (2001)	Scoring Method and Fuzzy Expert System		
Degraeve et al. (2000)			Total Cost of Ownership Review
Lee (2000)	Activity Based Costing and Total Cost of Ownership	Mixed Integer Programming	
Bhutta			Supplier Selection Problem: Methodology
Li et al.	Grey Based Rough Set Approach		

CHAPTER 4

DEVELOPMENT OF THE DECISION SUPPORT SYSTEM

Existing Supplier Evaluation & Order Allocation System

Company Profile

The company under study is one of the lead players in the Turkish white goods sector, with several facilities in and outside Turkey. Its successful performance in 2007 is also reflected in the financial results. The company gives high importance to research and development and adds new products to its portfolio each year. Strategic partnerships and acquisitions are very valuable for global targets especially in Europe. As the market shrank in 2007, the company has invested on new brands and business areas.

Purchasing Department and Production Planning Department Relations

Purchasing processes are carried out by the Purchasing Directorate that reports directly to the general manager as shown in Figure 3 and these processes are organized centrally at the headquarters for all of the brands. Considering the numerous production facilities and the brands that the company owns, there are approximately 14,000 manufactured goods where 7,000 are active. For each and every good, Marketing Department forecasts the next year's monthly sales figures during the annual budget planning. When the final budget is approved by the management, the monthly production targets are sent to the Production Department of each facility and they structure the related production plans. At the Production Department, the Materials Resource Planning (MRP) software is run and the required supply item quantities are calculated by using the product tree defined in Enterprise Resource Planning (ERP) software. At this stage, the Production Department proposes the supplier candidates with which the Purchasing Department will negotiate. From that point on, the Purchasing Department is responsible for evaluating the supplier candidates.

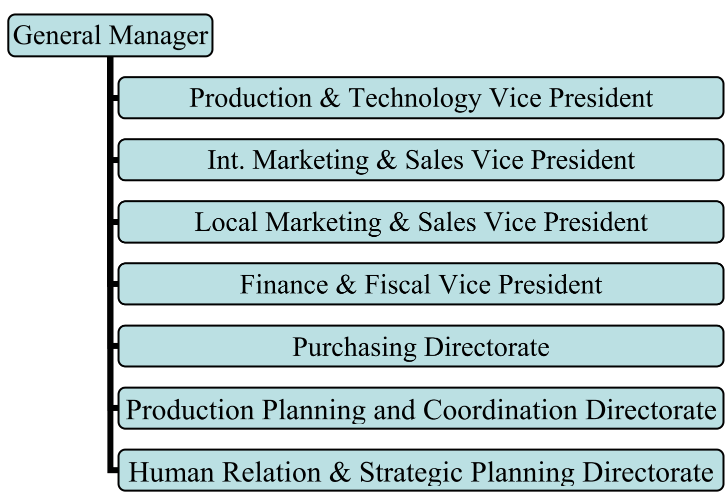

Figure 3. Organization structure

Supplier Evaluation

There exists a web based supplier portal used for the registration of the supplier candidates and the evaluation of the suppliers. Supplier evaluation consists of several stages. First of all, the supplier is evaluated according to the Quality Management Systems and Environmental Systems it holds and the Code of Conduct applied at its production site which should be in accordance with the agreement the company has signed with the European Committee of Domestic Equipment Manufacturers. If the supplier is rated to have the required standards, then the supply item prototypes are submitted to the Quality Subdivision of the Production & Technology Department. Quality Subdivision evaluates the prototypes and reports back to the Purchasing Department. In accordance with the result of the reports, the Purchasing Department chooses to work or not to work with the supplier.

The Purchasing Department defines all of the suppliers that have worked with the company for the last 2 years as “active suppliers”. The Purchasing Department meets with the active suppliers that are currently working with the company at least three times a year and these suppliers go through performance evaluation every six months. During these assessments, the representatives of the company’s Production Department conduct a detailed evaluation at the supplier site and rate the supplier according to its performance in the past six months. If the supplier’s rating is above the required value, it passes the evaluation, if not the supplier is asked to take measures in order to improve its performance. In case of ongoing low performance, the company terminates working with the supplier.

Order Allocation

After the supplier evaluation stage, if the supplier pool is adequate enough to assign annual order quotas, there comes the order allocation stage. At this phase, the market conditions, the policies of the Purchasing Department and the company policies affect the allocation of the annual order quota.

As a purchasing policy, the Purchasing Department chooses to work with at most 3-4 suppliers for each supply item. This strategy is used mostly when the aim is to develop a long term relationship with the suppliers. In some cases, single sourcing is preferred, especially when the weekly lot sizes are small for a supply item. On the other hand, for supply items with large weekly lot sizes, the company chooses to work with more suppliers and allocates an annual quota to every supplier. If the supply item is a commodity which can be obtained from several sources with the same specifications, the company uses the aggressive competition among the suppliers to decrease the unit purchase price. This policy favors one supplier over the other and the responsibility of meeting the buyer's demand is upon the suppliers' shoulders.

Finally, if there is a new supplier, the Purchasing Department chooses to allocate a small fraction of the overall supply item quota to this new supplier to test its performance.

Pricing

Some strategic supplies that are used in the most valuable parts of white-goods are purchased from the most reliable suppliers, although it may not be the most cost effective choice. On the other hand, for the supplies like sheet iron, the price is set by an authority or a market organization outside Turkey and price negotiation is not possible for these supply items.

If there exist many suppliers in the market and the volume of the annual quota for a supply item is high, then the orders are diversified by e-bidding. Assuming that the whole quota might be allocated to only one supplier, all of the suppliers are asked to state their unit prices with respect to the monthly production plan distributed by the company. According to the quantitative and qualitative judgments on the supplier offers, a new quota allocation is prepared and the suppliers are asked to review their prices. These prices and quota allocations go on until both sides agree upon a plan.

When the negotiations are over, a formal agreement is made between the parties that basically includes the annual allocated quota and the rules on maximum delivery duration, minimum and maximum delivery lot sizes, etc.

Supplier Relations

The main responsibility of the Purchasing Department ends when the formal agreement is signed with the supplier. Then the Production Department at each facility can give orders from the ERP system directly to the supplier in accordance to the agreement determined by the Purchasing Department. It should be noted that this process flow is quite extraordinary since in most of the manufacturing companies, it is the purchasing department which gives the orders.

Occasionally, the Sales Department reviews the budgeted sales figures, say every two weeks, and makes the necessary changes in the ERP system. The Production Department reviews the production plans according to these updates in demand rate.

There exists a close relationship between the company and the suppliers. The company is concerned about the relationship with the suppliers. They share their problems and concerns with the company by means of a supplier portal where they can e-mail and share supply/order information. Furthermore, meetings are arranged once or twice every year.

Development of the Supplier Evaluation Model

When the literature is examined, the main criteria considered in supplier evaluation are found to be cost, quality, technology, delivery and business issues (Dağdeviren & Eren, 2001, Wang et al., 2004, Çebi & Bayraktar, 2003). Concerns related to cost are the unit price per supply item, the logistics cost – if it is handled by the buyer – warranty costs or returns processing costs, operating costs and terms of payment. Quality issues include rate of perfect supplies, after sales service quality, application of quality standards. Technology related evaluation criteria are production capacity, potential for collaboration and involvement in new product development and problem solving. Delivery related issues are the size of the supply lot, flexibility of lot sizes, delivery conditions and geographic distance. Finally, business concerns include the corporate structure, reputation and financial structure of the supplier.

The supplier evaluation criteria that appear above are discussed with the company and the resulting issues are designed as an AHP model as can be followed in

Figure 4. Accordingly, supplier evaluation is mainly based on issues on cost, quality, logistics and technology. Business policy is an important criterion. However, it was stated that if a firm is categorized as a potential supplier then it should not have any problems regarding these issues. Similarly, technological issues are not considered an evaluation criteria for a supplier, since a supplier with insufficient technology is not allowed to be an active supplier for the company. In other words business issues and technological issues are in the form of constraints rather than evaluation criteria for supplier selection. The current business and technological state of the supplier are the main concerns in defining a supplier as a “candidate supplier”. They are used to eliminate the suppliers which do not have any potential to work with in the future. Thus the eliminated suppliers are not subject to evaluation by AHP.

The evaluation of the main criteria and the sub-criteria is done by using the Saaty’s fundamental pair-wise comparisons. Equally important pairs receive 1 point and an item which is absolutely more important then the other in the comparison gets 9 points. The scaling details can be followed in Table 1. Definition of the criteria and sub-criteria in the supplier evaluation model and how they will be evaluated are explained below in detail:

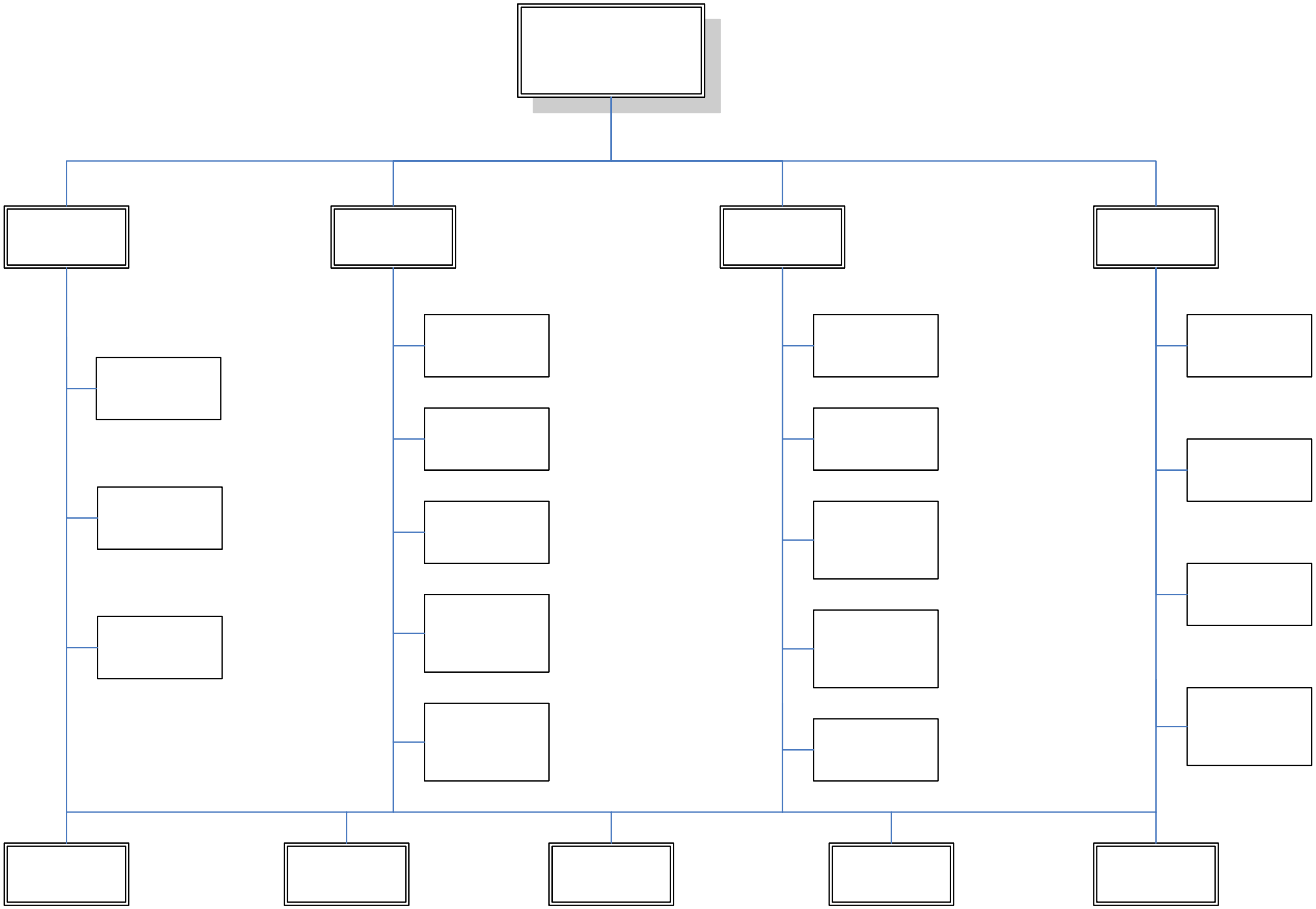

Figure 4. AHP model for supplier evaluation

Cost

- Cost criterion is one of the most important issues of supplier evaluation and order allocation problem. The evaluation of the potential suppliers on this issue will be conducted by the Purchasing Department.
  - Unit Purchase Price: It is defined as the price of a single item that the supplier charges to the company. It includes the transportation cost and is measured in YTL/unit. Pair-wise comparisons should be made between suppliers with respect to the unit purchase price and a grade between 1 and 9 should be given to the preferred supplier.
  - Terms of Payment: In general suppliers are asked to have similar conditions regarding this issue. However, slight differentiations might occur according to the financial status of the supplier. A supplier that does not ask for payment before a deadline or does not have any monetary problems with its sub-contractors gets 9 points.
  - Cost Reduction Projects: Although cost reduction projects are merely submitted by the suppliers, it is a good indicator to gain cost advantage and can be added to the model. Suppliers are evaluated in pairs for their contribution to cost reduction projects. A supplier that comes up with cost reduction projects frequently compared to a supplier that does not generate such projects will get 9 points.
- Quality and its sub-criteria will be evaluated by the Production Department at each facility and the Quality Department.

- Perfect Order Fulfillment: It is defined as the percentage of non-defective items delivered to the company. The company counts the quantity of imperfect supply items during the sampling process of a received lot and the production and parts per million (PPM) level is obtained. The suppliers are evaluated in accordance to their ppm level and a supplier with a very low ppm level compared to another supplier with a high ppm level gets 9 points.
- After Sales Service: Production facilities assess the suppliers according to their after sales service level. A supplier that is not available for help and service after the sale is done will get 1/9 points compared to a supplier that is always ready to solve the issues raised after purchase.
- Application of Quality Standards: Application of quality standards also includes the environmental concerns and the suppliers will be evaluated on the ISO related standards. During the evaluation existence of a quality department, documentation of quality systems and management commitment on quality issues are important aspects. Suppliers will be assessed in pairs for the aspects stated above and the supplier that accomplishes those satisfactorily compared to a supplier that is poor on these issues will receive 9 points.
- Corrective and Preventive Maintenance System: It will be measured according to how many incidences are received due to the supply item delivered by the supplier and how many of these incidences are solved in time. Suppliers will be compared regarding how many incidences they have

caused and how many of them are solved. A supplier with very few or no incidences compared to a supplier that causes problems in the production very frequently will receive 9 points.

  - Improvement Efforts in Technology and Quality: This criterion reviews the supplier's continuous efforts on improving its technology and quality standards. As the production goes on, new technical and qualitative requirements are requested by the company and the supplier is asked to meet these requirements. A supplier that does not meet these requirements gets 1/9 points compared to a supplier that meets these improvements continuously.

- Logistics is a main criterion in supplier evaluation and it will be evaluated by the Production Planning Department.
  - On Time Delivery: On time delivery is a very important sub-criterion under the logistics issue. Suppliers are compared with each other on their on time delivery levels and the supplier with frequent late deliveries compared to a supplier which is always on time gets 1/9 point.
  - Order Lead Time: It is a significant issue, especially in high demand terms. Order lead time is defined as the time elapsed between the order and the delivery of the supply item to the production facility. Suppliers will be evaluated according to their order lead times and a supplier with a very short order lead time will receive 9 points compared to a supplier having a longer order lead time.

- Delivery Conditions and Packaging Standards: Suppliers are also responsible for the delivery conditions and packaging standards of the supply items. If a supplier causes problems in the delivery conditions and packaging standards very frequently compared to another supplier that is careful and obedient to these issues, it will get 1/9 point.
- Flexibility of Transport: Ability to transport flexible order quantities is defined as the second most important sub-criterion under the logistics issue. The supplier is stated as flexible in order quantities if it can adapt to sudden changes in lot sizes. The supplier who is flexible to transport order quantities according to the demand compared to a supplier very strict on lot sizes will receive 9 points.
- Geographic Distance: Geographic distance brings monetary advantage and reduces loss of time in case of a change in the production plan. The suppliers are compared according to how far they are situated to the production facility and the supplier that is very distant compared to a supplier which has a warehouse close to the production facility obtains 1/9 point.

- The last main criterion which will be rated by the Production Department at each facility is the technological performance of the supplier.
  - Allocated Capacity: Allocated capacity is defined as the portion of the supplier's annual production capacity allocated for the company. If a supplier has allocated more to the company, it is expected that the supplier will be more reliable and cooperative compared to the supplier who has allocated less units of supply items and the first supplier gets 9 points.

- Flexibility of Capacity: It is described as the ability to increase the production level due to increases in the demand rate. If a supplier can respond to the increased demand conditions all the time as compared to a supplier that is not flexible in capacity, it gets 9 points.
- Flexibility of Technology: Flexibility of technology encapsulates the technological requirements for the production line and the support services. A supplier that can adapt their technologies to the changing needs of the manufacturer is said to have flexibility of technology. A supplier who is not flexible in technology is assigned 1/9 points compared to a supplier that is flexible in technology.
- Involvement in New Product Development: Suppliers are evaluated according to their involvement and potential in new product development which defines how dedicated a supplier is to becoming a real partner and facilitating/supporting the company for new product development projects. The supplier that is involved in new product development projects compared to a supplier that does not participate in such projects receives 9 points.

Development of the Order Allocation Model

The purpose of the order allocation model is to determine the annual order quotas for the selected suppliers after the evaluation process. Actually one might choose to work with the most preferred supplier after the evaluation process. However, there are other concerns that bring the necessity to work with more than a single supplier. These concerns are in the form of either goals or restrictive constraints. In literature the goals and the constraints considered in order allocation models are listed in Tables 4 and 5 respectively.

Table 4. Objectives in Order Allocation Models

Author	Maximize Utility	Minimize Cost	Maximize Profit	Minimize Lot Size Difference	Minimize Defective Supply Item	Minimize Late Deliveries	Maximize Past Business Index	Maximize Service Level
Kokanguk & Susuz (2008)	X							
Aguezzoul & Ladet (2007)		X						
Pehlivan (2007)		X			X		X	
Özgen et al. (2007)	X				X			
Choi & Chang (2006)		X						
Liao & Rittscher (2006)		X						
Perçin (2006)	X	X			X	X		X
Cakravastia & Takahashi (2004)			X	X				
Wang et al. (2004)	X	X						
Benyoucef et al. (2003)	X							
Çebi & Bayraktar (2003)	X	X			X	X		
Dağdeviren & Eren (2001)								
Ghodsypour & O'Brien (2001)		X						
Degraeve & Roodhooft (1999)		X						
Ghodsypour & O'Brien (1998)	X							

Table 5. Constraints in Order Allocation Models

Author	Production Capacity	Expected Lead Time	Demand Fulfillment	Min-Max Production Capacity	Tolerance of Non-Conformity Deliveries	Budget	Number of Suppliers to Work With	Limited Outside Procurement	Limited In-house Production	Order Priority	Perfect Order Fulfillment	% of Long Term Suppliers
Kokanguk & Susuz (2008)			X	X		X	X					
Aguezzoul & Ladet (2007)	X	X										
Özgen et al. (2007)		X	X									
Pehlivan (2007)	X		X			X	X					
Choi & Chang (2006)			X									
Liao & Rittscher (2006)			X									
Perçin (2006)				X		X	X					
Cakravastia & Takahashi (2004)						X		X	X			
Wang et al. (2004)			X	X								
Benyoucef et al. (2003)			X	X	X	X	X					
Çebi & Bayraktar (2003)			X	X			X					X
Dağdeviren & Eren (2001)	X					X				X		
Ghodsypour & O'Brien (2001)			X	X							X	
Degraeve & Roodhooft (1999)			X				X					
Ghodsypour & O'Brien (1998)			X								X	

The findings of the literature survey are discussed with the company and their prerequisites are assessed while constructing a goal programming model for the order allocation problem.

The first goal is to maximize the overall utility which is a function of the suppliers' grades obtained by the AHP evaluation. The overall utility is defined as the sum of the supplier grades weighted by the proportion of the allocated quantities to the suppliers. The aim is to allocate more quota to the preferred supplier.

The second goal is to minimize the total purchase cost and the operational costs of the order allocation. Operational costs are defined as the transaction costs of working with a specific supplier. Total transaction cost increases as the number of suppliers increase. This goal incorporates the decision maker's dilemma; working with few suppliers where the transaction costs are lower versus working with many suppliers to bring down the unit purchase price. However this policy increases the transaction costs.

The third goal is to maximize the overall delivery performance so that the total production time wasted due to the deficiencies in supplier deliveries is kept as short as possible. When there is a problem with supply availability, the production process has to be shut down until the supply is received. This unfavorable situation is known as blocking and the company keeps track of the blocking experiences with each supplier. The delivery performance of each supplier is evaluated and a supplier with less blocking experiences is assigned a higher delivery performance grade. The overall delivery performance is the weighted sum of the delivery performance grades where the weights are the proportions of the allocated quantities to the suppliers. It is aimed to maximize the overall delivery performance.

The fourth and the fifth goals are related to the quality performance of the suppliers. The company keeps track of the quality performance of each supplier by using two metrics: the PPM-level and the rework performance. The total rate of defective supply items detected upon arrival to the system or during the production is defined as the PPM-level, measured as number of parts per million and a high PPM-level disturbs the smooth flow of operations in production because the supplier is asked to replace it with a non-defective one. The overall defective material level to be minimized is defined as the sum of PPM-levels of the suppliers weighted by the proportion of allocated order quantities to each supplier.

The final goal is related to the rework load of the defective end items. If a defective supply item is not detected on arrival to the production facility or during the production process, it will probably be detected during the last quality controls. End items that have or are believed to have defective supply items are reworked. The rework process brings extra cost to the company and furthermore decreases the effective production time. The rework performance of each supplier is evaluated with respect to its past experiences, and a higher rework performance grade is given to a supplier with a better performance. It is aimed to maximize the overall rework performance which is the sum of rework performance grades of the suppliers weighted by the proportion of the allocated quantities to each supplier.

It is obvious that, it is not possible to attain all these goals simultaneously. Thus the company is asked to propose target levels for each of these goals during their application.

In addition to these goals, there are regular constraints that are related to the satisfaction of demand, number of suppliers to work with and the minimum quota to be allocated to a supplier. In order to achieve the production plans satisfactorily, the company has to purchase the required quantity of supply items and fulfill its demand. Furthermore, there exists a policy to work with a specific number of suppliers for each supply item and this policy should be accomplished. In most cases the company prefers to work with 2-3 suppliers to be more flexible against several risks. Finally, if the company chooses to work with a supplier then there is a minimum level for the quota that can be allocated to that supplier. On the contrary, no quota should be allocated to an unselected supplier.

The details of the order allocation model are given below:

1. Decision Variables

X_i : Annual order quota for supplier *i* *i=1,2,…,n*

$$Y_i = \begin{cases} 0, \text{ if supplier } i \text{ is not selected.} \\ 1, \text{ if supplier } i \text{ is selected.} \end{cases} \qquad i=1,2,\ldots,n$$

2. Parameters

U_i : AHP Rating of supplier *i* (obtained from AHP model), $U_i \in [0,1]$ *i=1,2,…,n*

C_i : Unit cost of supply item from supplier *i* [YTL/unit] *i=1,2,…,n*

T_i : Annual transaction cost for supplier *i* [YTL/supplier] *i=1,2,…,n*

D_i : Delivery performance grade for supplier *i*, $D_i \in [0,100]$ *i=1,2,…,n*

P_i : Annual defective rate (ppm) for supplier *i*, $P_i \in [0,1000000]$ *i=1,2,…,n*

R_i : Rework performance grade for supplier *i*, $R_i \in [0,100]$ *i=1,2,…,n*

A : Annual expected demand [unit]

S : Number of suppliers to work with [supplier]

3. Goals

i. Maximize Overall Supplier Utility:

$$\sum_{i=1}^{n} U_i \frac{X_i}{\sum_{i=1}^{n} X_i} * 100 \geq \textit{Utility Target},\ i = 1,2,\ldots,n \tag{4}$$

ii. Minimize Total Cost: $$\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} T_i Y_i \leq \textit{Budget Target},\ i = 1,2,\ldots,n \tag{5}$$

iii. Maximize Overall Delivery Performance:

$$\sum_{i=1}^{n} D_i \frac{X_i}{\sum_{i=1}^{n} X_i} \geq \textit{Delivery Performance Target},\ i = 1,2,\ldots,n \tag{6}$$

iv. Minimize Defective Material Level:

$$\sum_{i=1}^{n} P_i \frac{X_i}{\sum_{i=1}^{n} X_i} \leq \text{Average PPM Target},\ i = 1,2,...,n \tag{7}$$

v. Maximize Overall Rework Performance:

$$\sum_{i=1}^{n} R_i \frac{X_i}{\sum_{i=1}^{n} X_i} \geq \text{Rework Performance Target},\ i = 1,2,...,n \tag{8}$$

4. Regular Constraints

i. Demand Constraint: Annual demand should be satisfied.

$$\sum_{i=1}^{n} X_i \geq D\ ,\ i = 1,2,...,n \tag{9}$$

ii. Supplier Quantity Constraint: *S* suppliers should be selected from *n* suppliers.

$$\sum_{i=1}^{n} Y_i = S\ ,\ i = 1,2,...,n \tag{10}$$

iii. An order is allocated to a supplier if and only if it is selected.

$$X_i \leq MY_i\ ,\ \text{where } M \in \Re \text{ is very large and } i = 1,2,...,n \tag{11}$$

iv. Minimum Quota Constraint: If supplier *i* is selected the annual order quota allocated should be at least $Q_{\min}$.

$$X_i \geq Q_{\min} * Y_i\ ,\ i = 1,2,...,n \tag{12}$$

In accordance with the selected goals, goal constraints are generated by using the goal deviation variables Y_j^+ and Y_j^- for objective $j = 1,2,...,5$. A positive Y_j^+ shows that goal target is exceeded whereas a positive Y_j^- shows that goal target is not reached.

5. Goal Deviation Constraints

Utility Goal: $\sum_{i=1}^{n} U_i \frac{X_i}{\sum_{i=1}^{n} X_i} * 100\ (Y_u^+ - Y_u^-) = \textit{Utility Target},\ i = 1,2,...,n$ (13)

Budget Goal: $\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} T_i Y_i - (Y_b^+ - Y_b^-) = \textit{Budget Target},\ i = 1,2,...,n$ (14)

Delivery Performance Goal:

$\sum_{i=1}^{n} D_i \frac{Xi}{\sum_{i=1}^{n} X_i} - (Y_d^+ - Y_d^-) = \textit{Delivery Performance Target},\ i = 1,2,...,n$ (15)

Average PPM Goal: $\sum_{i=1}^{n} P_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_p^+ - Y_p^-) = \textit{Average PPM Target},\ i = 1,2,...,n$ (16)

Rework Performance Goal:

$\sum_{i=1}^{n} R_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_r^+ - Y_r^-) = \textit{Rework Performance Target},\ i = 1,2,...,n$ 17)

6. Objective Function

Omnibus objective function is developed to minimize the total deviation cost from the selected target levels where α^+ and α^- are the unit deviation costs input by the decision maker.

Minimize: $\textit{Total Cost of Deviation} = \sum_{j=1}^{5} \alpha_j^+ Y_j^+ + \alpha_j^- Y_j^-$ (18)

CHAPTER 5

ILLUSTRATION OF THE DECISION SUPPORT SYSTEM ENVIRONMENT

The DSS Architecture

A Decision Support System is a highly flexible and interactive information technology (IT) system that is designed to support decision making when the problem is not structured (Haag et al, 1998). Typically, a DSS gives the opportunity to perform a series of "what-if" analysis to see how certain inputs affect the outputs of the system. It uses different modeling tools such as regression, mathematical modeling, simulation, data mining, etc. to analyze information. At the end, the output is represented with summary reports and graphs for fast decision making and clear understanding of the results. As stated above, a DSS supports the decision makers for better decision making and improves the performance of the management.

In this study, DSS is developed to support supplier evaluation and order allocation decisions. Sensitivity analysis can be performed to examine the effect of an input parameter change on the supplier evaluation and order allocation decisions.

Furthermore re-solve option is added to perform scenario analysis and change more than one parameter at a time.

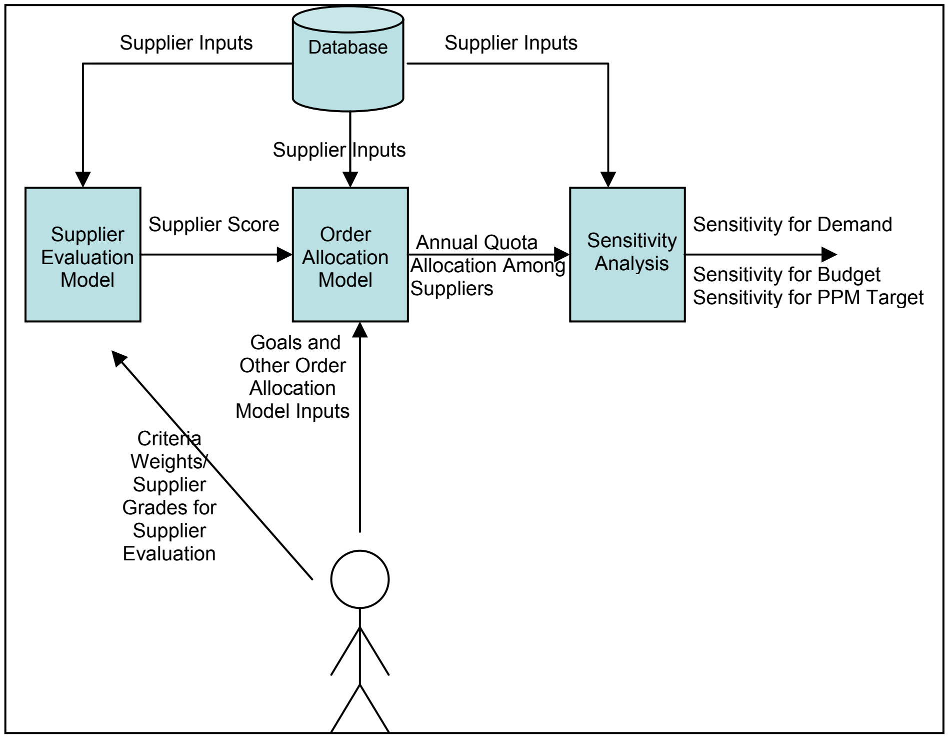

Figure 5. The structure of the generated DSS

The general structure of the generated DSS that consists of a database, a graphical user interface and a model base are shown in Figure 5.

Database covers the input data needed and the output data generated after the models are run. In this study, Microsoft Office Excel 2003 environment is used for the following purposes. It is very easy to develop a model for supplier evaluation on this database environment and input data control is easily accomplished.

Graphical User Interface is developed for the decision makers and it is user friendly. The interface includes all the instructions required at each step. The decision maker has the chance to change the input values throughout the supplier evaluation and order allocation processes. The input values are submitted to the database. They are controlled at each stage for consistency and data type. The result of the supplier evaluation and order allocation models is displayed as a list and the result of the sensitivity analysis is plotted in the form of charts. These sensitivity reports are generated to view the change in order allocation with respect to a change in the demand, minimum supplier quantity or the target levels. The graphical user interface that provides easy interaction with the MS-Excel is developed by the Visual Basic programming language.

Model Base: Model base consists of the supplier evaluation model and the order allocation model as seen in Figure 6. In the supplier evaluation model, the decision makers compare the criteria, sub-criteria and alternatives of the AHP model. The order allocation model is solved using "What's Best" freeware provided by the Lindo Software Co. which runs on Excel environment.

Illustration of the DSS by an Application

The decision support system environment generated in this study is developed with Microsoft Visual Basic 6.0 and is named "SEOA" which stands for Supplier Evaluation and Order Allocation.

An example is given below to illustrate the flow of activities in SEOA with the data provided by the company. Appendix B is provided to view all of the DSS screens illustrated with the real case data acquired from the company.

When the end-user runs the SEOA software, the following label in Figure 6 appears on the screen and enables the user to access the main menu.

Figure 6. SEOA label

The software is designed in a tabular form and the Help screen is enabled automatically as seen in Figure 7. The user can terminate the program any time by clicking the Exit button.

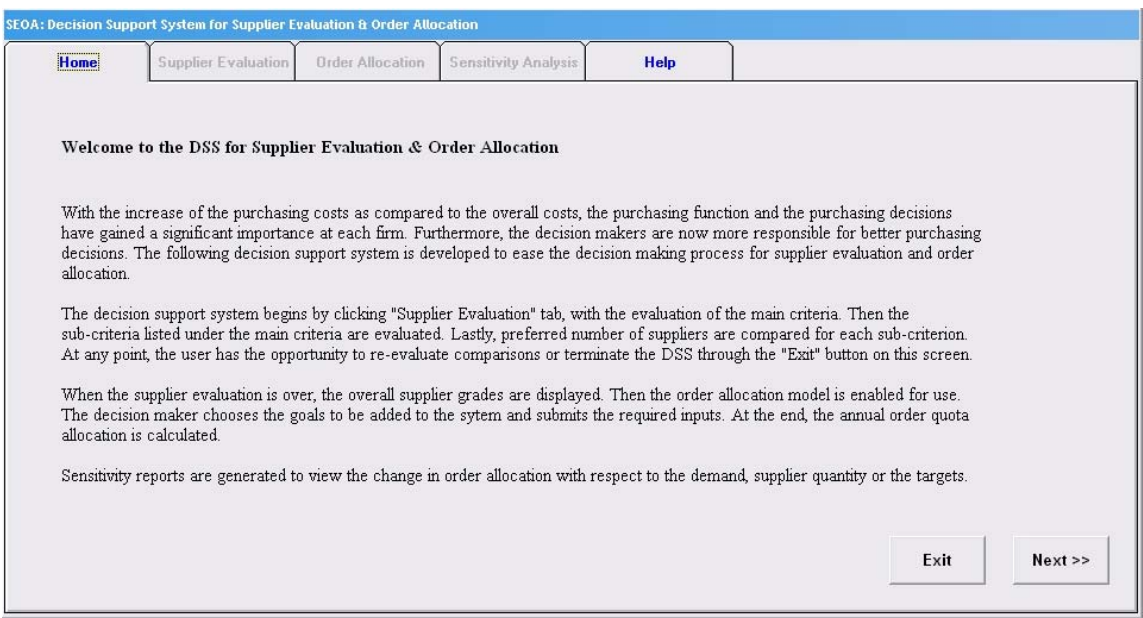

Figure 7. Home screen

The Help screen, which is shown in Figure 8, includes Saaty's scale for evaluation and a button is added to view the AHP Hierarchy Model in pdf format.

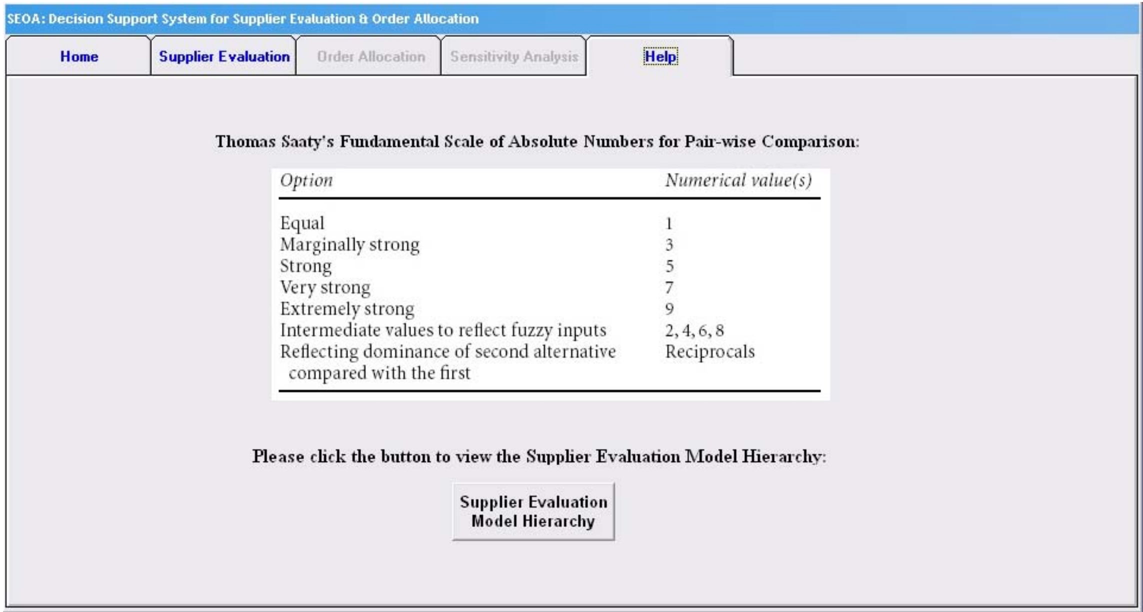

Figure 8. Help screen

The end-user starts the supplier evaluation process by clicking the Next button on the Home screen and the following screen on Figure 9 pops up. On the left hand side lies the hierarchy tree and the starting point of the evaluation is the pair-wise comparison of the main criteria, cost, quality, logistics and technology. The evaluation matrix is on the upper right half of the screen and the decision maker uses the combo-boxes for data input. On the bottom, the descriptions of the compared elements are positioned to provide information. If the user leaves a comparison blank, submits an input other than Saaty's scale or the evaluation is not consistent, then a reminder is displayed on the screen which asks for re-evaluation, as can be seen from Figures 10,11 &12. If an evaluation is done without any errors, the resulting weights are displayed on the right.

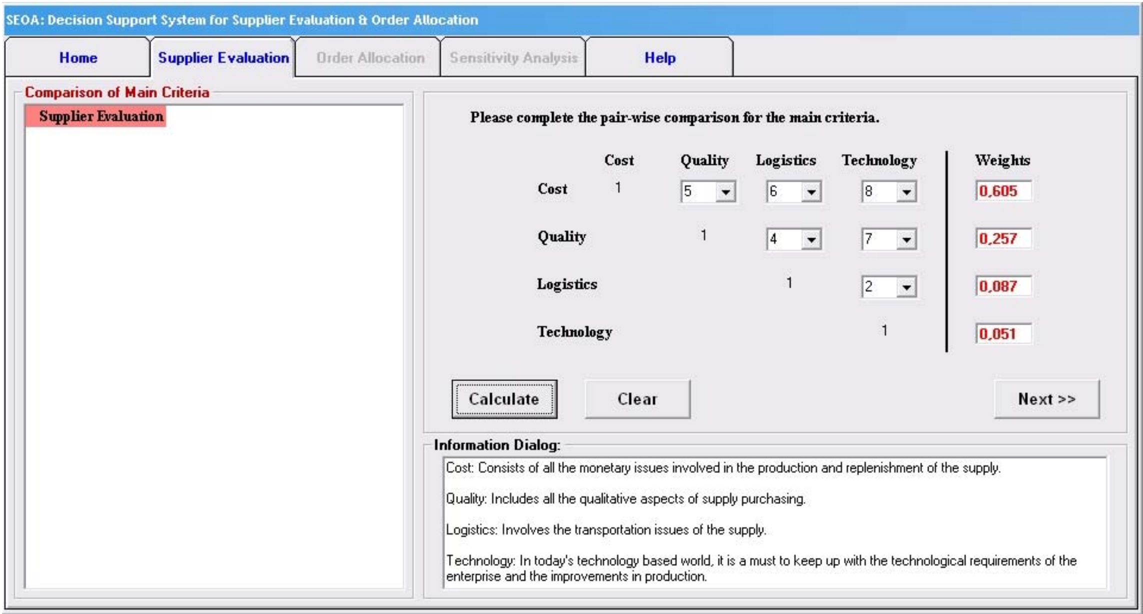

Figure 9. Comparison of main criteria

As the user progresses, the evaluated criteria appear in green, leaving the last element in progress in red and bold font, as can be seen in Figure 13.

Figure 10. Reminder for blank comparison

Figure 11. Reminder for input type

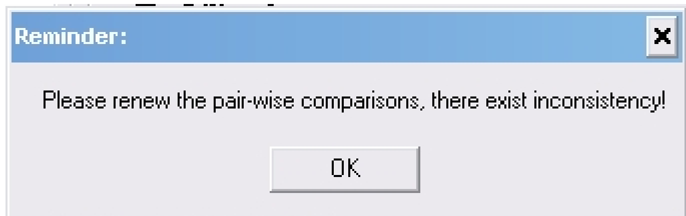

Figure 12. Reminder for inconsistency

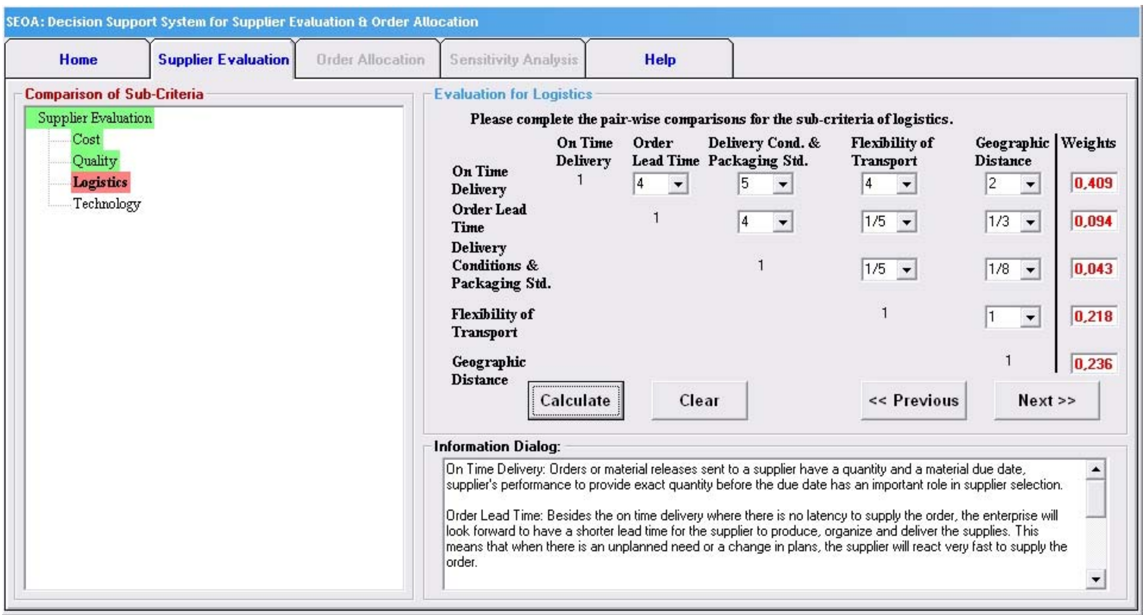

Figure 13. Progress in evaluation

When the evaluation of the main criteria and their sub-criteria are done, the user is asked to submit the number of suppliers to evaluate for the rest of the model, as displayed in Figure 14.

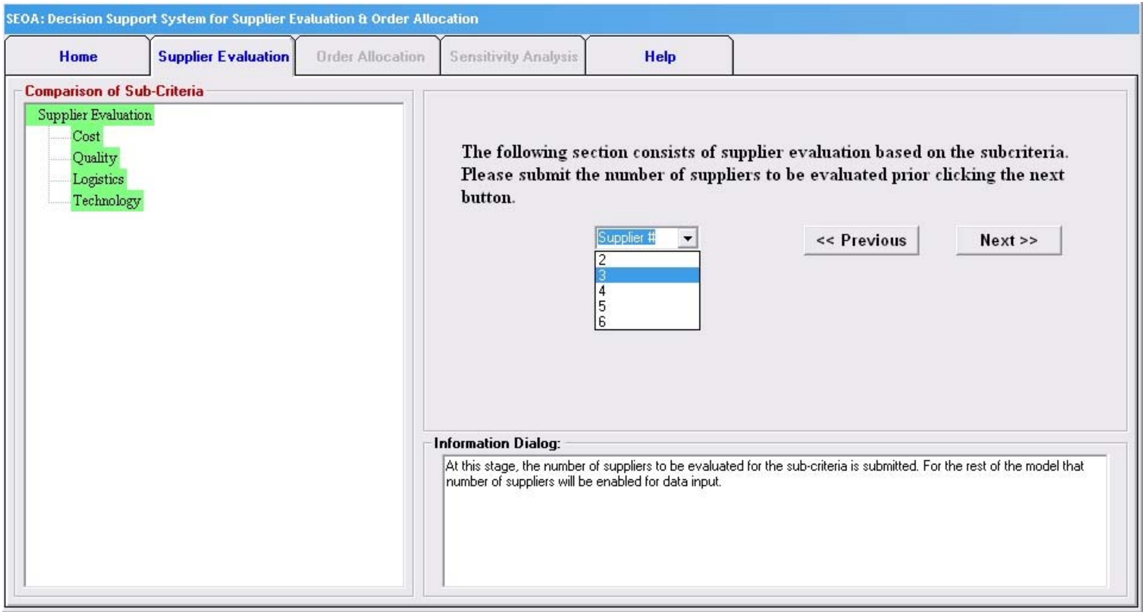

Figure 14. Input for supplier quantity

After the selection of number of suppliers to be evaluated, the AHP tree on the left hand side is expanded and the user starts the comparison of sub-criteria, as seen in Figure 15.

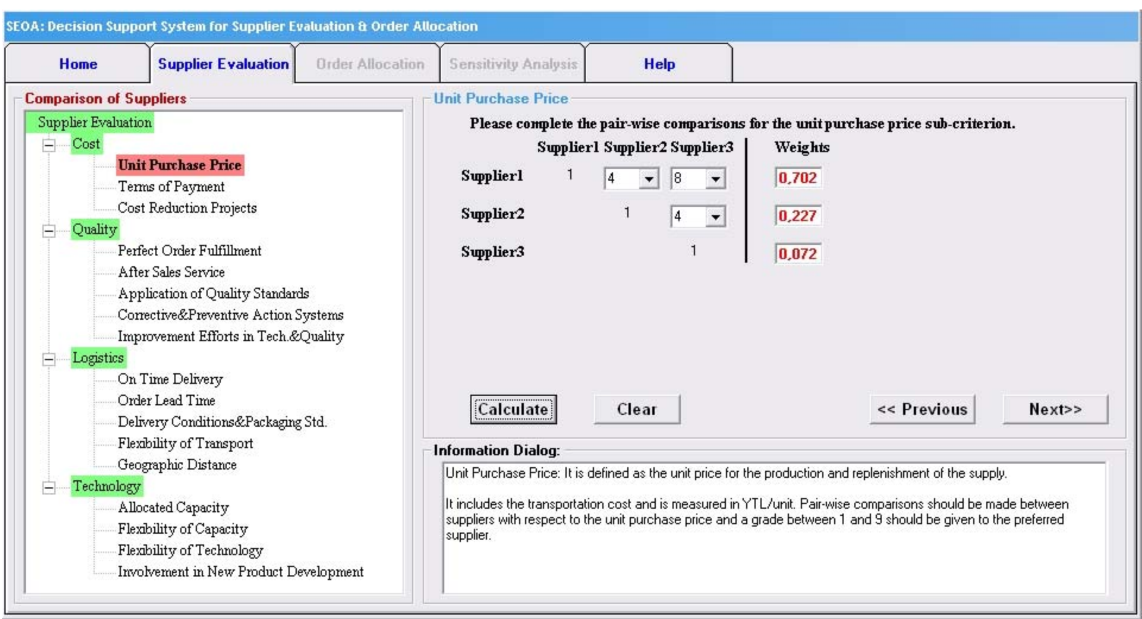

Figure 15. Evaluation of suppliers with respect to the sub-criteria

When the evaluation is over for all of the suppliers, the resulting grades are displayed in a screen similar to Figure 16. At this point, the user can terminate the supplier evaluation process and proceed to the order allocation model or can go back to the pair-wise comparisons to reconsider the evaluation. The user has the opportunity to save the pair-wise comparisons and their resulting grades by pressing the Save Evaluation button for future reference.

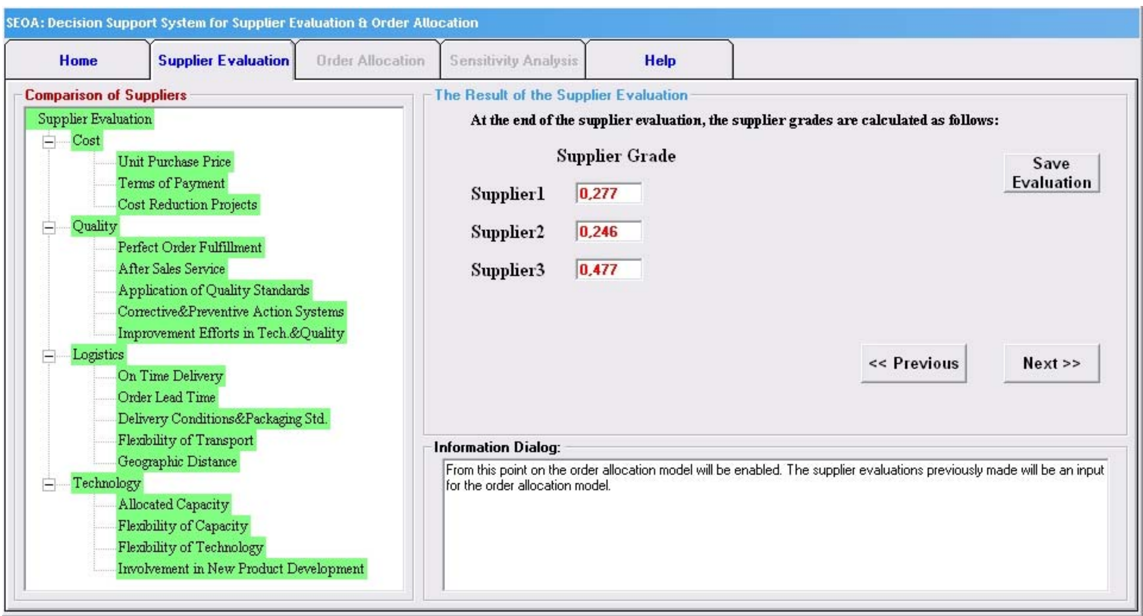

Figure 16. Resulting grades

On the order allocation model, first of all the user is asked to choose the goals to be added to the model. Although utility and budget goals are common in all studies in this area, they are optional in the DSS. It is advised to incorporate these goals to the order allocation model as in Figure 17.

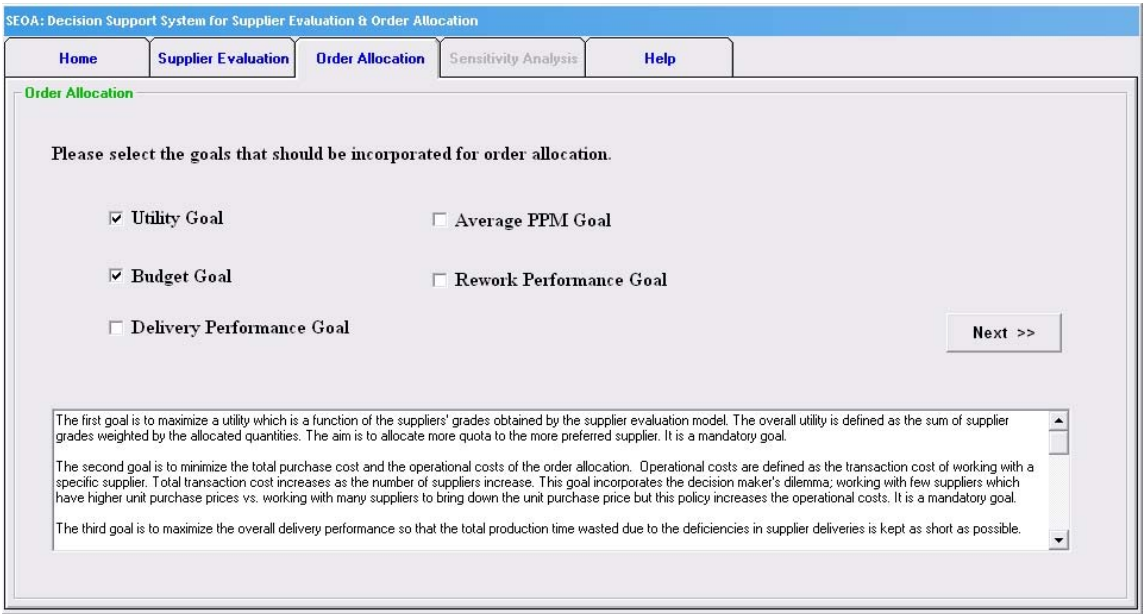

Figure 17. Goal setting

According to the number of suppliers selected in the supplier evaluation process and the goals set, an input screen for supplier inputs is displayed as in Figure 18. It is required to enter unit cost, transaction cost and other inputs for the selected goals and suppliers.

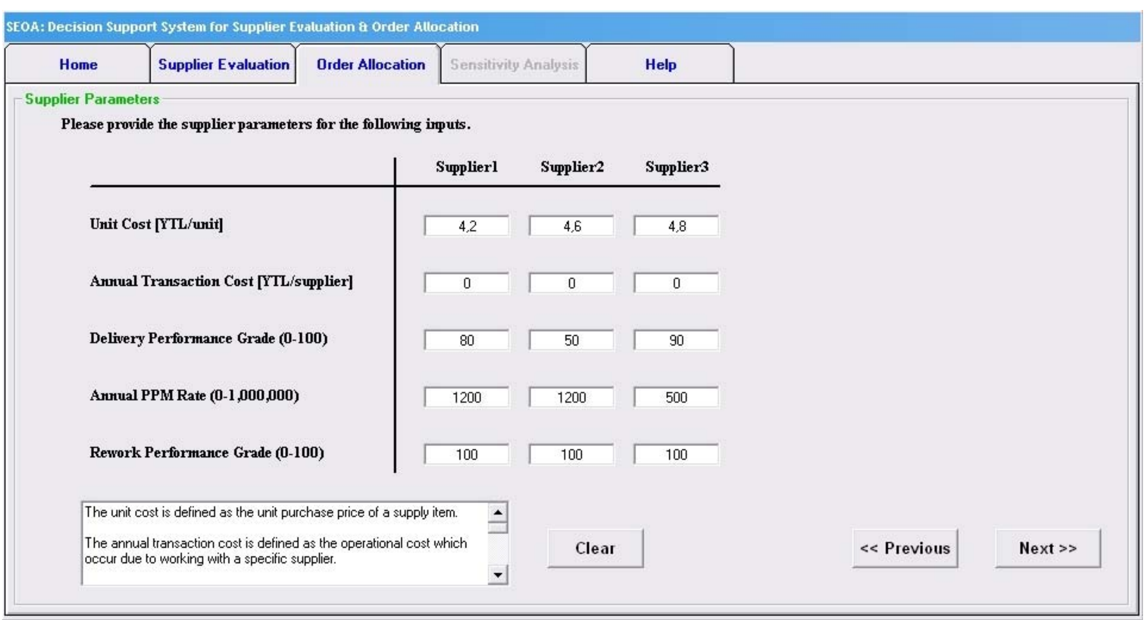

Figure 18. Supplier parameters

If all the required data is not entered a reminder similar to Figure 19 pops up.

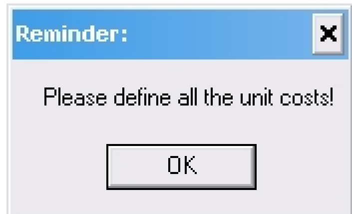

Figure 19. Reminder for data input

When the Next button is clicked on Figure 19, a new input screen appears, as shown in Figure 20. Here, it is required to enter target levels and the deviation costs for only the previously selected goals. Furthermore, other parameters are entered for the constraints like annual demand, number of suppliers to work with and minimum quota to be allocated.

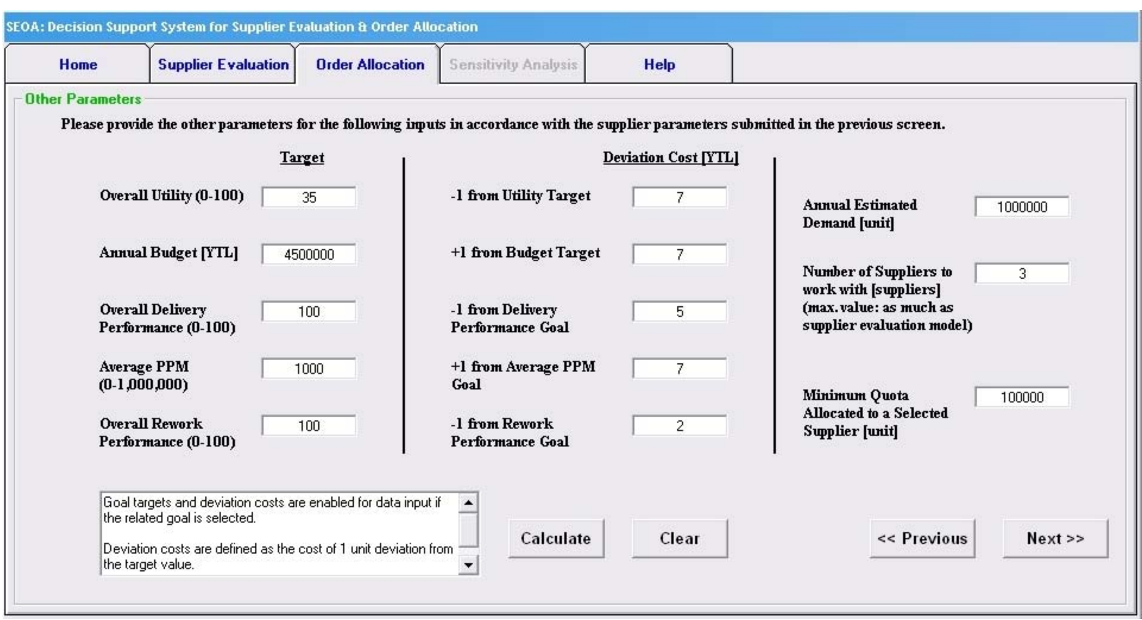

Figure 20. Other parameters

In the next stage, the final ratings calculated at the supplier evaluation model and the input values submitted at the order allocation process are interpreted by the mathematical solver software What's Best and the report, like in Figure 21, is displayed. At this point, the end user has the opportunity to go through what-if analysis and find out the result of different scenarios. The user can resolve the order allocation problem for different combinations of 5 goals and with different input values. The results of the order allocation model can be saved onto a file by clicking the Save Allocation button.

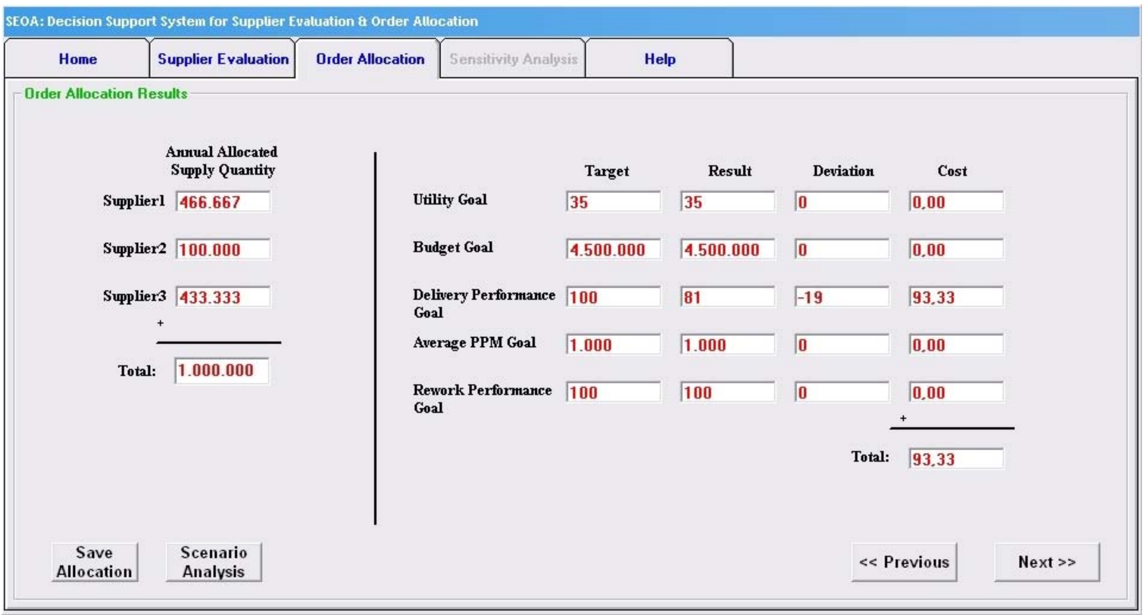

Figure 21. Order allocation results 1

If the utility and budget goals are removed from the order allocation model, the results change as seen in Figure 22. In this case, the goals that should be attained are maximizing the delivery performance grade, minimizing the average ppm rate and maximizing the rework performance grade. Supplier 3 has the best parameter values regarding these targets; therefore, it receives 800,000 supply items and the other suppliers recieve 100,000 supply items as annual quota allocated.

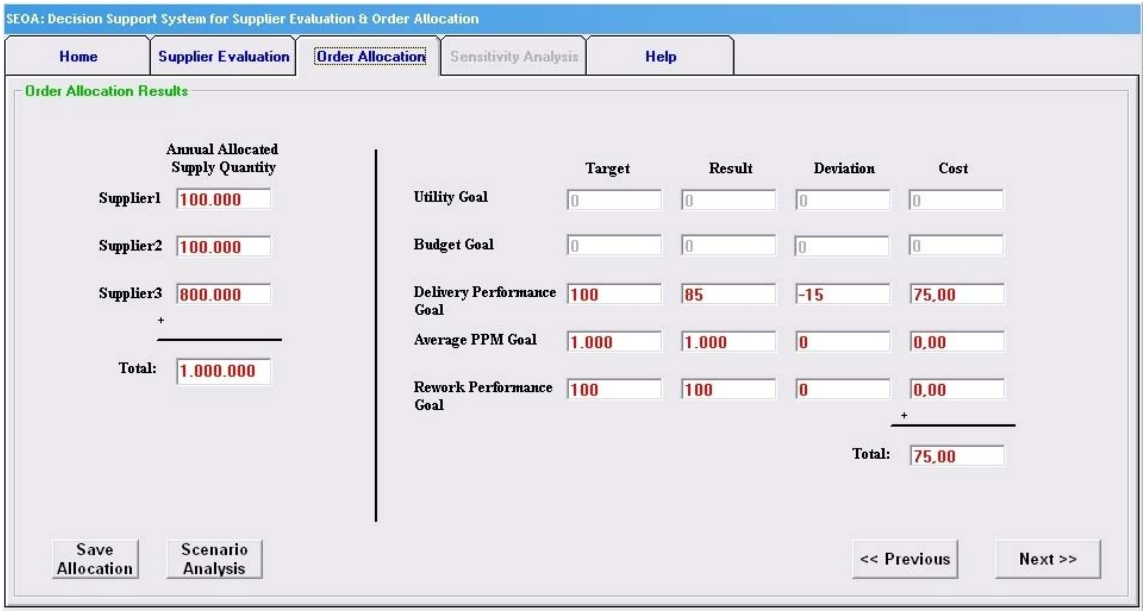

Figure 22. Order allocation results 2

The decision maker can press the Scenario Analysis button and calculate the results of different order allocation scenarios. As seen in Figure 23, annual order quotas are allocated manually and results are observed.

Figure 23. Scenario Analysis

Finally, sensitivity analysis can be conducted for the input parameters that appear in Figure 24, such as annual demand, goal target levels, etc. The user chooses the sensitivity increment percentage from the combo-box and clicks an analysis button.

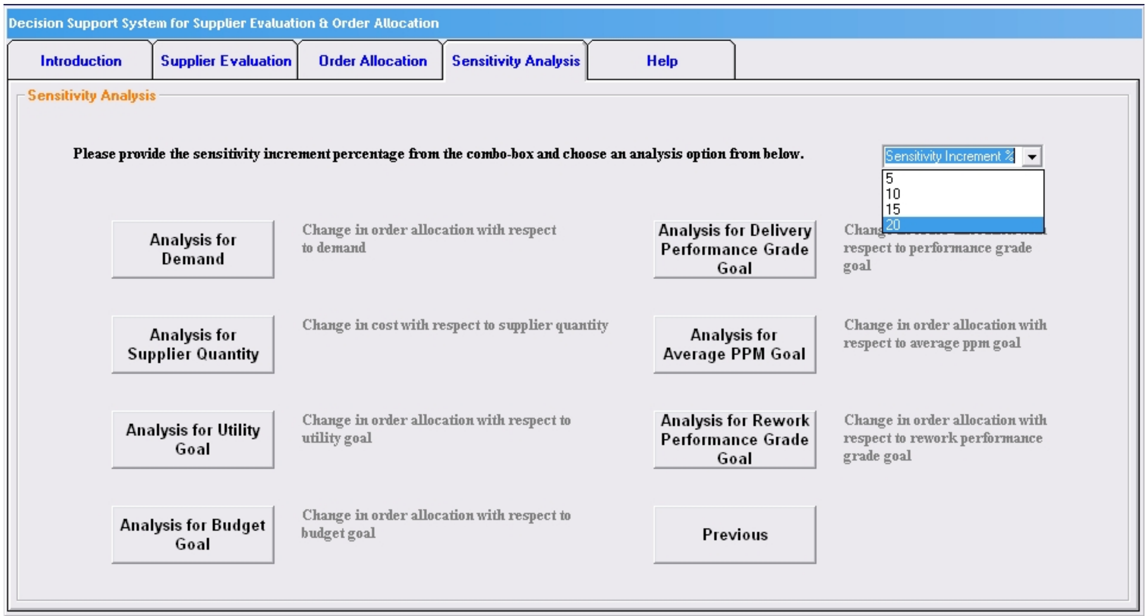

Figure 24. Sensitivity analysis list

A sample chart is shown in Figure 25 and it can be saved onto a directory by clicking Save Chart button to compare different reports afterwards.

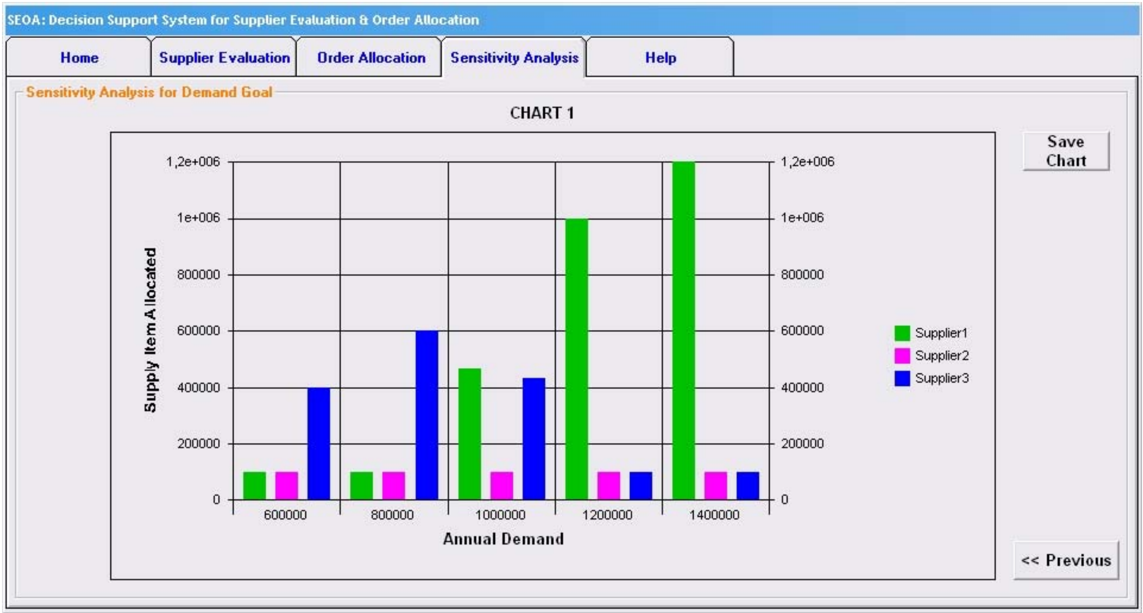

Figure 25. Sensitivity analysis for demand

CHAPTER 6

CONCLUSION

In this thesis study, a decision support system for one of the leaders of the white-goods manufacturing sector in Turkey is developed. The DSS provides the decision maker with the ability to evaluate the possible suppliers according to the pre-defined criteria and sub-criteria. Afterwards, the user has the opportunity to diversify the annual quota to these suppliers according to the goals and the purchasing policies. A DSS software, SEOA, is developed with an easy to use GUI to submit data and view the results regarding the supplier evaluation and order allocation. The order allocation model can be resolved several times to see the effect of a change in an input data on the resulting distribution. Sensitivity analysis can be conducted after the annual quota allocation is done to visualize the results with respect to the targets. Both the results of the supplier evaluation and order allocation models including the sensitivity analysis reports can be saved for further analysis. All screens are supported by information dialogs and clear instructions are provided for the decision maker.

The efficiency of the DSS is assessed by the company and the software is enhanced in accordance to these feedbacks.

In application at the company, the first difficulty was faced during the frequent error messages indicating inconsistencies in AHP evaluations. To overcome this difficulty a detailed explanation for consistency is added to the information dialog.

Another feedback acquired from the purchasing managers is that the order allocation model consists of quantitative goals and constraints only. However, in realty the decision maker takes into account many circumstances while diversifying the quota in which some of them are informal or subjective and thus it is impossible to model them in such a DSS environment. In response to this feedback, it has been emphasized that the qualitative criteria were incorporated in the supplier evaluation model and that the DSS was developed to aid the decision maker, but not to replace the functionality of the decision maker. Developing a scenario analysis function for DSS, in which the decision maker can allocate annual order quota to the selected suppliers and observe the result of the order allocation model straightaway, has been proposed.

As future work, the decision support system environment may be enhanced by adding a simulation feature to observe the percentage of late deliveries and order fulfillment when the demand rate and order lead times are random.

Another enhancement option might be developing the supplier evaluation model with the group decision making perspective. The group of decision makers can list the main criteria and sub-criteria which should be included in the model separately, then evaluate the whole list and decide on the final supplier evaluation model. The rest of the DSS environment will be preserved as is it.

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APPENDICES

A. CRITERIA & SUBCRITERIA DEFINITIONS

1. Cost: Consists of all the monetary issues involved in the production and replenishment of the supply. How payment is done to the supplier and the overhead costs that add up afterwards the sale on the enterprise's side are also included.

    a. Unit Purchase Price: It is defined as the unit price for the production and replenishment of the supply.

    b. Terms of Payment: The terms of payment are significant aspects when the enterprise makes an agreement with a supplier. Besides the price, how frequent payment is, in what portions and in which terms are elements for selecting the most suitable supplier.

    c. Cost Reduction Projects: Although such projects are submitted rarely, this is an important criterion. If a supplier comes up with a cost decreasing project it is not a naïve approach. It is due to gaining cost benefit in order allocation and to increase the relationship in between.

2. Quality: This criterion involves the fill rate, after sales service, application of the required quality standards and corrective & preventive action system on the supplier's site.

    a. Perfect Order Fulfillment: Perfect order fulfillment incorporates the fill rate and the enterprise will put an upper boundary for the defective supply quantity/ratio per order. The selected supplier(s) should not exceed that amount.

b. After Sales Service: This defines how the supplier will give service after the delivery and payment. For a long-term and reliable relationship the supplier should be supporting the enterprise afterwards.

c. Application of Quality Standards: The enterprise will choose the suppliers which comply with the quality standards (ISO/TS/QS) it holds/looks for. It is important that the notion of quality is communicated, understood and maintained throughout the organization with performing periodic internal quality audits.

d. Corrective & Preventive Action System: Supplying non-defective items, after sales service or acquiring quality standards are not enough to satisfy the quality criterion. Corrective and preventive action system on the supplier's production site is important to avoid defective prototypes or entire lot. This system will save time and a lot of investment.

e. Improvement Efforts in Tech. & Quality: Having the sufficient technology and quality are not enough. It should be a policy for the supplier to have improvement efforts in technology and quality and it will support the production plans of the enterprise.

3. Logistics: Logistics criterion consists of the on time delivery of the supplies, delivery lead time, the conditions of the supplier products, ability to change the transportation of the order quantities and the geographic distance in between the enterprise and the supplier.

   a. On Time Delivery: Orders or material releases sent to a supplier have a quantity and a material due date and supplier's performance to provide exact quantity before the due date has an important role in supplier selection.

   b. Order Lead Time: Besides the on time delivery where there is no latency to supply the order, the enterprise will look forward to have a shorter lead time for the supplier to produce, organize and deliver the supplies. This means that when there is an unplanned need or a change in plans, the supplier will react very fast to supply the order.

   c. Delivery Conditions & Packaging Std.: The supplier should comply with the delivery conditions and the packaging standards enterprise sets as requirements. They can be defined as the sizing of packages, the number of supplies in each package and the material used to pack the packages.

d. Flexibility of Transport: It may turn out that the order quantities for a certain delivery period has to be changed. In that situation, how the supplier reacts to this change is very important. If the supplier can change quantities of order in transportation this is a positive mark for them.

e. Geographic Distance: The distance in between the enterprise and the supplier will be important when the materials planning and logistics costs are high and an urgent production is needed.

4. Technology: In today's technology based world, it is a must to keep up with the technological requirements of the enterprise and the improvements in production. The following sub-criteria underline the issues involved in technology criterion.

    a. Allocated Capacity: Supplier may not have a scarcity in capacity but could not supply enough to the enterprise. Allocated capacity makes sure that needed amount of supply is always set aside for the orders of the enterprise.

    b. Flexibility of Capacity: The supplier will not only have allocated capacity to supply its enterprise, but will have flexibility in capacity to support the unplanned extra orders or incremental changes.

    c. Flexibility of Technology: Defines supplier's response to enterprise expectations in a manner to support customer change-overs/launches. Tolerating the changes in the supply specifications should be within the supplier's technological capability.

    d. Involvement in New Product Development: It is a must to supply the required supplies with the appropriate specifications. Furthermore, the supplier is encouraged to be involved in new product development with the enterprise. This way, the supplier will enhance its production and will be more committed to a long term relationship.

B. ILLUSTRATIVE EXAMPLE FOR THE DSS

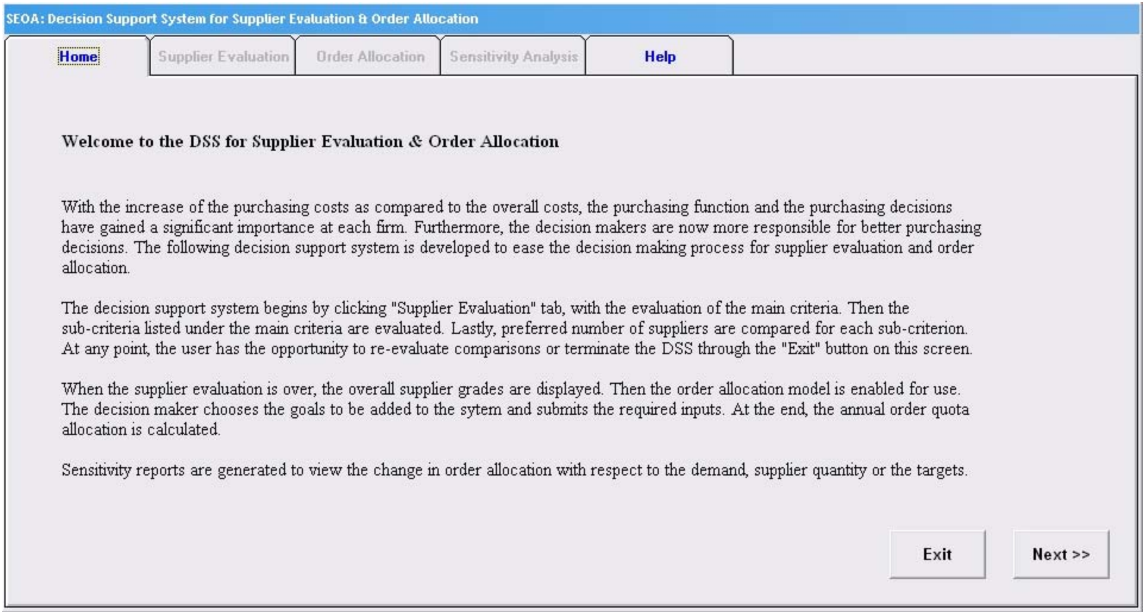

Figure 26. Home screen

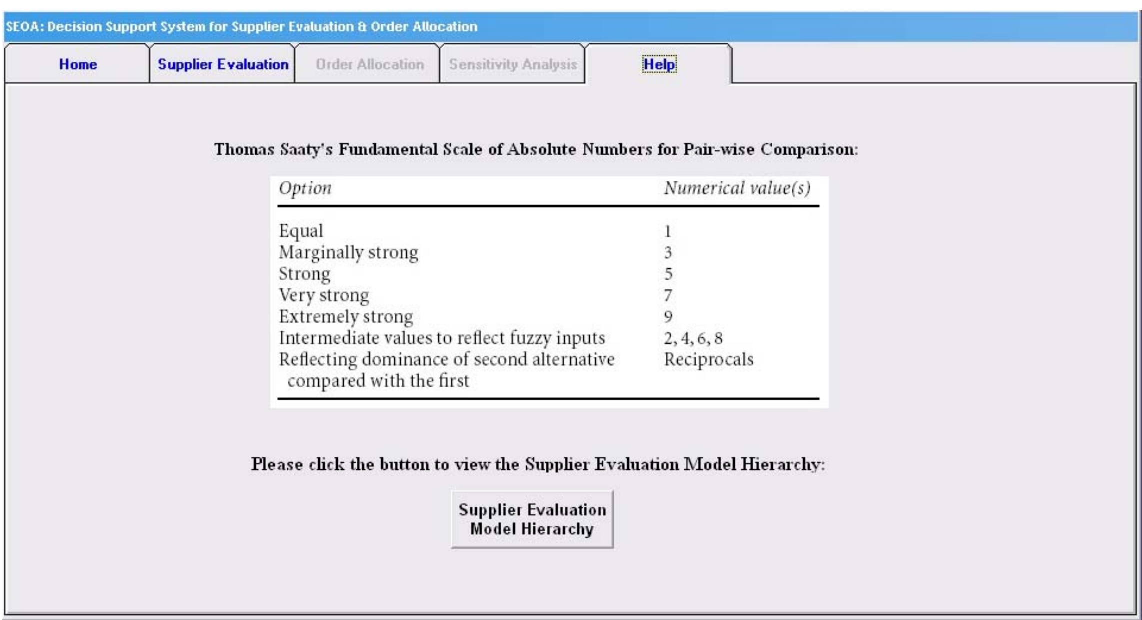

Figure 27. Help screen

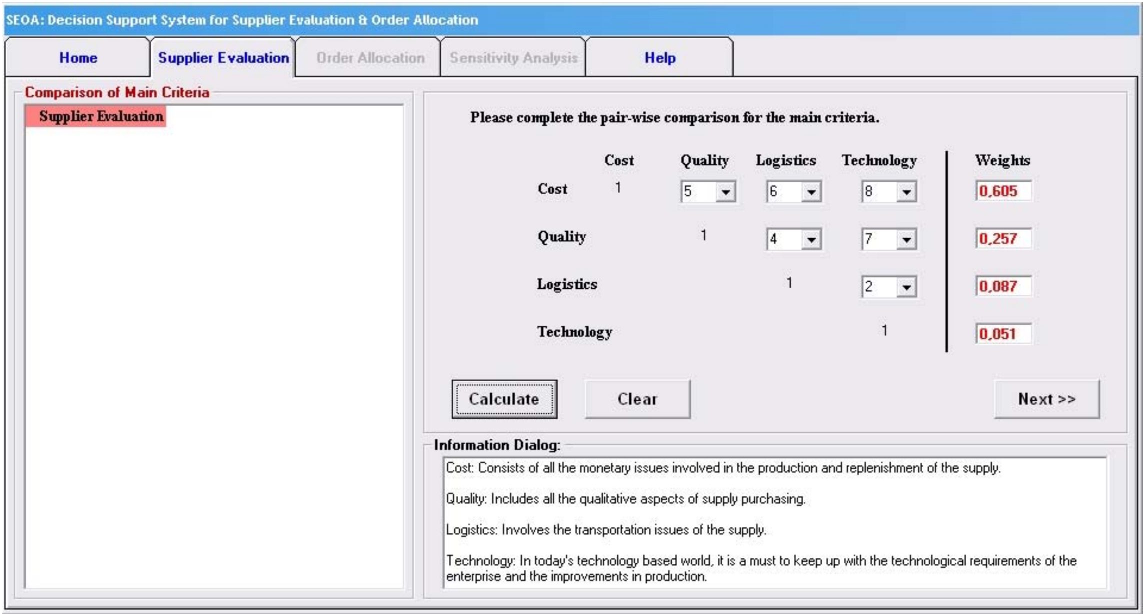

Figure 28. Main criteria evalaution

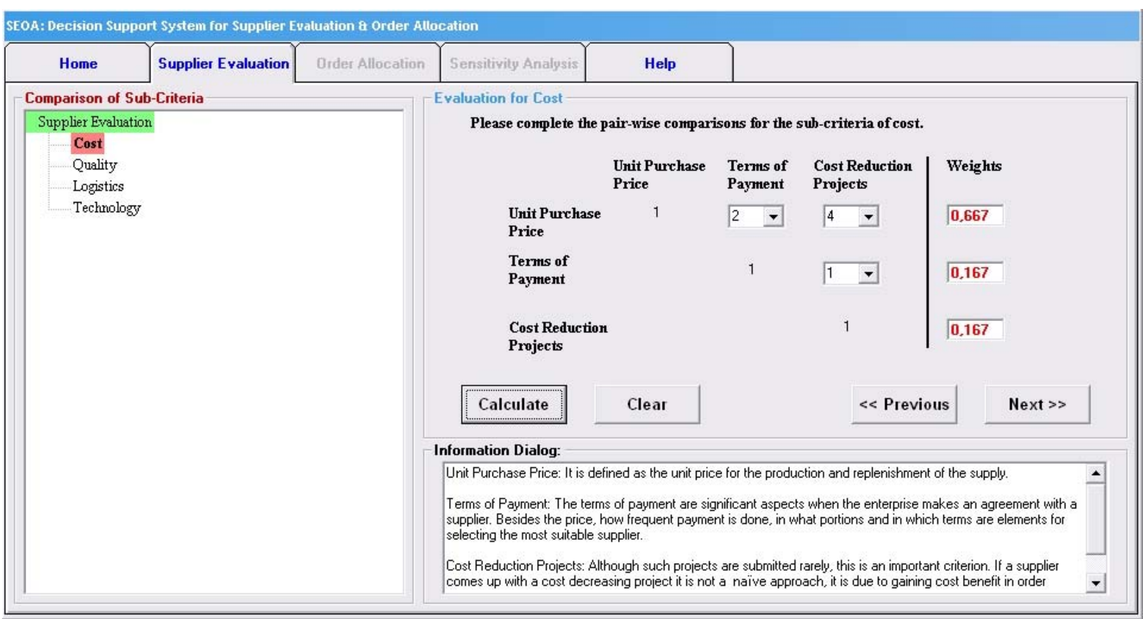

Figure 29. Sub-criteria evaluation for cost

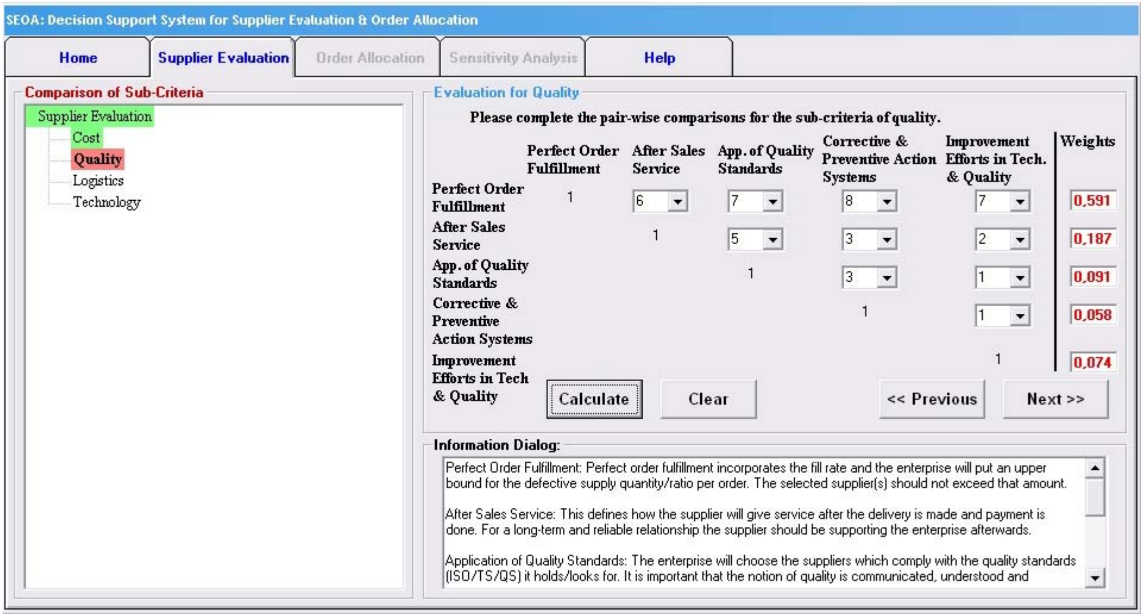

Figure 30. Sub-criteria evaluation for quality

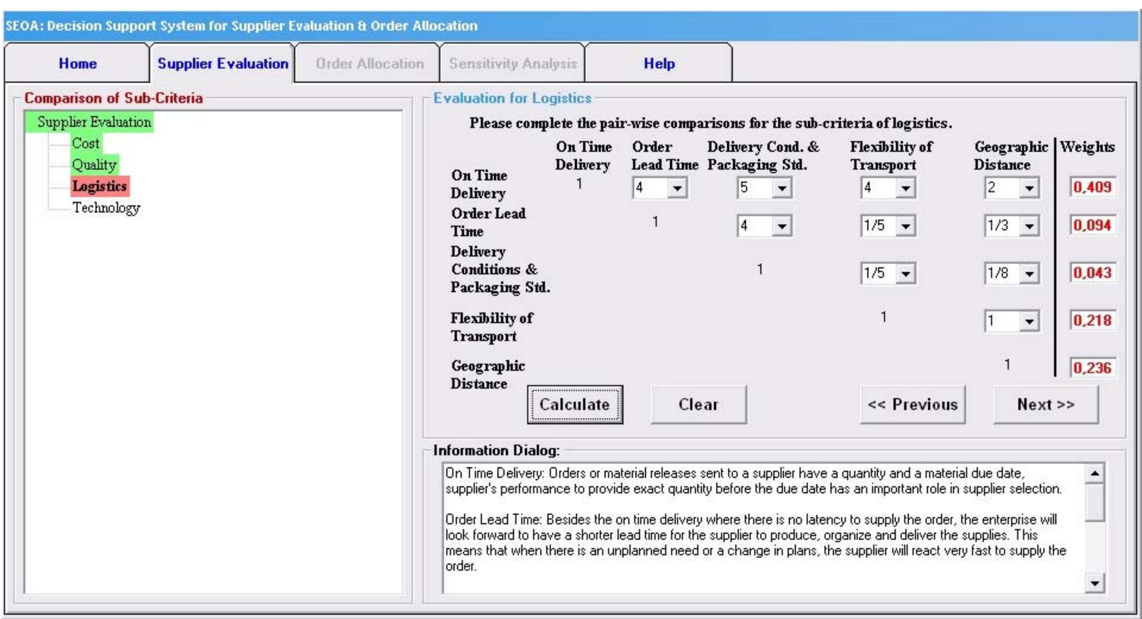

Figure 31. Sub-criteria evaluation for logistics

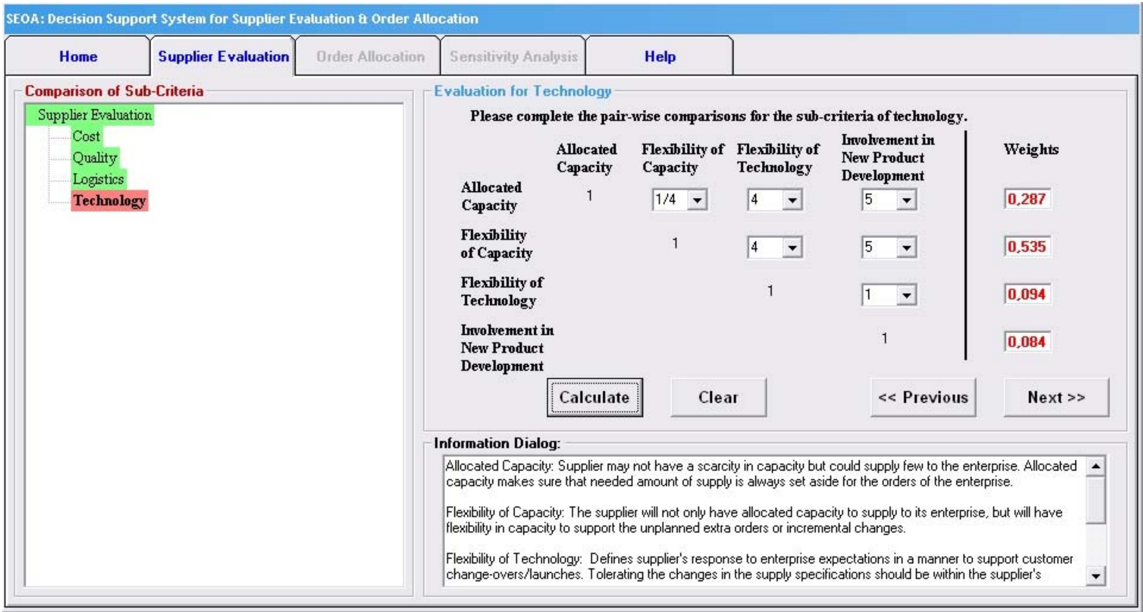

Figure 32. Sub-criteria evaluation for technology

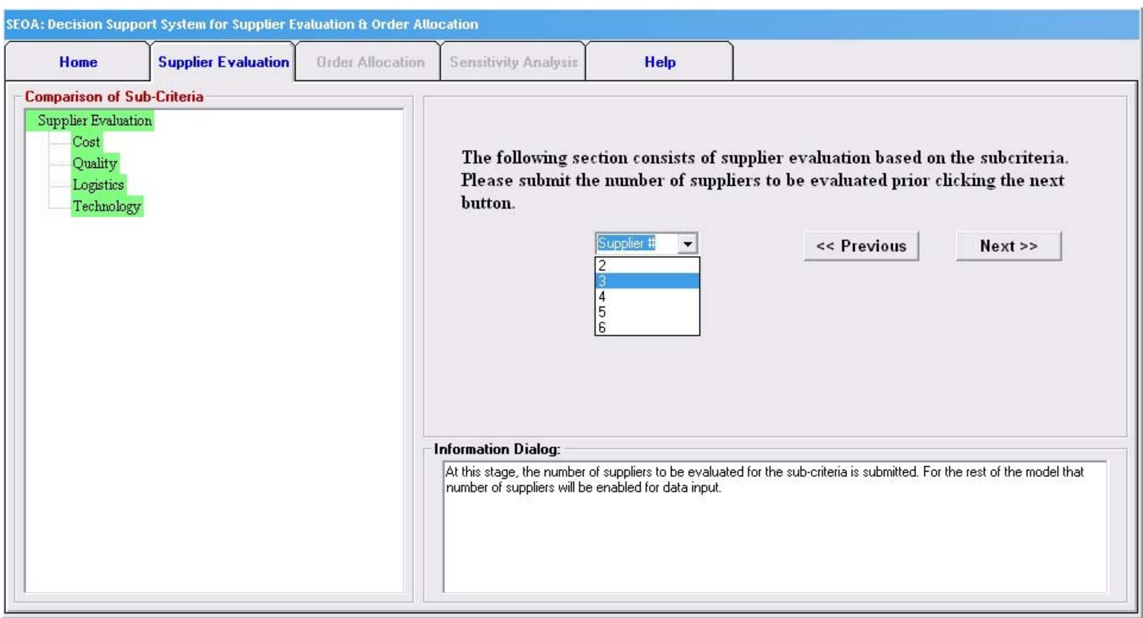

Figure 33. Supplier number selection

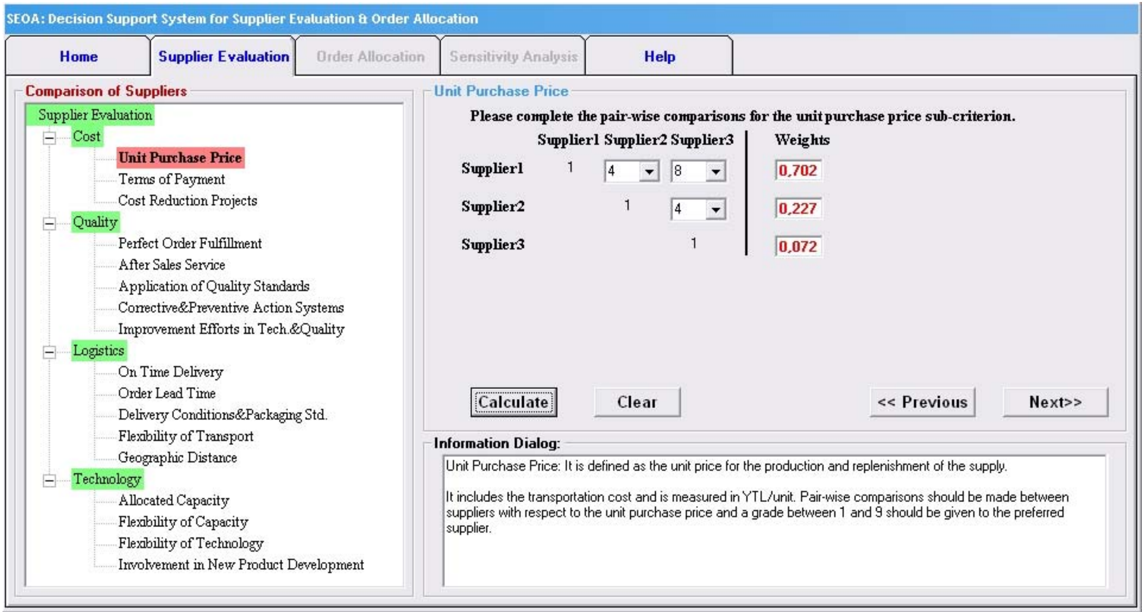

Figure 34. Pair-wise comparison of suppliers for price sub-criterion

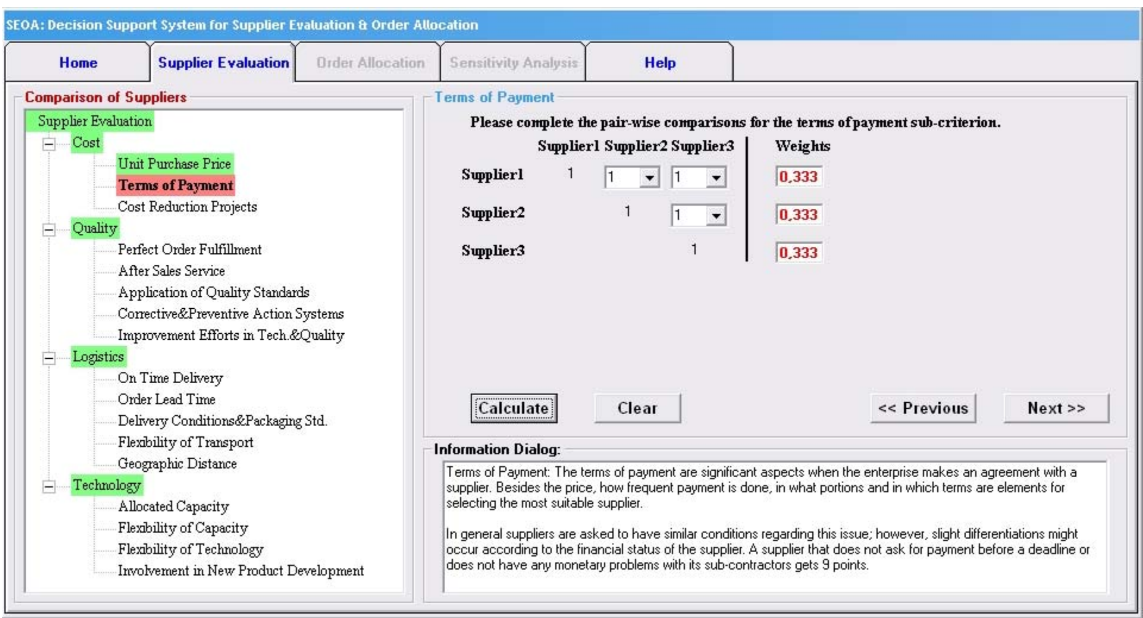

Figure 35. Pair-wise comparison of suppliers for terms of payment sub-criterion

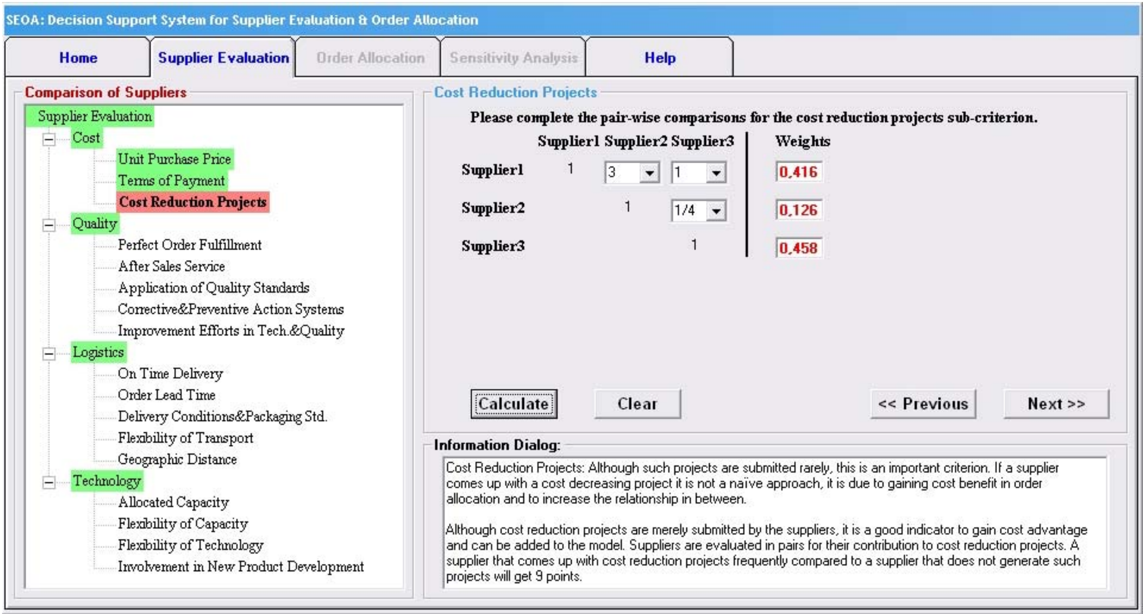

Figure 36. Pair-wise comparison of suppliers for cost reduction projects sub-criterion

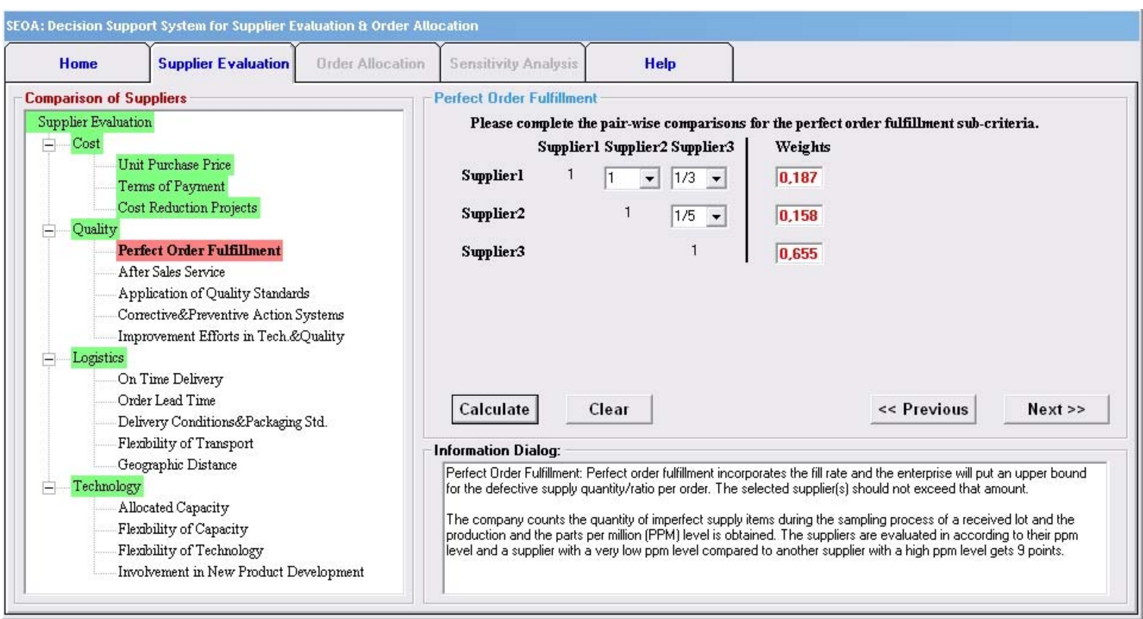

Figure 37. Pair-wise comparison of suppliers for perfect order fulfillment sub-criterion

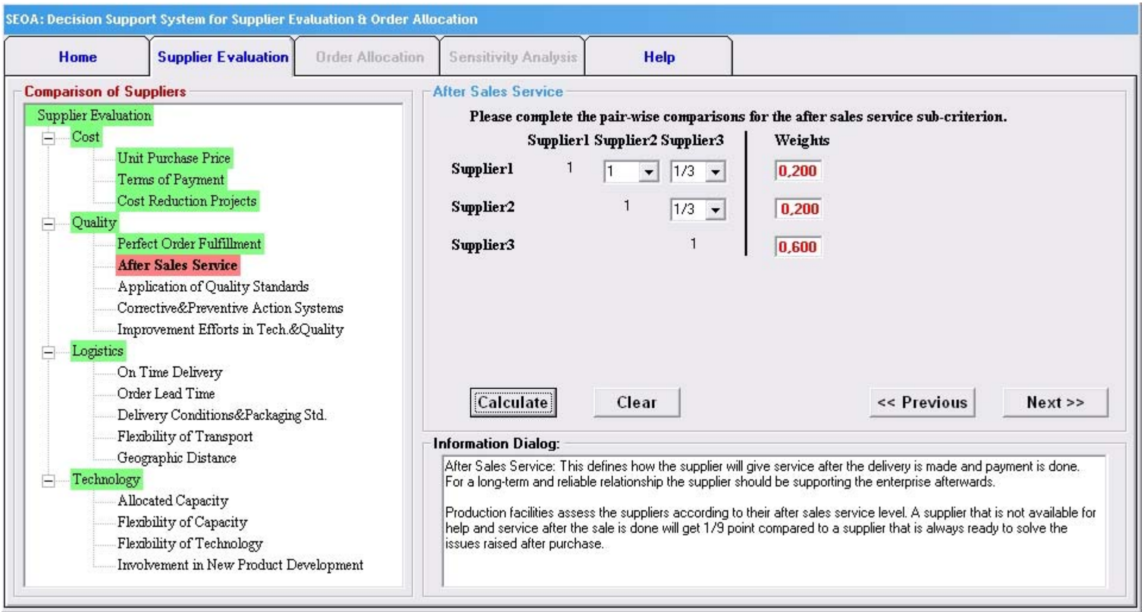

Figure 38. Pair-wise comparison of suppliers for after sales service sub-criterion

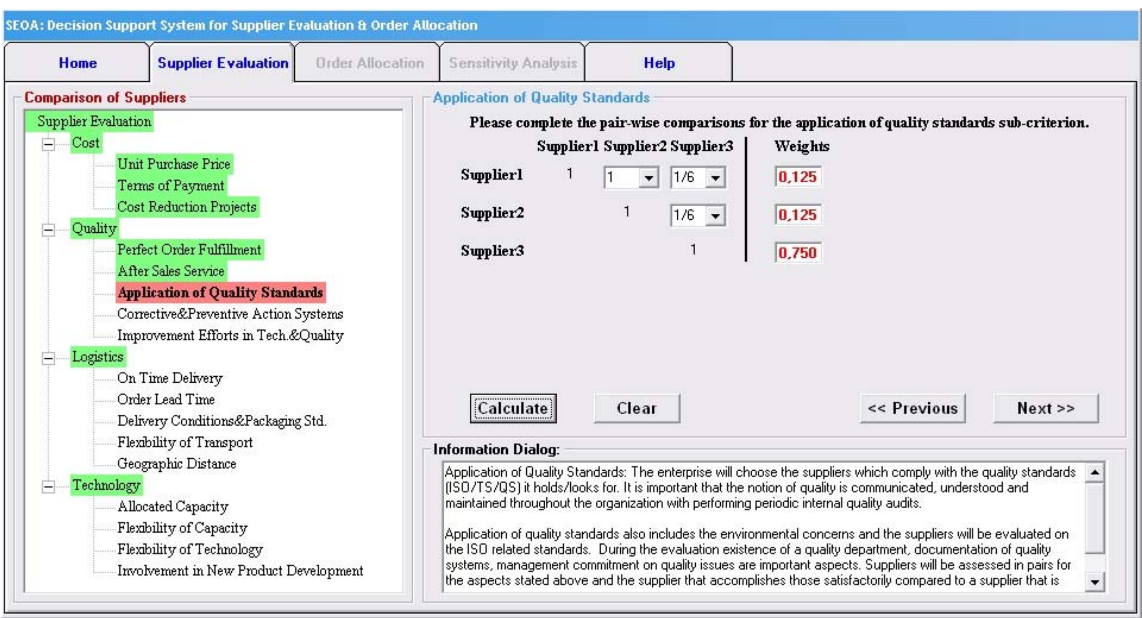

Figure 39. Pair-wise comparison of suppliers for applications of quality standards sub-criterion

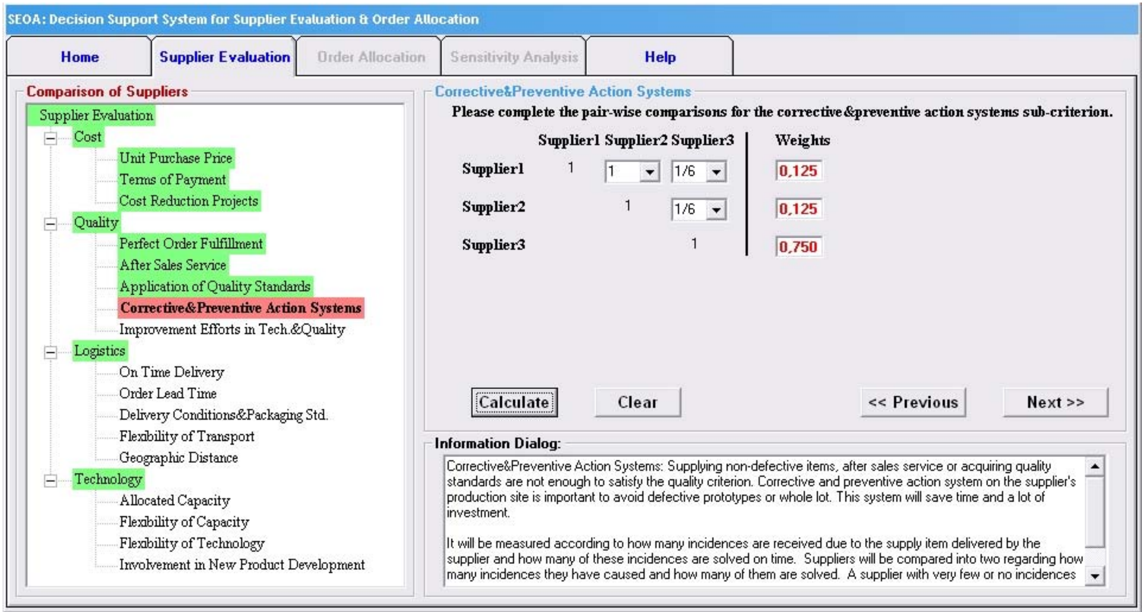

Figure 40. Pair-wise comparison of suppliers for corrective&preventive action systems sub-criterion

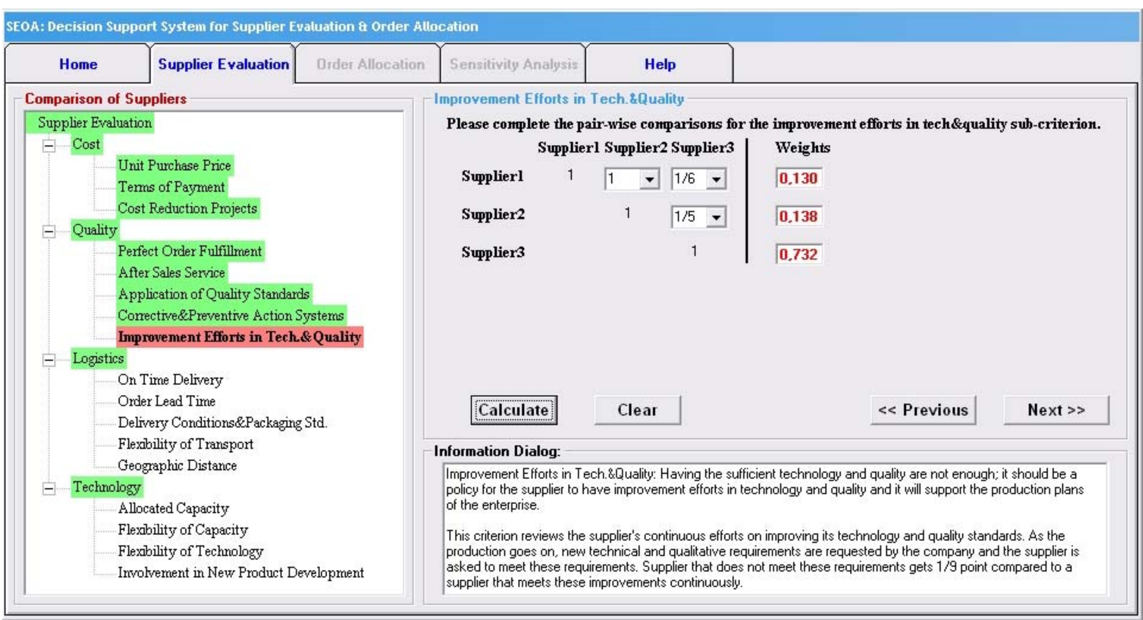

Figure 41. Pair-wise comparison of suppliers for improvement efforts in tech.&quality sub-criterion

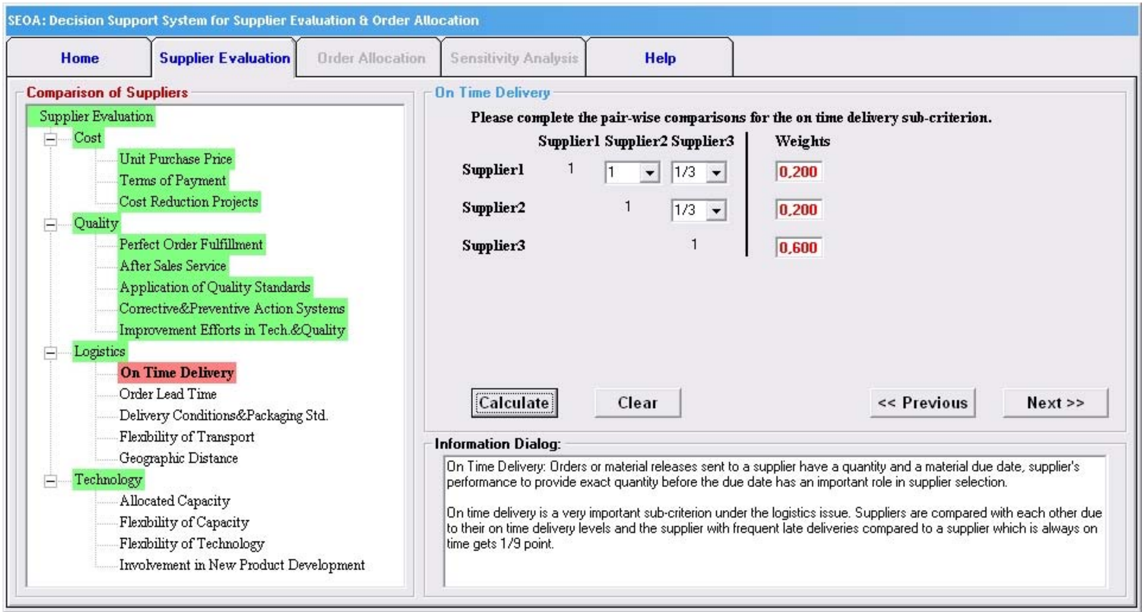

Figure 42. Pair-wise comparison of suppliers for on time delivery sub-criterion

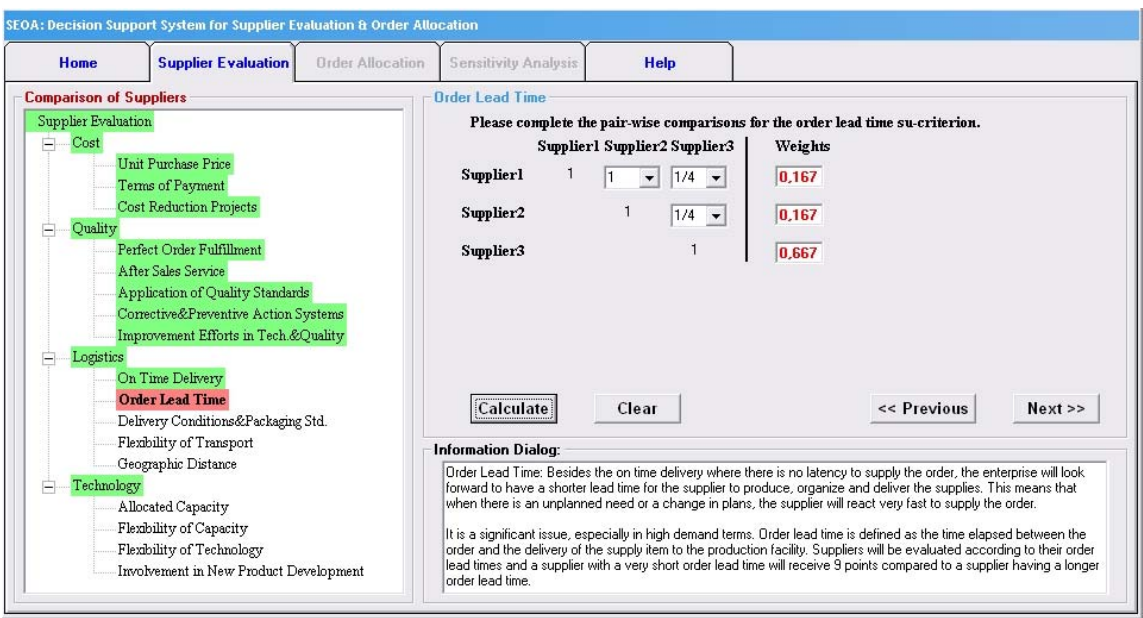

Figure 43. Pair-wise comparison of suppliers for order lead time sub-criterion

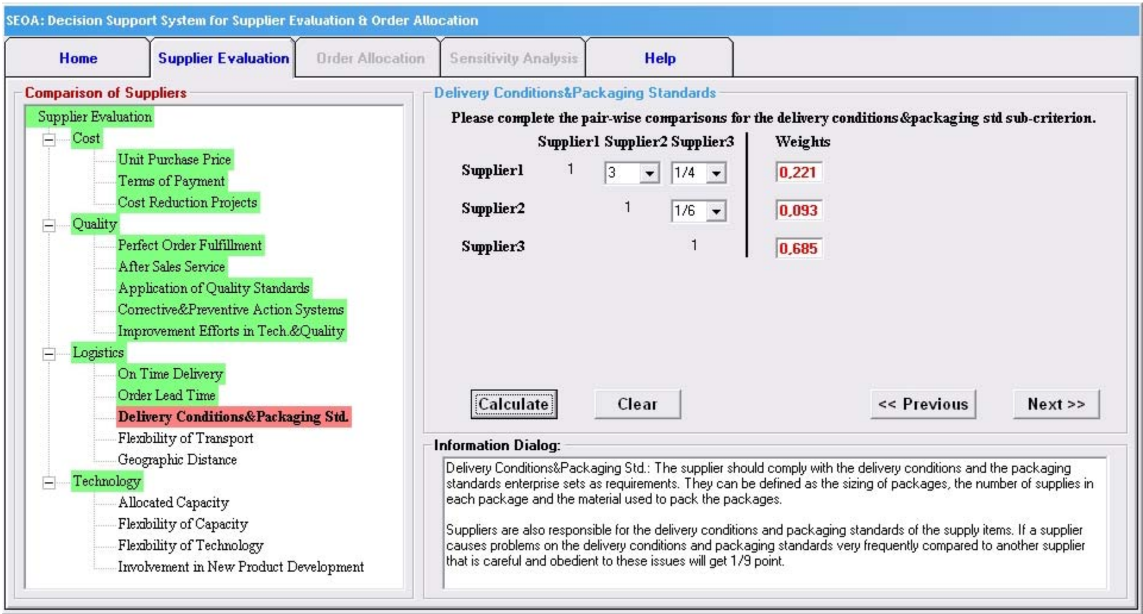

Figure 44. Pair-wise comparison of suppliers for delivery conditions&packaging std. sub-criterion

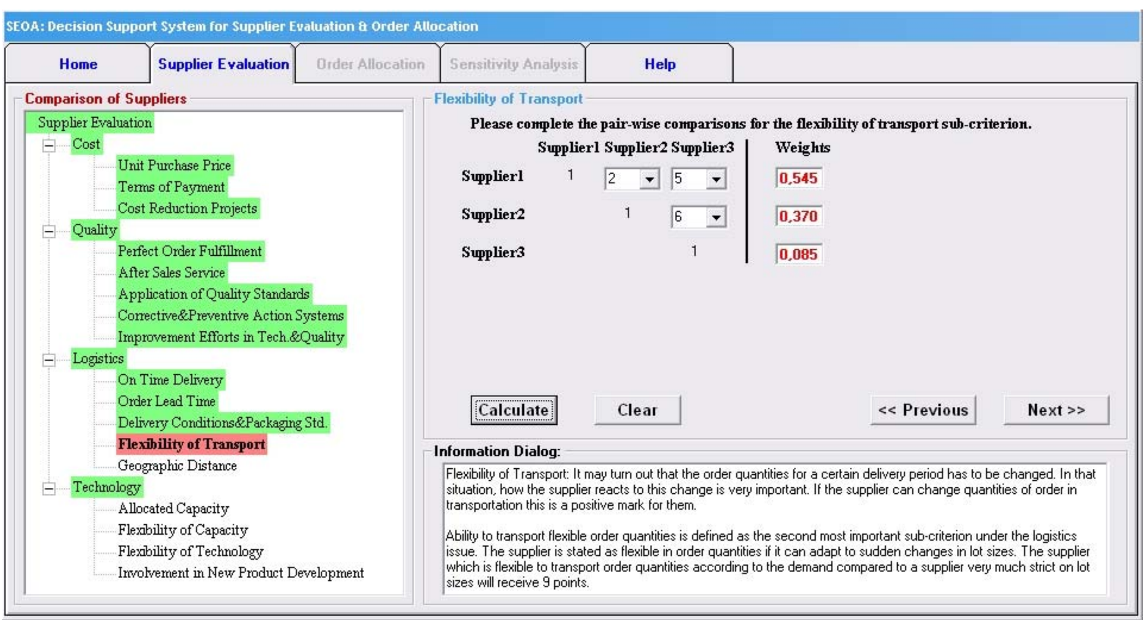

Figure 45. Pair-wise comparison of suppliers for flexibility of transport sub-criterion

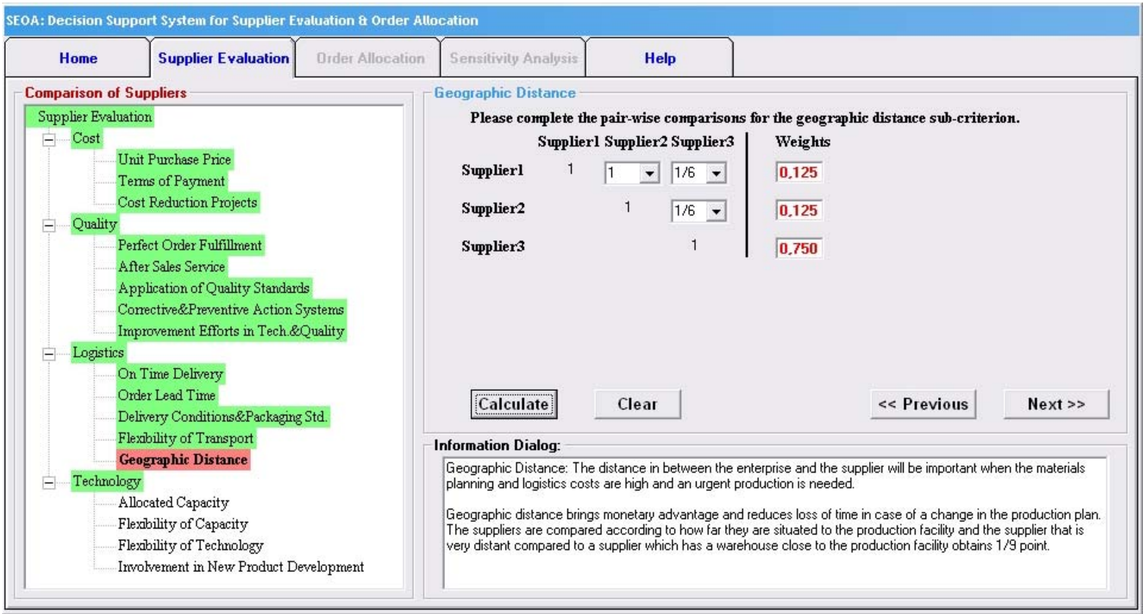

Figure 46. Pair-wise comparison of suppliers for geographic distance sub-criterion

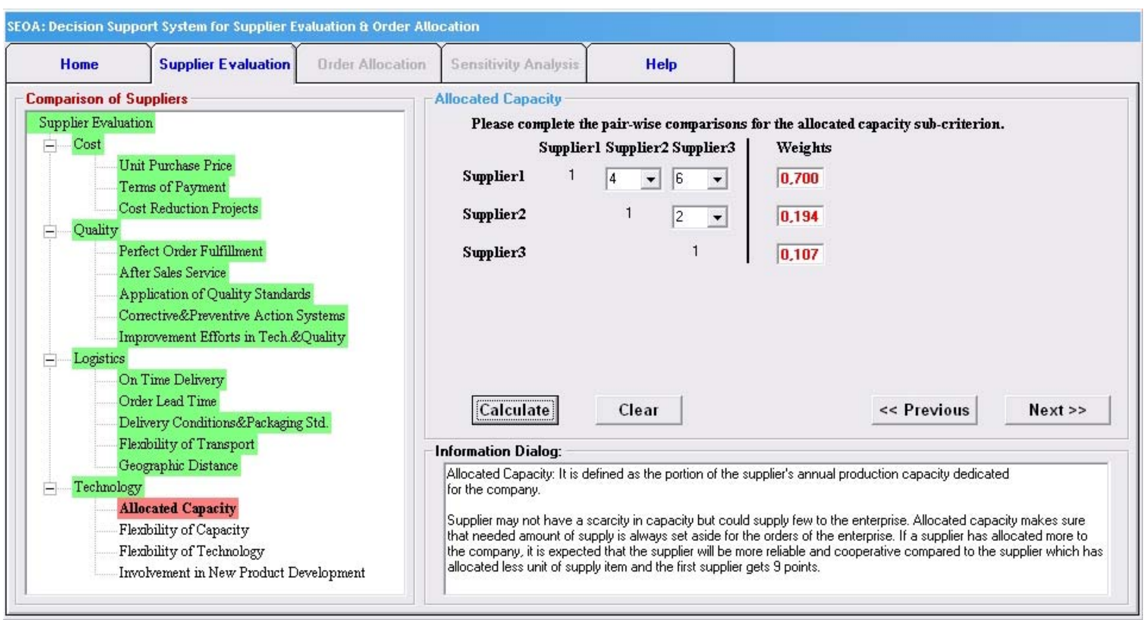

Figure 47. Pair-wise comparison of suppliers for allocated capacity sub-criterion

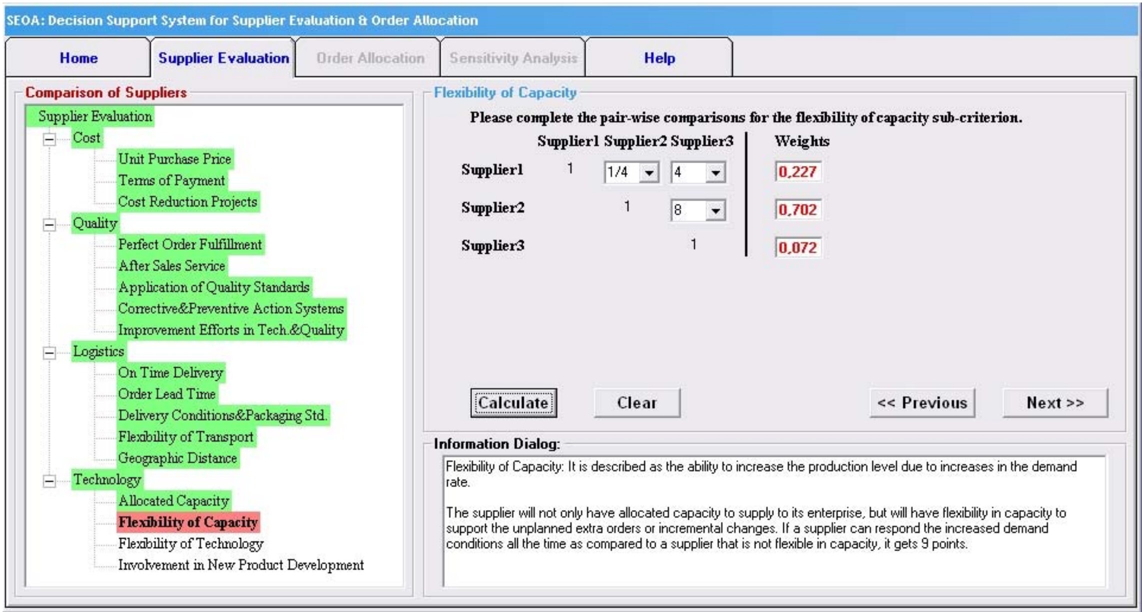

Figure 48. Pair-wise comparison of suppliers for flexibility of capacity sub-criterion

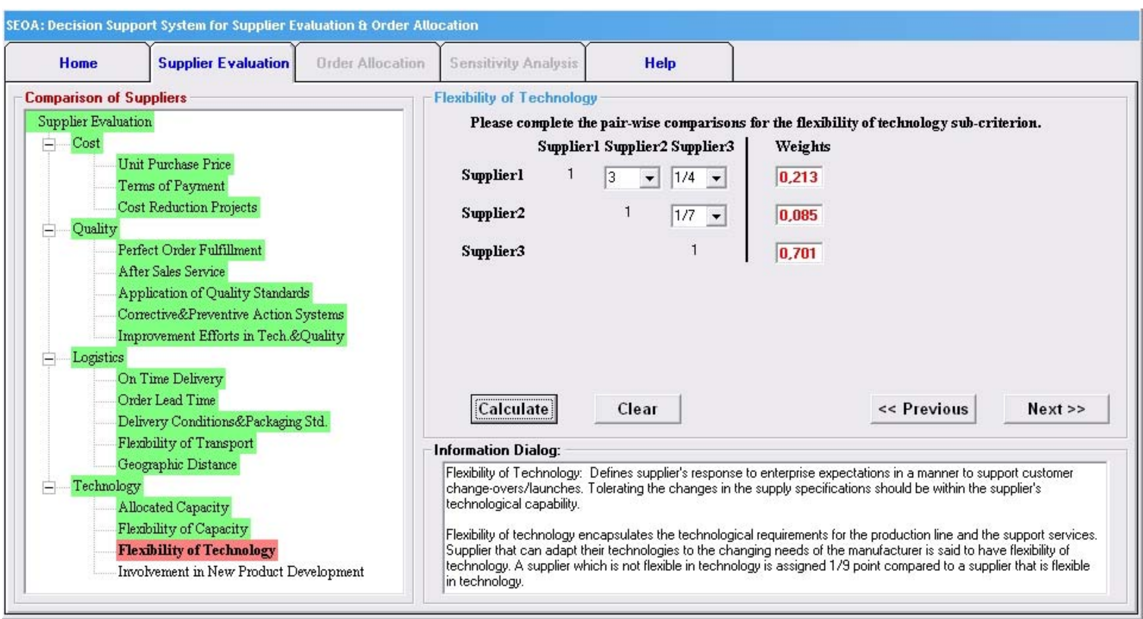

Figure 49. Pair-wise comparison of suppliers for flexibility of technology sub-criterion

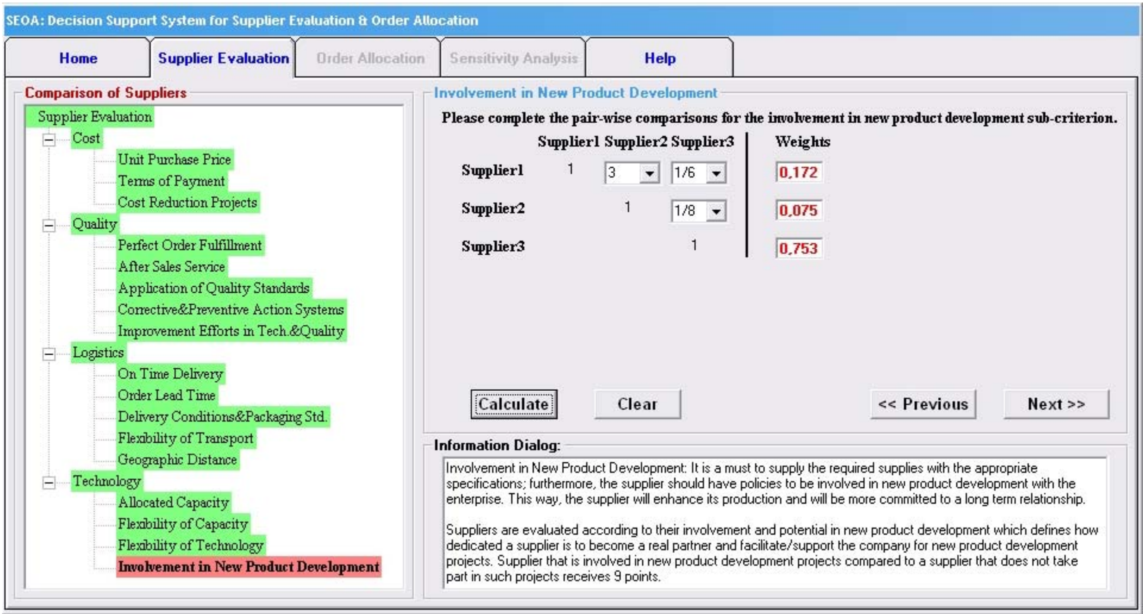

Figure 50. Pair-wise comparison of suppliers for involvement in new product development sub-criterion

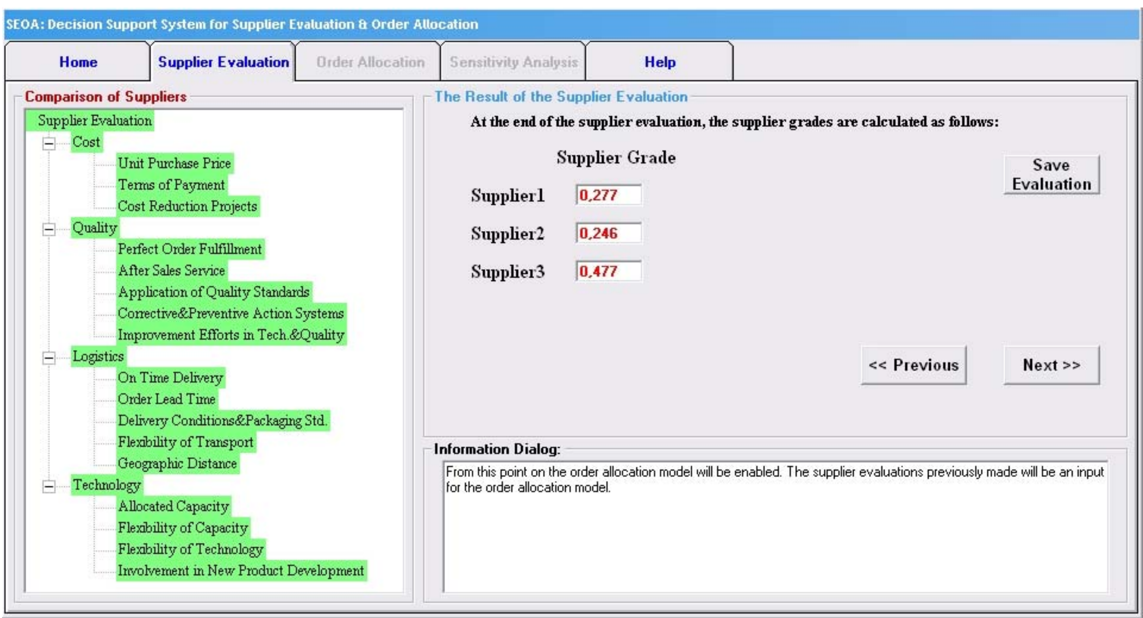

Figure 51. Resulting grades

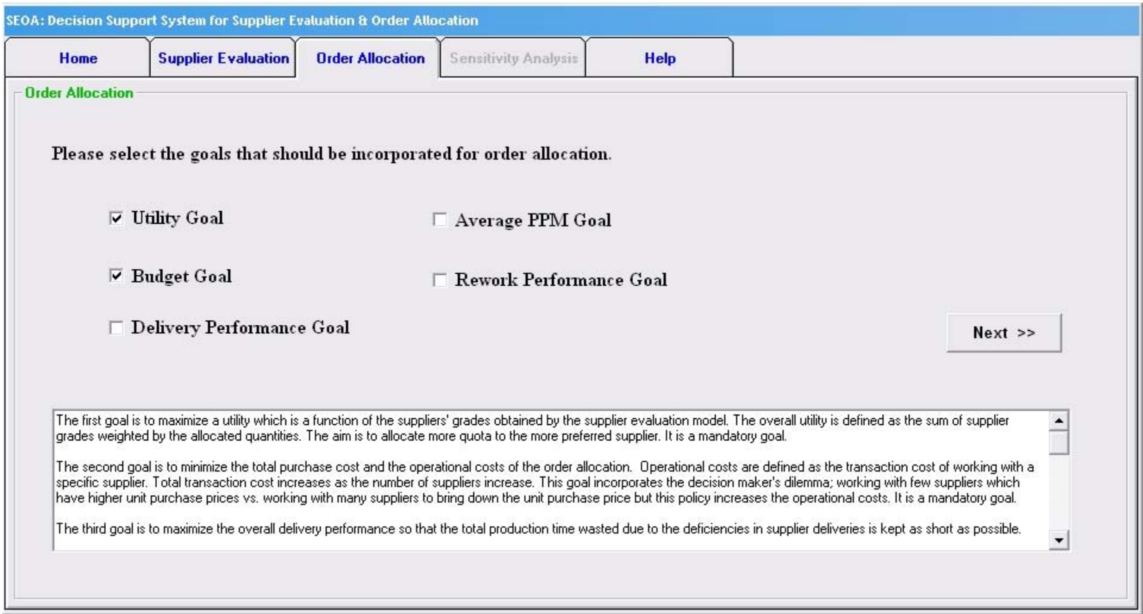

Figure 52. Order allocation model goal setting

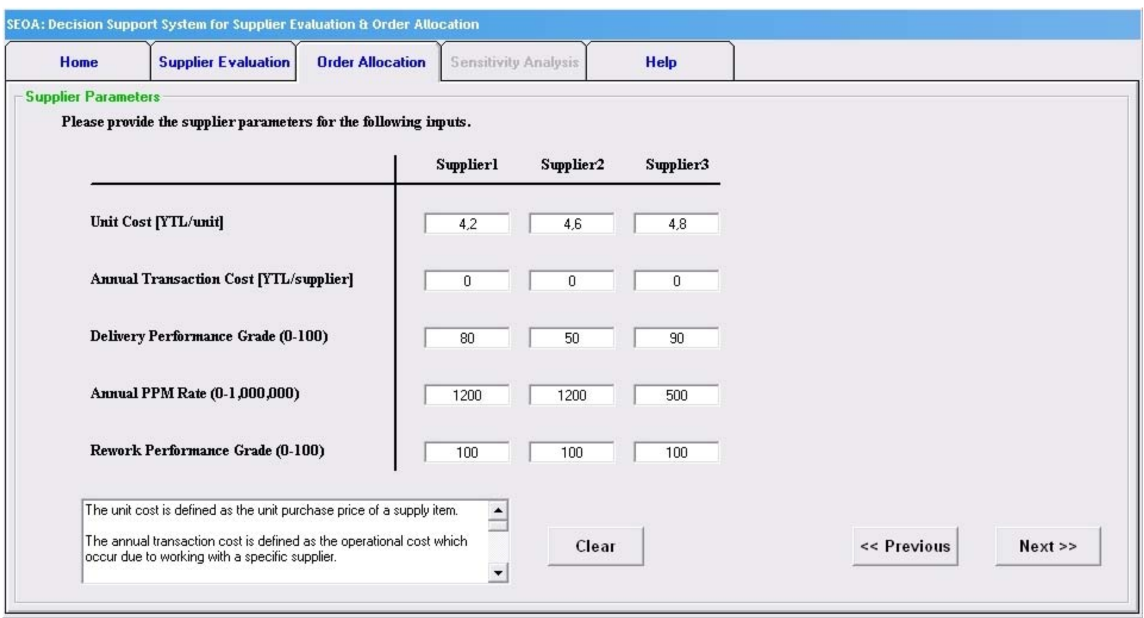

Figure 53. Data input for supplier paramteres

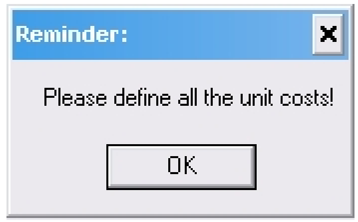

Figure 54. Reminder for data input

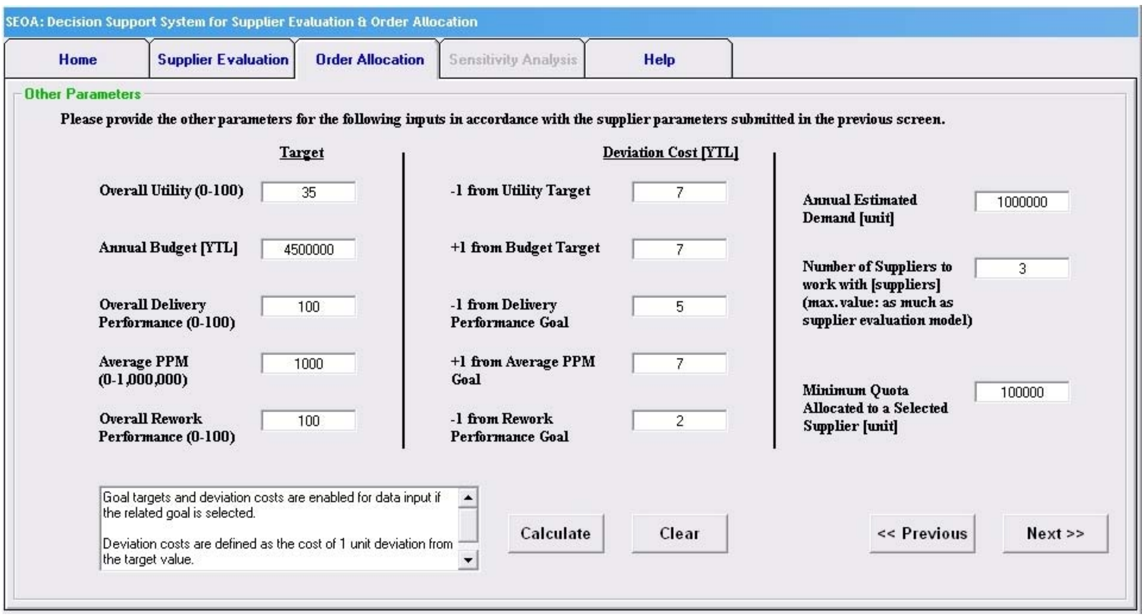

Figure 55. Data input for other parameters

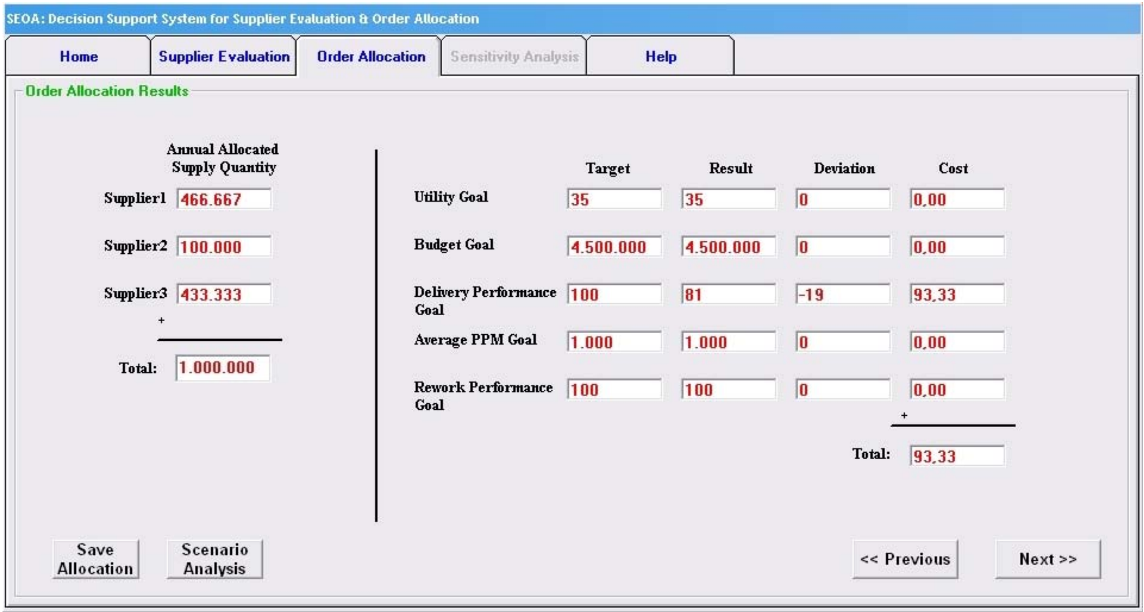

Figure 56. Order allocation results 1

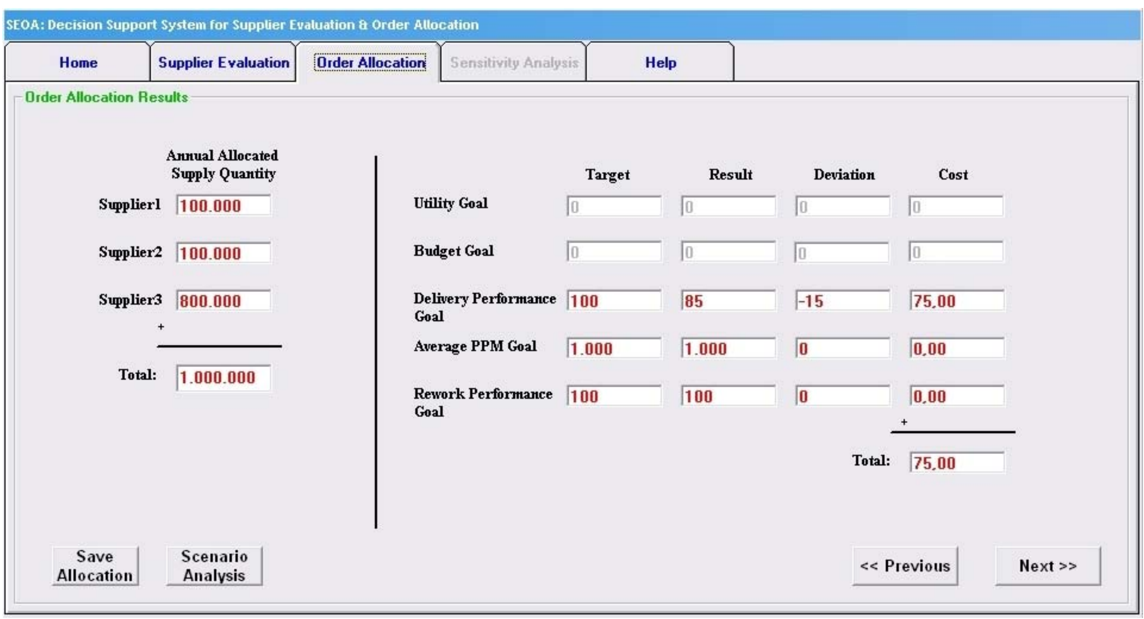

Figure 57. Order allocation results 2

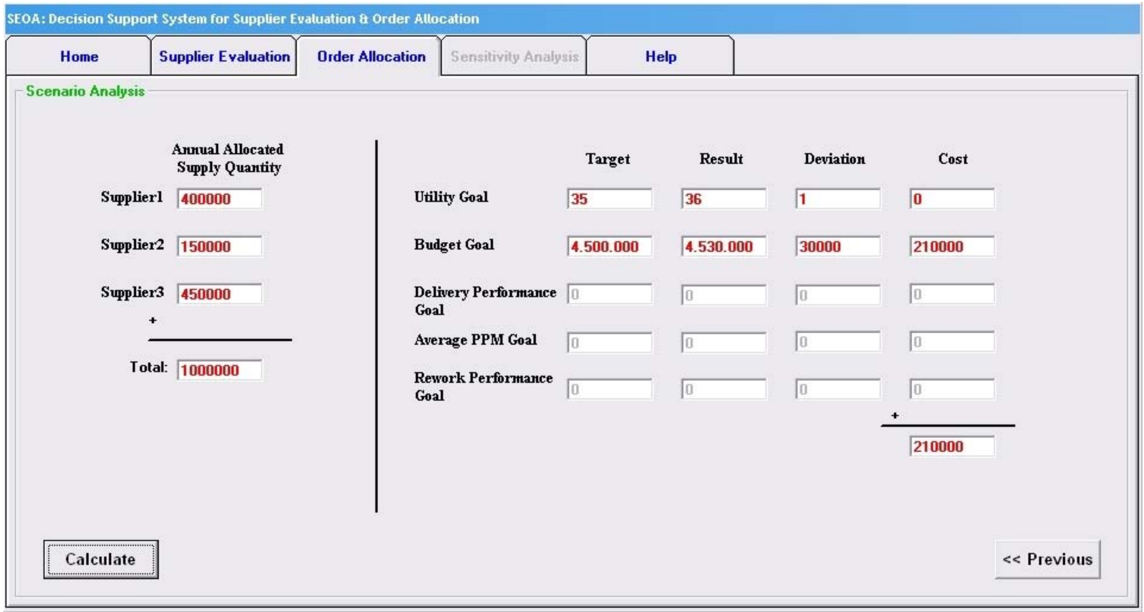

Figure 58. Scenario analysis

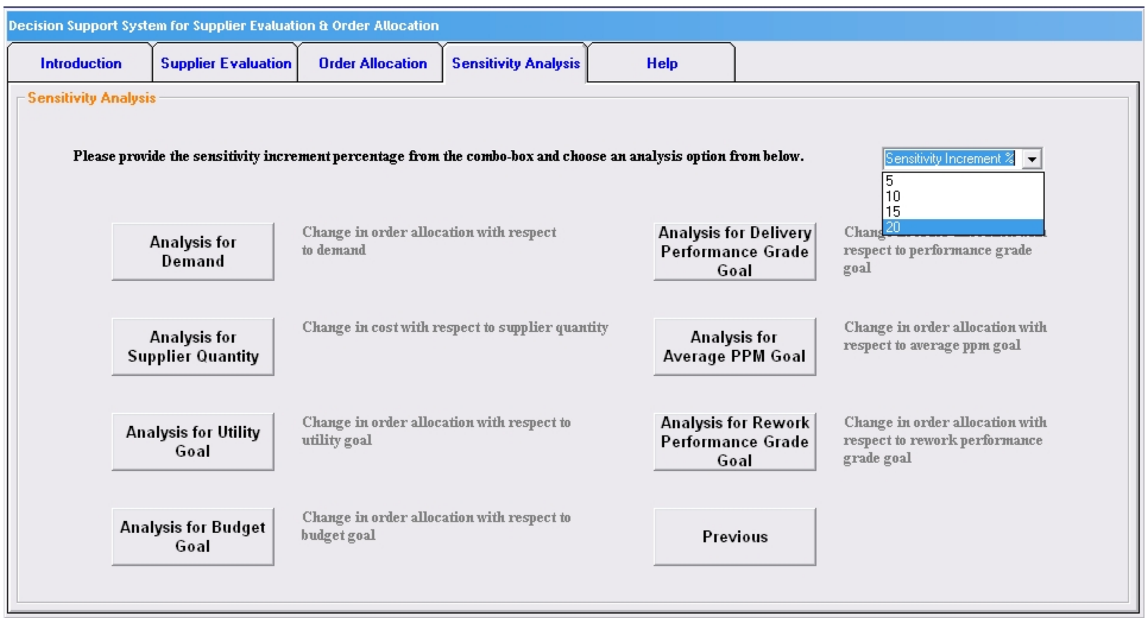

Figure 59. Sensitivity analysis list

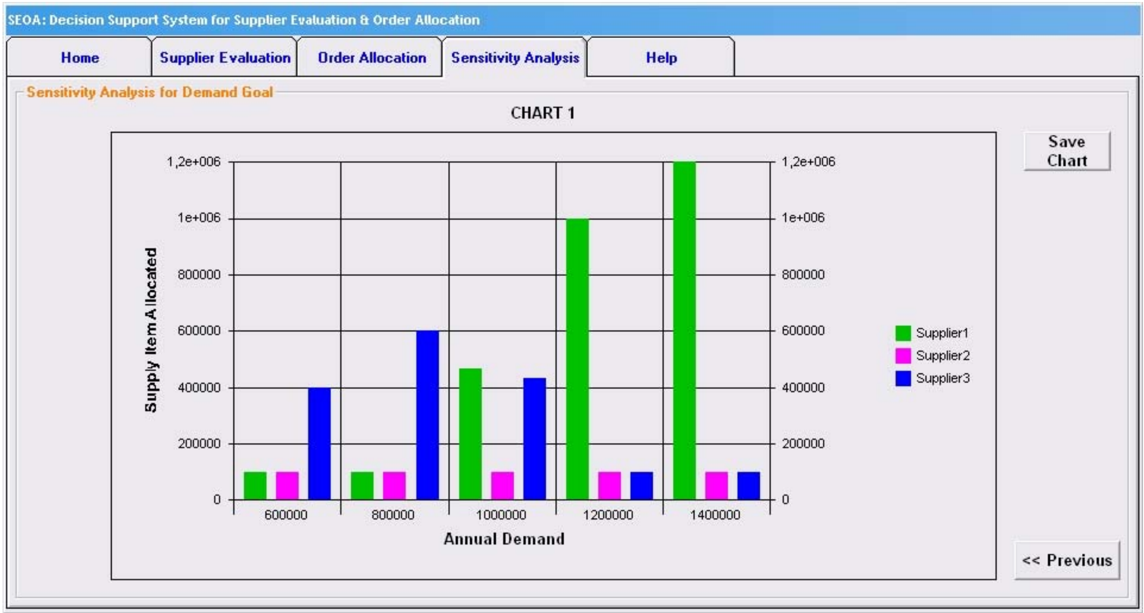

Figure 60. Sensitivity analysis for demand

As the demand increases, it is feasible to allocate more order quota to first supplier rather than the third.

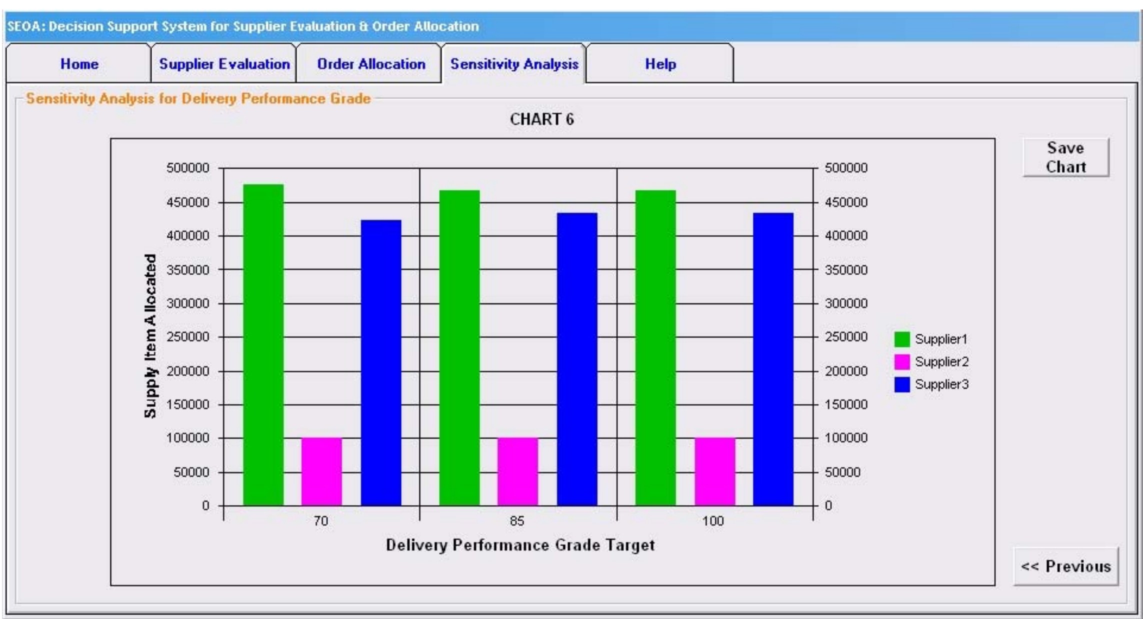

Figure 61. Sensitivity analysis for delivery performance grade

The change in the target value does not have any affect on the results.

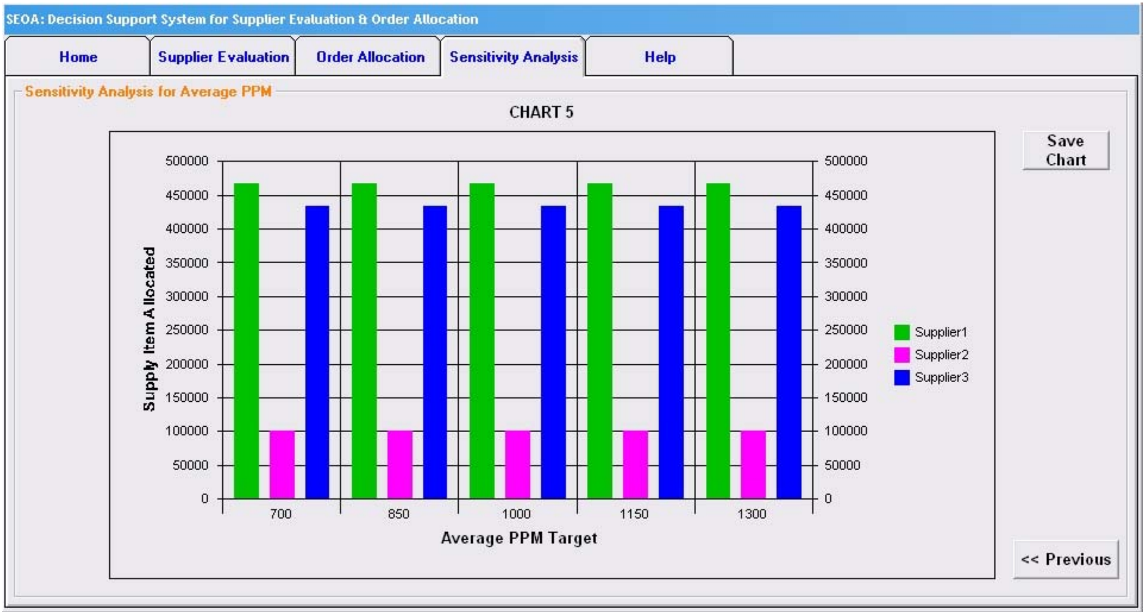

Figure 62. Sensitivity analysis for average ppm rate

The change in the target value does not have any affect on the results.

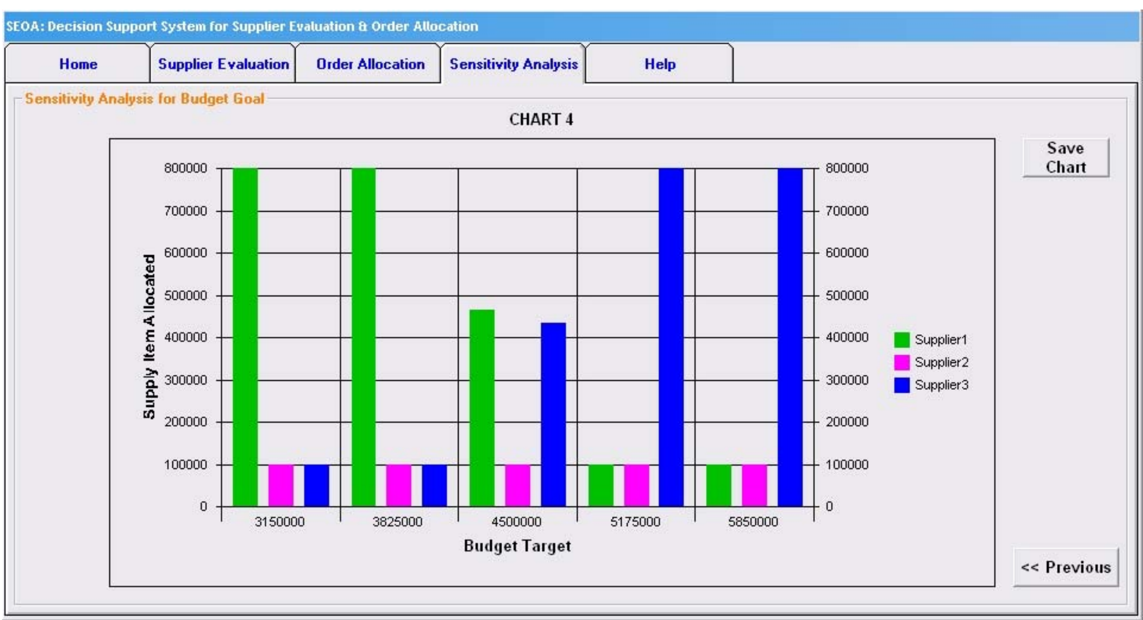

Figure 63. Sensitivity analysis for budget target

As the budget increases, it is possible to allocate more annual order quota to Supplier 3 who is more reliable on quality issues, thus whose unit purchase price is the highest.