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Development of a decision support system for supplier evaluation and order allocation

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ABSTRACT

This study aims to develop models and generate a decision support system (DSS) for the improvement of supplier evaluation and order allocation decisions in a supply chain. Supplier evaluation and order allocation are complex, multi criteria decisions. Initially, an analytic hierarchy process (AHP) model is developed for qualitative and quantitative evaluation of suppliers. Based on these evaluations, a goal programming (GP) model is developed for order allocation among suppliers. The models are integrated into a DSS that provides a dynamic, flexible and fast decision making environment. The DSS environment is tested at the purchasing department of a manufacturer and feedbacks are obtained.

1. Introduction

Successful supply chain management requires an effective and efficient sourcing strategy to eliminate the uncertainties in both supply and demand. Sourcing decisions are critical more than ever, since with the increase of the purchasing costs as compared to the overall costs, the purchasing function and the purchasing decisions have gained a considerable 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, Çelebi, & Taşkın, 2007). Thus purchasing decisions have significant effects on lowering costs and increasing profits.

Sourcing decisions have some characteristics which are affected by globalization and the recent advances in information technologies. These decisions require the analysis of large amount of data obtained globally and this raises the issue of using advanced models in decision making. Secondly, sourcing decisions require the involvement of several decision makers in the global environments that further increases the complexity of decision making. Moreover sourcing decisions are made periodically and require tracking of the supplier performances on a regular basis. Computerized decision support systems (DSS) are often proposed as a remedy to overcome the difficulties and complexities involved in such decision processes.

Purchasing processes are analyzed in two stages: first stage is the selection of suppliers formally by filtering them through an evaluation process that includes both qualitative and quantitative measures. Second stage is the order allocation where the order amounts for each supplier are determined. Although there are numerous studies in the literature for supplier evaluation and order allocation, very few companies consider these approaches in their decision making processes. The reasoning is mostly due to the fact that manual application of these models is quite time consuming, complex and most often requires a model expert. Besides, these decisions are repetitive processes; companies not only seek for a single evaluation but also need to keep track of past performances of the suppliers. Moreover, the targets and the related constraints in the decision process are subject to change in time. Thus the models should be supported by integrated databases. In application, all these features should be embedded into a DSS that provides a dynamic, fast and flexible environment for decision making. This fact is heavily emphasized in the recent studies by Ordoobadi (2009a, 2009b), Pal and Kumar (2008), Ting and Cho (2008) as well as the earlier studies by Yang and Chen (2005) and Lee, Ha, and Kim (2001). In this study, such a DSS is developed and experimented in one of the leading white goods manufacturers in Turkey. The model base includes an analytic hierarchy process (AHP) model which is developed for supplier evaluation by using qualitative and quantitative criteria. Furthermore, a goal programming (GP) model is developed that uses the evaluations of the AHP model and allocates orders among suppliers.

The organization of the study is as follows: in Section 2, a literature survey of the recent studies on supplier selection problem and DSS applications are provided. In the third and fourth sections, the methodology of the study is introduced and the multi criteria decision models are developed. In Section 5, the DSS is presented with illustrations. Finally, conclusion and future work are proposed.

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2. Literature survey

Supplier evaluation and order allocation problem has attracted the attention of several researchers in the last decade. Boer, Labro, and Morlacchi (2001) present a review of decision methods reported in the literature for supporting the supplier selection process. Göçen (2008) groups the studies in the literature according to the methodologies used for supplier evaluation/selection and order allocation respectively. In a very recent study Ho, Xu, and Day (2010) review the literature related to multi-criteria decision making approaches for supplier evaluation and selection. Accordingly, the methods used for supplier selection can be categorized as linear weighting models like analytic hierarchy process (AHP), interpretive structural modeling (ISM), fuzzy set theory (FST); Total cost of ownership models; mathematical programming models such as linear programming (LP), mixed integer programming (MIP), goal programming (GP), data envelopment analysis (DEA); statistical/probabilistic models and artificial intelligence models like case based reasoning (CBR), genetic algorithm (GA), neural network (NN), expert systems (EX).

In an overall analysis of 181 articles referenced within these studies, AHP related methodologies seem to be the most popular techniques which are applied in over 36% of the studies. This is mostly due to the fact that AHP incorporates both qualitative and quantitative evaluation of the decision maker by the use of tangible and intangible factors designed in a hierarchical manner. It is suitable, flexible and easy-to-use for multi criteria decision making and can be applied in group decision making environments as well (Ho, 2008). Although the existence of large number of pair wise comparisons brings some limitations on the number of criteria used, this method has been proposed by many researchers to capture the individual judgments with all its facets (Forman & Gass, 2001).

The supplier evaluation process is followed by the order allocation decisions that are made mostly by developing mathematical programming approaches for multi criteria decision making. The great majority of the studies in the literature are dedicated to supplier selection problem only. The integrated models, which support both supplier evaluation and order allocation, constitute 23% of all the studies in this area. By its nature, order allocation problem includes several targets to be reached and thus, GP is widely used in order allocation for the selected suppliers.

In the extensive review on the approaches adopted in supplier evaluation and selection literature, Ho et al. (2010) propose that the integrated AHP–GP approach for supplier evaluation and order allocation is the most popular method. The main reason is that both AHP and GP have unique advantages respectively. The consistency verification operation of AHP ensures the unbiased evaluation on main criteria and sub criteria by the decision maker. AHP results provide consistent weightings of alternative suppliers; however, the decision maker needs to consider other constraints such as overall budget, quality of the supplies, time limitations, technology used in production, etc. while distributing the annual supply quota to its suppliers. GP provides a suitable model to evaluate these limitations so the integrated AHP–GP approach is assessed as the most beneficial technique for supplier evaluation and order allocation (Ho et al., 2010).

In the evolutionary context, Ghodsypour and O'Brien (1998) study is the earliest work that considers an integrated AHP-LP model to choose the best suppliers and place the optimum order quantities among them. Among the followers, Çebi and Bayraktar (2003) develop an integrated model by using AHP and lexicographic goal programming (LGP) to solve the supplier selection and order allocation problem. Wang, Huang, and Dismukes (2004) combine AHP and preemptive goal programming (PGP) to solve the supplier selection and order allocation problem. Wang, Huang, and Dismukes (2005) further improve the previous study and generate a procedure to calculate the overall supply chain effectiveness based on the effectiveness of supply item, product and supplier.

In addition to these inspiring studies, there exist more recent studies published in distinguished journals between 2005 and 2010. Liu and Wu (2005) combine AHP with DEA to make better decisions in supplier selection for order allocation. Yang and Chen (2005) incorporate gray relational analysis to the AHP methodology to select the best suppliers for cooperation. Bayazit and Karpak (2005) and Bayazit (2006) develop an AHP based model for vendor selection and sensitivity analysis is proposed for optimization. Bei, Wang, and Hu (2006) develop an AHP based model to find the most preferred supplier in manufacturing supply chain. Liao and Rittscher (2007) propose a non linear mixed integer programming model where the effect of lot sizing and carrier selection is included for dynamic demand allocation to suppliers. Perçin (2006) applies AHP-PGP integrated model for the order allocation problem of an automotive manufacturer. Aguezzoul and Ladet (2007) apply mixed non-linear programming for the order allocation model and the role of transportation is examined in order diversification. Özgen, Önüt, Tuzkaya, and Tuzkaya (2008) apply a two phase probabilistic linear programming methodology for multi-objective supplier evaluation and order allocation problems. Sevkli, Koh, Zaim, Demirbag, and Tatoglu (2007) propose AHP and weighted fuzzy linear programming (FLP) to solve the order allocation problem for an electronics manufacturer. Ha and Krishnan (2008) implement an integrated model of AHP, DEA and NN for supplier evaluation. Kokangul and Susuz (2009) develop an integrated model with AHP and multi objective non-linear integer programming where quantity discounts are incorporated at the mathematical model.

Although substantial modeling studies have been made for supplier evaluation and order allocation, the implementations by an advanced DSS is very few. Owing to the fact that supplier evaluation and order allocation decisions are multi criteria problems and require lengthy analysis on a periodical basis, it is recommended to implement the proposed methodologies into computer software and internet-based tools (Lee et al., 2001; Ordoobadi, 2009a, 2009b; Pal & Kumar, 2008; Ting & Cho, 2008; Yang & Chen, 2005).

There exist few numbers of studies which come up with a DSS development, but consider only the supplier evaluation problem. Humphreys, Huang, and Cadden (2005) develop a web based supplier evaluation tool by using expert systems. Humphreys, Wong, and Chan (2003) develop a knowledge-based DSS tool which helps companies to integrate environmental criteria into their supplier selection process. Choy et al. (2002a), Choy, Lee, and Lo (2002b) implement intelligent supplier management tools via case based reasoning and neural network. Akarte, Surendra, Ravi, and Rangaraj (2001) use AHP as a web based tool for the supplier evaluation process. Vokurka, Choobineh, and Vadi (1996) develop a prototype expert system to evaluate the potential suppliers.

Choi and Chang (2006) is the only study where a DSS is developed for the integrated problem of supplier evaluation and order allocation in a business to business e-procurement environment. Their approach is based on a two phased optimization that semantically builds a goal model through model identification and candidate supplier screening by a set of predefined rules. Our current study is similar to this study since a GP model based DSS is generated both for supplier evaluation and order allocation. However, it differs from this study with the inclusion of an AHP model that also handles the qualitative criteria in supplier evaluation. Furthermore the GP model is set with a different perspective of formulating the goals.

In the light of the literature review conducted, a DSS is developed in the next section which incorporates a dynamic, flexible and fast multi criteria decision making environment for both the supplier evaluation and order allocation problems by using the integrated AHP–GP modeling approach.

3. Methodology

Supplier evaluation and order allocation are complex multi criteria decisions. In this study, an analytic hierarchy process (AHP) model is developed that captures both the qualitative and quantitative criteria of supplier evaluation. The related evaluation criteria tree is formed by using the approaches in the literature and discussing these with the purchasing executives of the largest white goods manufacturer in Turkey.

In the next step, a goal programming (GP) model is developed for order allocation which uses the results of the AHP model. The model is used to allocate the yearly ordering quota among the suppliers by considering their past performances and other additional goals and constraints.

Manual application of the supplier evaluation and order allocation models is time consuming, complex and requires an expert. Besides, companies need to monitor the past performances periodically. Moreover, the weights of the evaluation criteria and the goal targets in the decision process change in time. With this motivation, in the third step, a DSS is generated that provides a dynamic, flexible and fast environment for data input, reporting, scenario and sensitivity analysis. Finally the DSS is experimented in the purchasing department of the selected manufacturer and practical implications are discussed.

4. The decision models

4.1. The current system

The company under study is one of the leader players in the Turkish white goods sector. Purchasing processes are carried out by the Purchasing Directorate that reports directly to the general manager. There are approximately 7000 manufactured goods and the marketing department forecasts the annual monthly sales for each good during the annual budget planning. When the final budget is approved by the management, the monthly production targets are sent to the production department where the production plans are made and supply item requirements are determined.

As a purchasing policy, the purchasing department chooses to work with at most 3–4 suppliers for most of the supply items since it is aimed to develop long term relationships with less number of 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 order quota to every supplier. If the supply item is a fast moving item which can be obtained from several sources, the company uses the aggressive competition between the suppliers in e-bidding environments to decrease the unit purchase price. 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.

4.2. The supplier evaluation model

In the literature, the criteria considered in supplier evaluation are numerous; however the most common issues that appear in almost every study are cost, quality, technology infrastructure, delivery performance and business issues (Wang et al., 2004; Çebi & Bayraktar, 2003). Based on 23 criteria that were originally developed by Dickson (1966), Weber, Current, and Benton (1991) review 74 articles which address vendor selection criteria in manufacturing and retailing environment and state that the priority of criteria depends on the firm's strategic management decisions. Bache, Carr, Parnaby, and Tobias (1987) and Rae, Suresh, and Turoff (1997) identify 60 criteria for supplier selection. Among these the most significant ones are price, quality, availability and delivery. Hou, Su, and Hull (2004) argue that in general potential suppliers are evaluated on several criteria such as technical capability, material selection, production technology, prices, product quality, service and geographic location. In the recent studies, there is an increasing consideration of the factors related to business perspectives. Thus the organization's vision, mission, priorities, ethical issues, corporate culture and potential for growth should also be taken into consideration.

During the study, these issues are discussed with the purchasing executives of the company and the resulting criteria are summarized as an AHP tree as shown in Fig. 1. Accordingly, the basic concerns in supplier evaluation are based on the issues of cost, quality, logistics and technology. Issues related to business policy are excluded since they are in the form of constraints rather than evaluation criteria for supplier selection. In other words, the suppliers which do not have any potential to work with in the future are eliminated from further evaluation.

The evaluation process of the potential suppliers on cost issue is discussed by the purchasing department and agreed upon three sub criteria. Here, unit purchase price is defined as the price of a single item that the supplier charges to the company with the added transportation cost. Terms of payment slightly differs between the suppliers depending on their financial status. For instance a supplier may ask prepayments before the order delivery which makes him less preferred among others. Cost reduction projects are the discount offers proposed by the suppliers and a supplier that comes up with frequent cost reduction projects is preferred.

Quality related sub criteria are evaluated by the production department and the quality department at each facility. Here, perfect order fulfillment is defined as the level of defective items delivered to the company and it is measured in parts per million (PPM). The quality level of the after sales services is the second issue. Application of quality standards is evaluated in accordance to the existence of a quality department, documentation of quality systems and commitment of management to the quality issues. It also includes the environmental concerns of the supplier and is evaluated on the ISO related standards. Corrective and preventive maintenance system is measured in accordance to the number of incidences occurred and recovered by the supplier in the previous periods. The sub criterion for improvement efforts in quality refers to the supplier's continuous efforts on improving its quality standards.

Logistics related sub criteria are evaluated by the production planning department. Suppliers are evaluated according to their on time delivery, order lead time, delivery conditions and packaging standards. Flexibility of Transportation is another issue defined as the ability to transport flexible order quantities. The supplier is more flexible in order quantities if it can adapt to sudden changes in lot sizes. Geographic distance brings monetary advantage and reduces loss of time in case of a change in the production plan.

The last main criterion which will be rated by the production department at each facility is the technological performance of the supplier. Allocated capacity is defined as the portion of the supplier's annual production capacity dedicated to the company and a supplier with higher allocation is preferred. Flexibility of capacity is described as the ability to increase the production level due to

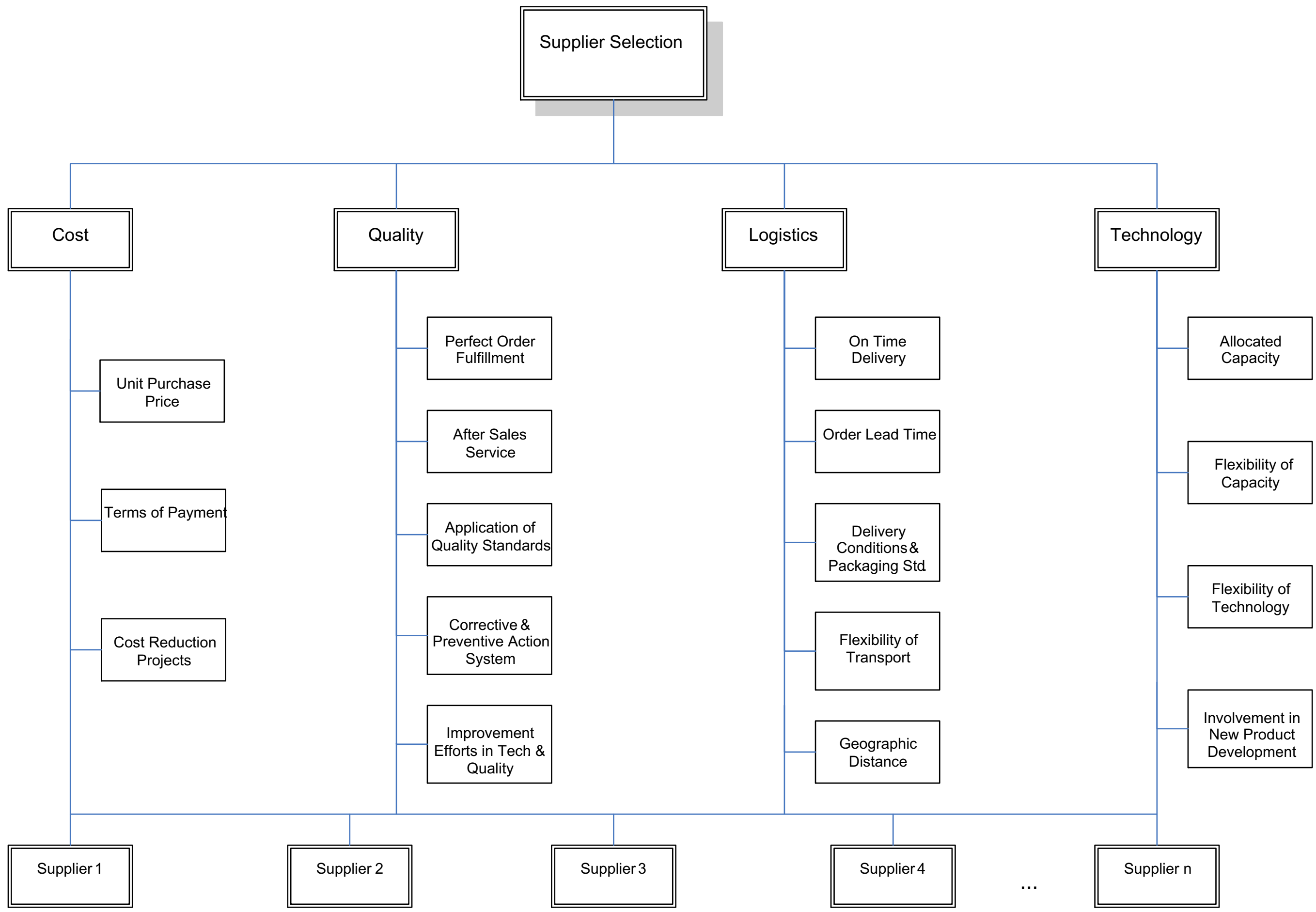

Fig. 1. Supplier evaluation model.

increases in the demand rate. Flexibility of technology encapsulates the technological requirements for the production line and the support services. Supplier that can adapt their technologies to the changing needs of the manufacturer is preferred. Finally, involvement and potential in new product development defines how dedicated a supplier is to become a real partner and support the company for new product development projects.

The evaluation of the relative weights of the main criteria and the sub criteria is done by using pair-wise comparisons of AHP methodology. According to the AHP methodology that is explained in detail in Saaty and Vargas (2001), equally important criteria pairs receive 1 point and the criterion that is absolutely more important in the comparison gets 9 points. Similarly the criterion that is absolutely less preferred to its pair receives 1/9 in criteria evaluation. After checking the consistencies in evaluations, the relative weights of each criteria and sub criteria are determined and candidate suppliers are evaluated by using the classical AHP approach. At this point, the lowest grade suppliers are eliminated and the grades of the successful candidate suppliers are input to the order allocation model.

4.3. The order allocation model

Purchasing department gives periodical orders to the suppliers and allocating this order among the suppliers is one of the main concerns of this department. In this section a GP model is developed to determine the annual order quotas for the successful suppliers selected 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 the order allocation model, five goals are identified among which the company should make a selection and identify target levels. The details of the order allocation model are given below for n candidate suppliers determined by the supplier evaluation model:

4.3.1. Mathematical formulation

4.3.1.1. Decision variables.

X_i: Annual order quota for supplier i $i = 1,2,\ldots,n$.

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

4.3.1.2. Parameters.

U_i: Rating of supplier i obtained from AHP model $i = 1,2,\ldots,n$.

C_i: Unit cost of supply item from supplier i [YTL/unit] $i = 1,2,\ldots,n$.

T_i: Annual transaction cost for supplier i [YTL/supplier] $i = 1,2,\ldots,n$.

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

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

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

A: Annual expected demand [units/year].

S: Number of suppliers to work with [suppliers].

$Q_{\min}$: Minimum annual quota that can be allocated to a selected supplier [units/year].

4.3.1.3. Goals.

(i) Maximize overall supplier utility:

$$\sum_{i=1}^{n} U_i \frac{X_i}{\sum_{i=1}^{n} X_i} \geqslant \textit{Utility goal}, \quad i = 1, 2, \ldots, n. \tag{1}$$

(ii) Minimize total cost:

$$\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} T_i Y_i \leqslant \textit{Budget goal}, \quad i = 1, 2, \ldots, n. \tag{2}$$

(iii) Maximize overall delivery performance:

$$\sum_{i=1}^{n} D_i \frac{X_i}{\sum_{i=1}^{n} X_i} \geqslant \textit{Delivery performance goal}, \quad i = 1, 2, \ldots, n. \tag{3}$$

(iv) Minimize defective material level:

$$\sum_{i=1}^{n} P_i \frac{X_i}{\sum_{i=1}^{n} X_i} \leqslant \textit{Average PPM goal}, \quad i = 1, 2, \ldots, n. \tag{4}$$

(v) Maximize overall rework performance:

$$\sum_{i=1}^{n} R_i \frac{X_i}{\sum_{i=1}^{n} X_i} \geqslant \textit{Rework performance goal}, \quad i = 1, 2, \ldots, n. \tag{5}$$

The first goal in order allocation is to maximize the overall utility which is a function of the suppliers' grades, U_i obtained by the AHP evaluation as seen in Eq. (1). The overall utility is defined as the sum of the supplier grades, U_i weighted by the proportion of the allocated quantities to the suppliers, X_i. The aim is to allocate more quotas to the more preferred supplier.

The second goal is to minimize the total purchasing cost and the operational costs of the order allocation as in Eq. (2). Operational costs are defined as the transaction costs of working with a specific supplier. Total transaction cost increases as the number of suppliers increase.

The third goal in Eq. (3) 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, 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, D_i is evaluated and a supplier with less blocking experiences is assigned a higher delivery performance grade. The overall delivery performance of an order allocation is the weighted sum of the delivery performance grades of the suppliers, D_i where the weights are the proportions of the allocated quantities to the suppliers, X_i.

The fourth and the fifth goals in Eqs. (4) and (5) are related with the quality performance of the suppliers. The company keeps track of the quality performance of each supplier by using two metrics: The PPM-level showing the defective rate, P_i and the rework performance, R_i. 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 the number of parts per million. A high PPM-level, P_i disturbs the smooth flow of operations in production, since 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, P_i weighted by the proportion of allocated order quantities to each supplier, X_i.

The final goal in Eq. (5) 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 after being sold to the customer. Rework process brings extra cost to the company and furthermore decreases the effective production time. The rework performance of each supplier, R_i 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, R_i, weighted by the proportion of the allocated quantities to each supplier, X_i.

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 the selected goals during their application. In addition to these goals, there are regular constraints that have to be satisfied by the orders allocated to the selected suppliers.

4.3.1.4. Regular constraints

(i) Demand constraint: Annual demand should be satisfied.

$$\sum_{i=1}^{n} X_i \geqslant A, \quad i = 1, 2, \ldots, n. \tag{6}$$

(ii) Supplier quantity constraint: S suppliers should be selected from n suppliers.

$$\sum_{i=1}^{n} Y_i = S, \quad i = 1, 2, \ldots, n. \tag{7}$$

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

$$X_i \leqslant MY_i, \text{ where } M \text{ is very large and}, \quad i = 1, 2, \ldots, n. \tag{8}$$

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

$$X_i \geqslant Q^*_{\min} Y_i, \quad i = 1, 2, \ldots, n. \tag{9}$$

The first constraint in Eq. (6) is the fulfillment of the demand, i.e., the company has to purchase at least the required quantity of supply items. Second constraint in Eq. (7) restricts the number of suppliers to work with. In most cases the company prefers to work with 2–3 suppliers to be more flexible against several risks. Third constraint in Eq. (8) is set to make sure that an order is allocated to a supplier if and only if it is selected. Fourth constraint in Eq. (9) defines the minimum level of quota to be allocated to a selected supplier.

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

4.3.1.5. Goal deviation constraints.

Utility goal:

$$\sum_{i=1}^{n} U_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_1^+ - Y_1^-) = \textit{Utility goal}, \quad i = 1, 2, \ldots, n. \tag{10}$$

Budget goal:

$$\sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} T_i Y_i - (Y_2^+ - Y_2^-) = \textit{Budget goal}, \quad i = 1, 2, \ldots, n. \tag{11}$$

Delivery performance goal:

$$\sum_{i=1}^{n} D_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_3^+ - Y_3^-) = Delivery\ performance\ goal, \quad i = 1,2,\ldots,n. \tag{12}$$

Average PPM goal:

$$\sum_{i=1}^{n} P_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_4^+ - Y_4^-) = Average\ PPM\ goal, \quad i = 1,2,\ldots,n. \tag{13}$$

Rework performance goal:

$$\sum_{i=1}^{n} R_i \frac{X_i}{\sum_{i=1}^{n} X_i} - (Y_5^+ - Y_5^-) = Rework\ performance\ goal, \quad i = 1,2,\ldots,n. \tag{14}$$

4.3.1.6. Objective function. Omnibus objective function of the GP model is developed to minimize the total deviation cost from the selected target levels where α_j^+ and α_j^- are the respective deviation costs for goal j, $j = 1,2,\ldots,5$, input by the decision maker.

$$Minimize\ total\ cost\ of\ deviation = \sum_{j=1}^{5} \alpha_j^+ Y_j^+ + \alpha_j^- Y_j^-. \tag{15}$$

5. The decision support system environment

5.1. The DSS architecture

The DSS environment generated in this study is developed with Microsoft Visual Basic 6.0 and it is named as "SEOA" that stands for Supplier Evaluation and Order Allocation. The environment provides an easy graphical user interface (GUI) for making evaluations, inputting parameter values, running models, getting reports and making sensitivity analysis. 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 controlled at each stage for consistency and data entry errors. Sensitivity reports are generated to view the change in order allocation with respect to a change in the demand, minimum supplier quantity or target levels.

Microsoft Office Excel 2003 environment is used for the input and output purposes. However in application, it should be enhanced to be compatible with the current database structure of the company. Model base consists of the AHP model for supplier evaluation and the GP model for order allocation developed in the previous section. The order allocation model uses "What's Best" solver provided by Lindo Software Co.

The scheme of the DSS environment is presented in Fig. 2. Firstly the decision maker submits the main criteria and sub criteria weights for supplier evaluation to the supplier evaluation model, i.e., AHP model. At each step the consistency of the pair wise comparisons is controlled and the final supplier scores are input to the order allocation model, i.e., GP model. Next the decision maker enters the inputs of the GP model like the selected goals, their target levels and the parameters for constraints. The annual quota diversification that is obtained by the GP model solution is submitted to the sensitivity analysis module where the sensitivity for demand, budget and quality (PPM) targets can be further investigated.

5.2. Illustration of the DSS by an application

In this section, the DSS environment is illustrated by an application in a white goods manufacturer in Turkey. Two executives from the purchasing department are asked to use the DSS with their own data for a selected raw material.

The SEOA software is designed in a tabular form and supported by Help options in every screen. The end-user opens the supplier evaluation window in Fig. 3 by proceeding through Next button

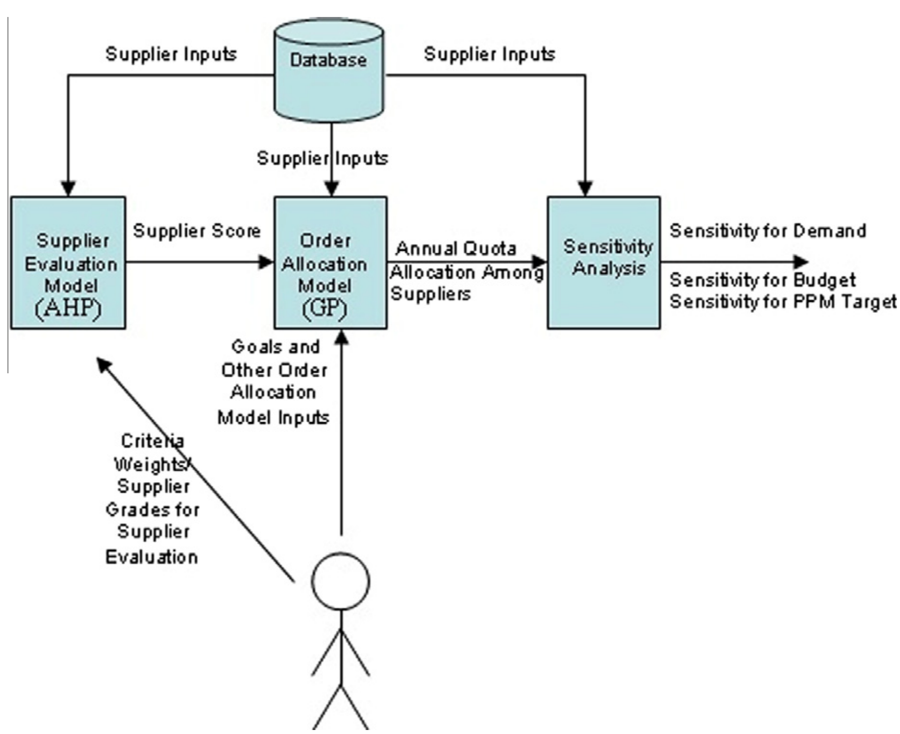

Fig. 2. The scheme of the DSS environment.

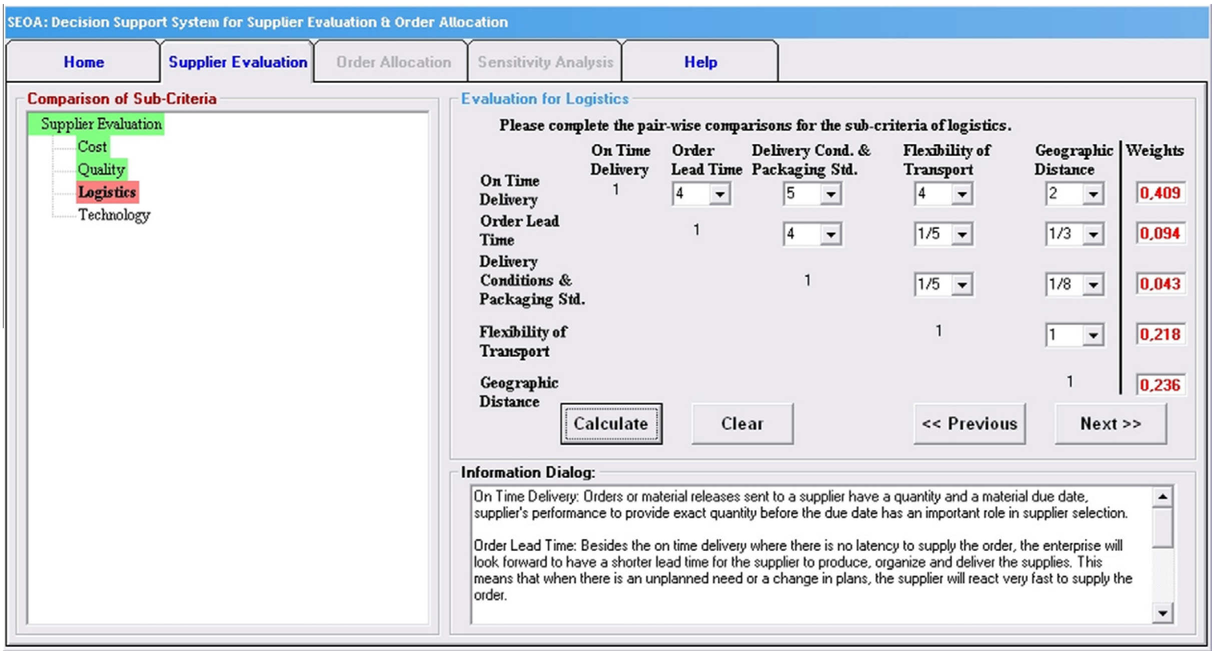

Fig. 3. Progress in evaluation.

on the Home screen. The main criteria of the hierarchy tree, i.e., cost, quality, logistics and technology are on the left hand side. The sub criteria evaluation matrix for the selected main criteria is placed on the right and the decision maker uses the comboboxes for data input. On the bottom, the descriptions of the compared sub criteria are placed to provide information. A reminder is displayed on the screen, if the user leaves a comparison blank. Finally the consistency check of the evaluation is made and the resulting weights are displayed on the right. In this example, criteria for geographic distance and flexibility of transportation receive the highest weights of 0.236 and 0.218 respectively. Note that all these weights add up to one. Similarly, as the user progresses, the evaluated criteria appear in green color on the left menu, leaving the currently evaluated criteria in red color and bold font.

Criteria weights evaluation is followed by the supplier evaluation and the resulting supplier grades are displayed as in Fig. 4. The resulting grades for the three suppliers are 0.277, 0.246 and 0.477 respectively, showing that the third supplier is more preferred among others. At this point, the user may select the suppliers to work with by eliminating the low grade suppliers 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 Save Evaluation button for future reference. In this example the user selects all three suppliers for order allocation and proceeds to the next step.

In the order allocation screen in Fig. 5, the user is asked to choose the goals to be added to the GP model. Initially all five goals

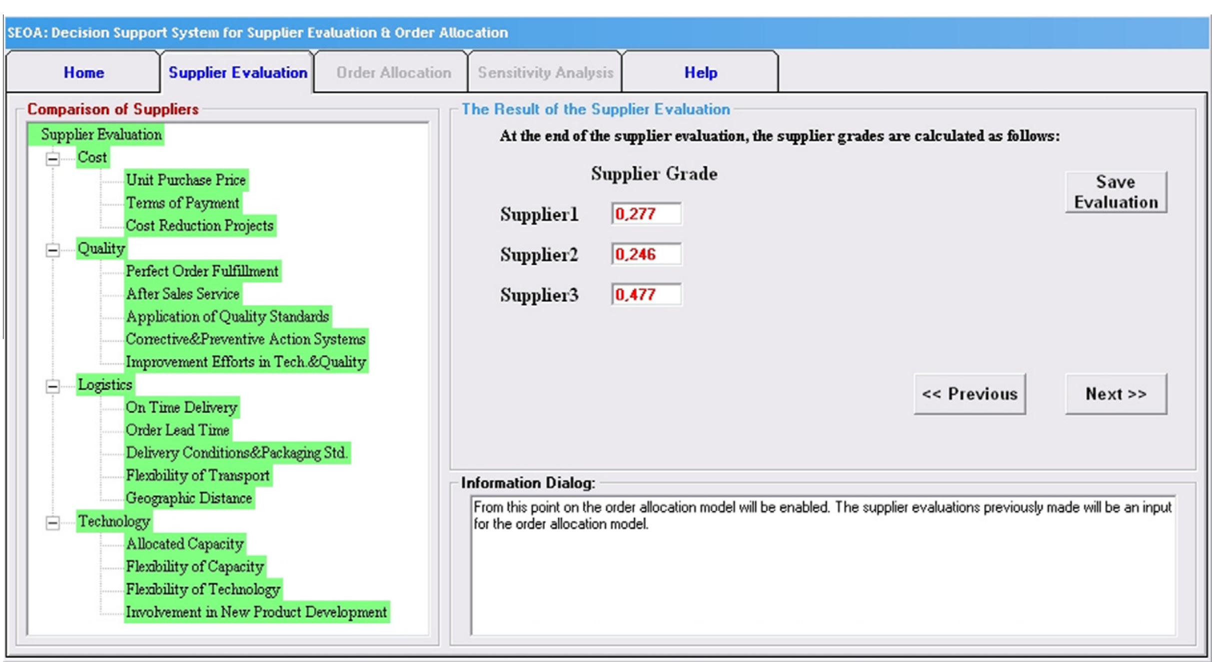

Fig. 4. Resulting grades.

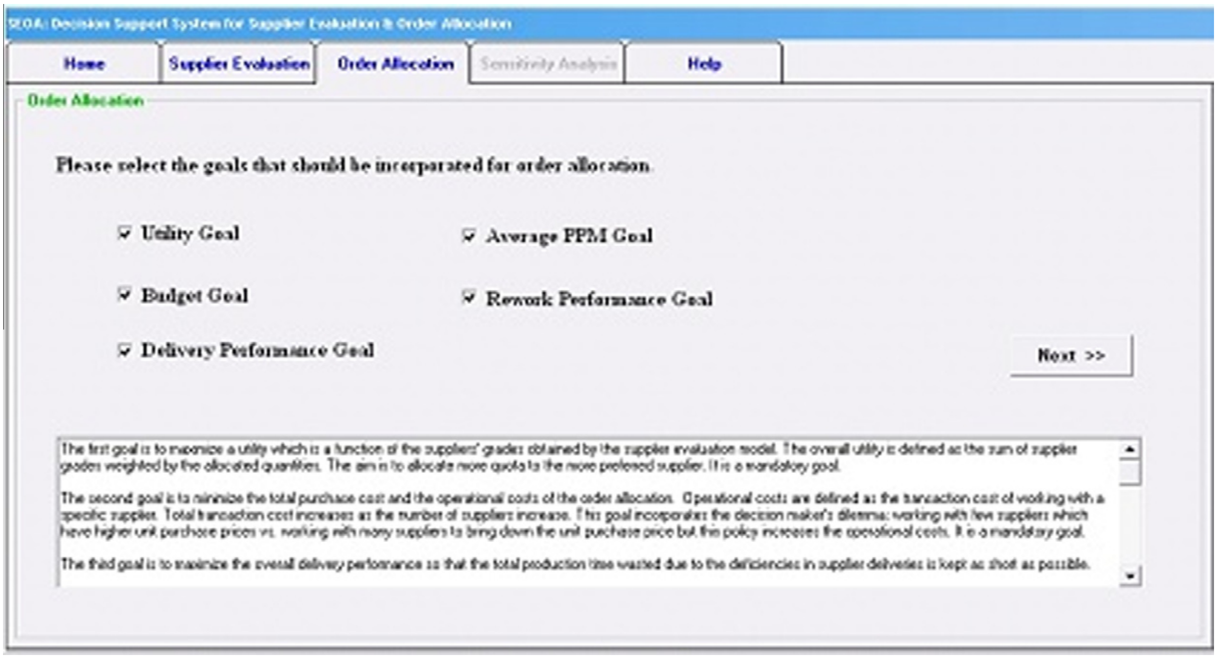

Fig. 5. Goal setting.

are selected. According to the number of suppliers selected in the supplier evaluation process and the goals set, the supplier inputs are submitted as seen in Fig. 6. Here, the goal targets and the deviation costs are entered where the annual demand to be allocated is 1 million units, minimum number of suppliers to work with is 3 and minimum quota allocation to a single supplier is 100,000 units.

As a result, the order allocation is interpreted by the mathematical solver software What's Best and the report in Fig. 7 is displayed. In this example, 1 million units is allocated among three suppliers where the first one gets 466,667 units, second one gets 100,000 units and third one gets 433,333 units. With this allocation, all goals except the delivery performance goal are met. At this point, the end user has the opportunity to go through what-if analysis and find out the solutions of alternative scenarios with different selection of goals and input parameters.

In an alternative scenario analysis, if the utility and budget goals are removed from the order allocation model, the results change as seen in Fig. 8. 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 parameters regarding these issues; therefore, it gets the highest annual order quota of 800,000 supply

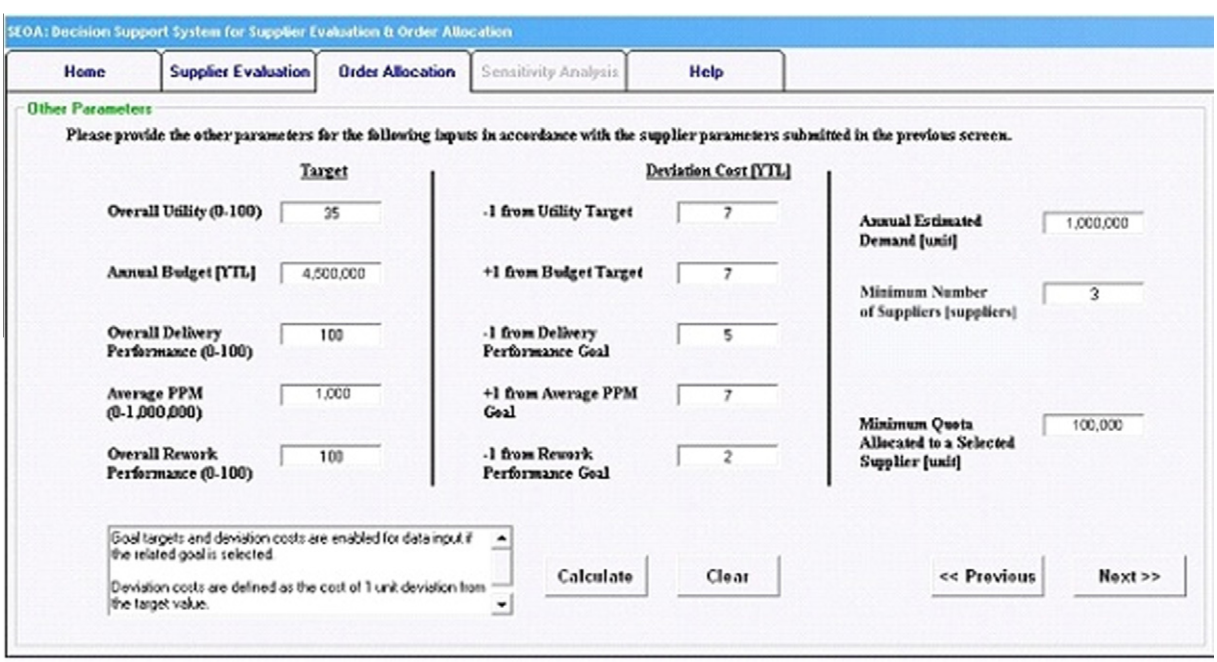

Fig. 6. Input screen.

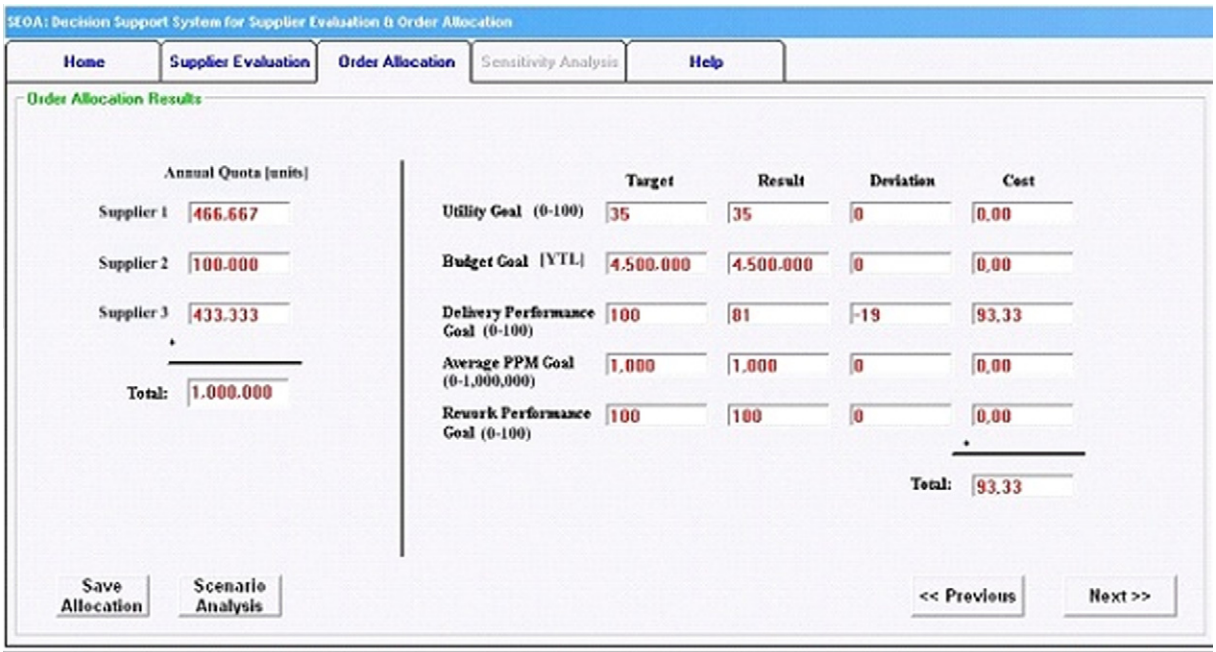

Fig. 7. Order allocation results – 1.

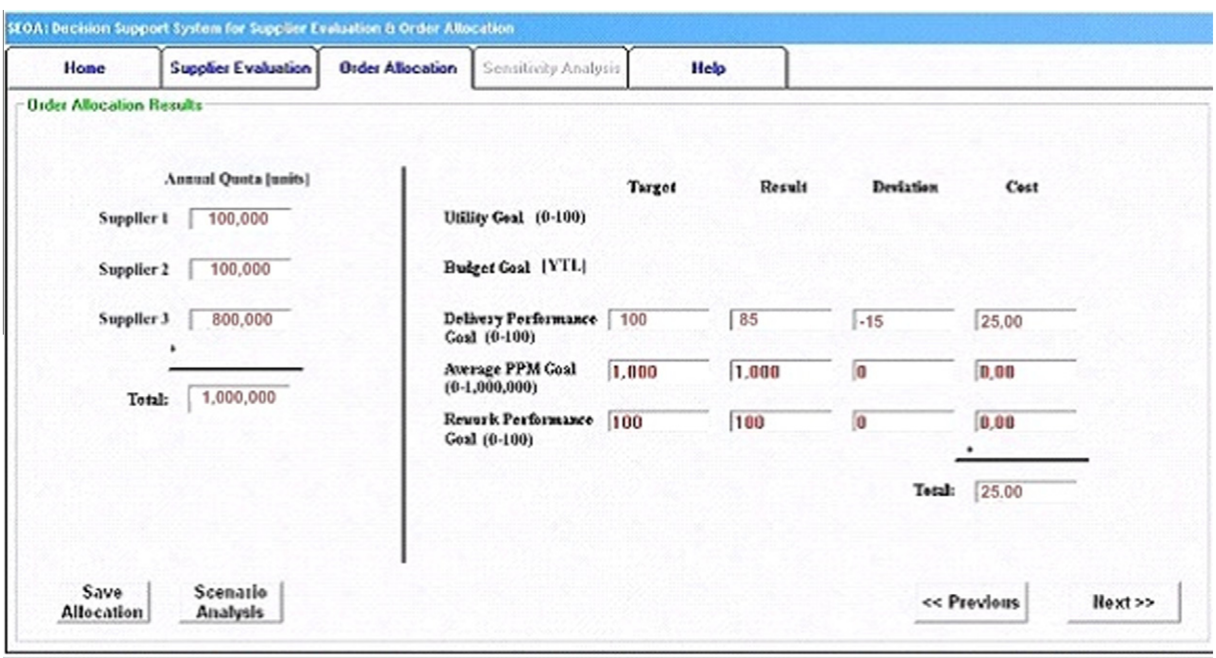

Fig. 8. Order allocation results – 2.

items and the other suppliers get 100,000 supply items each because the company chooses to work with at least three suppliers and the model allocates at least as much as the minimum quota to a selected supplier. This time the optimal total goal deviation cost is smaller since there is less number of selected goals. The delivery performance goal is still not attained; however it is closer to its target in the second scenario.

Finally, sensitivity analysis can be conducted for the input parameters of annual demand, goal target levels, etc. A sensitivity analysis showing the change of optimal allocation with respect to the changes in the annual demand is given in Fig. 9 and it can be saved to a directory by clicking Save Chart button for comparison.

5.3. Evaluation of the DSS environment by the company

Eventually, the efficiency of the DSS is assessed by the executives of the purchasing department and the environment is enhanced in accordance to these feedbacks. It is stated that in general, the DSS provides a fast, dynamic and flexible environment for sourcing decisions. Noting that the supplier evaluation and order allocation decisions are repetitive, the DSS provides a reliable monitoring environment based on standard evaluations with several different aspects.

The difficulties faced during implementation are mostly due to the frequent error messages indicating inconsistencies in AHP

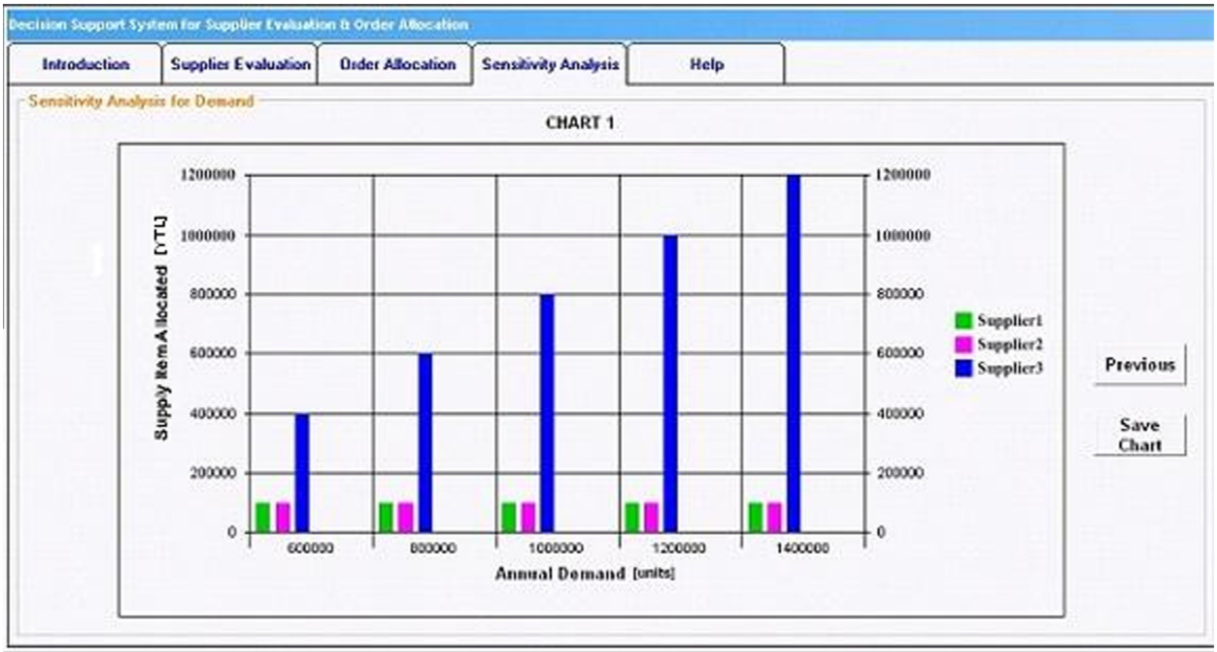

Fig. 9. Sensitivity analysis for demand with order allocation results – 2.

evaluations. Noting that this is one of the major drawbacks of AHP methodology, a detailed explanation for consistency is added to the information dialog to overcome this difficulty.

Another feedback acquired from the purchasing executive is on the measurability of the delivery performance and rework performance in the GP model. These were initially measured quantitatively as the proportion of late deliveries and proportion of rework respectively. However it is stated that these issues include other concerns like attitude and responsiveness of the supplier, duration of late delivery, etc. Hence it is agreed to evaluate the performances for delivery and rework in an overall manner by incorporating these new attributes.

For setting the scales of the measures, it is observed that the managers provide the easiest and fairest evaluation by using the standard measures and scales that they are used to in their current evaluation system. Thus PPM is used to measure the defectives rate, since it is a standard measure in the current evaluation system. However, the standard scale [0–100] is used for the overall evaluation of new measures of delivery and rework performance.

In the GP application, the major difficulty is encountered in the initial setting of the goal targets and their deviation costs. To facilitate the appropriate determination of the unit goal deviation costs, the users are asked to experiment in the DSS environment and gain insight for the behavior of the models. To overcome these difficulties, the DSS is enhanced by what-if analysis and sensitivity analysis suit to help the users learn the behavior of the models.

Apart from the modeling aspects, the GUI of the DSS is also evaluated by the users with respect to its clarity and consistency as suggested by Şeref, Ahuja, and Winston (2007). The error checks and help options provided on every screen are all found to be useful and enhanced on some pages. The clearness of the instructions, labeling and control tips, setting default values are all revised in accordance to the feedbacks. Noting that the users are inclined to interact with an interface according to their expectations in input prompts, button locations or viewable options, the navigation and calculations buttons, are grouped separately. Moreover, these buttons and the sheet titles are kept at the same position on every screen to attain consistency. It is observed from the feedbacks that such features increase the ease of use of the DSS environment.

6. Conclusion

In this study, integrated AHP-GP models and a DSS are developed for one of the leaders of the white-goods manufacturing sector in Turkey. The DSS environment provides the decision maker the ability to evaluate the possible suppliers according to the pre-defined criteria and sub criteria. The user has the opportunity to optimally diversify the annual quota to these suppliers according to the selected goals and the purchasing policies. The efficiency of the DSS is assessed by the company and the software is enhanced in accordance to these feedbacks.

Supplier evaluation and order allocation problem includes several qualitative and quantitative comparisons. Major drawback of optimization models is their inability to cope with qualitative measures. This problem is overcome by the inclusion of the AHP methodology in the evaluation process. Nevertheless, based on these evaluations, optimal allocation is made by the GP model. Second issue that is raised by this study is the incorporation of the DSS environment that supports the model applications. In accordance with the rapidly changing marketing and manufacturing conditions, decision maker needs a fast, dynamic and flexible decision making environment where he/she can select from a set of objectives, define new ones, change the existing ones, etc. The decision maker needs to learn the behavior of the system by the use of scenario and sensitivity analysis. Finally the DSS can be used to monitor the supplier performances with respect to time.

As future work, the DSS environment may be enhanced by adding simulation features to observe the percentage of late deliveries and order fulfillment when the demand rate and order lead times are random. Another enhancement option is to develop the supplier evaluation model with the group decision making perspective that allows group collaboration and discussion.

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