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AN INTEGRATED APPROACH FOR SUPPLIER SELECTION IN MILITARY CRITICAL APPLICATION ITEMS

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ABSTRACT. Supplier selection for defence procurement is a crucial function of a Ministry of Defence. The Ministry spends huge amounts of money each year to procure a vast array of equipment, goods and services. The ongoing financial crisis demands less subjective and more cost-saving methods for selecting a supplier. The approach advocated in this article integrates Analytic Hierarchy Process (AHP) with Goal Programming (GP) in order to combine conflicting criteria to select the best suppliers and allocate optimum order quantities among them. This paper presents a model close to real-world situations. Findings demonstrate that cost savings is a feasible result along with a viable combination of conflicting criteria in the suppliers' selection area.

INTRODUCTION

Military procurement is an important function of a Ministry of Defence (MoD), as indicated by several financial data. In general, U.S. suppliers account for 50 to 80 percent of major items' value (GAO-98-87, 1998). Additionally, in fiscal year 2006, the US Army's purchases of weapons, goods, and services, comprised 58 per cent of its budget (RAND Corporation, 2012). Hellenic MoD's defence budgets for the years 2014-2017 fluctuate from €2.968 to €2.852 billion (Hellenic Ministry of Finance, 2013) allocating a significant portion for military procurement. The MoD is one of three main pylons of the National

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Defence Frame of Greece which, in general, consists of the following (Hellenic Ministry of Defence, 2014):

- The Permanent Committee of National Defence and Foreign Affairs of the Parliament.
- The Governmental Council on Foreign Policy and National Defence, presided over the Prime Minister.
- The Ministry of Defence. A detailed analysis of the departmental organization of the Hellenic MoD is shown in Appendix B at the end of the manuscript.

The Hellenic MoD procurement actions take place within the Greek legal framework on Public Procurement for products and services, which is separated into two major categories. The category of our concern is related to defence and security products and services. It is mainly governed by National Law 3978 of 2011 which transposed European Directive (ED) 2009/81 into the Hellenic Legislation and provided the main frame for current military procurement. The law 3978 (2011) strengthens the transparency of the defence policy by calling for independent scrutiny and co-operation of the main organs of the MoD that deal with military procurement. It also provides rules for supplier selection, offers/bids evaluation and contract awarding as well as the judicial frame of all administrative provisions related to the application of review procedures for the award of public contracts.

In the academic literature of Procurement, the need for public/private sector cooperation, in order to resolve procurement issues, has already been highlighted (Choi, 2010). Consequently, the existence of several sophisticated and popular supplier selection tools in the private sector allows hopeful thoughts for their use in the public sector. Towards this direction, Tadelis (2012) argued for the need to enhance the tools that are currently at the disposal of public sector procurement offices from the private sector, without limiting the transparency of the selection/evaluation procedures. Ho, Xiaowei, and Prasanta (2010) provided a spectrum of the supplier evaluation and selection methods/models used widely in the private sector, pointing out that the integrated Analytic Hierarchy Process-Goal Programming approach is the most popular method. Goal Programming, a branch of multi-criteria decision-making analysis (Tamiz, Jones, & Romero, 1998), is useful in real world decision-making problems involving multiple conflicting objectives and goals (Ignizio & Romero, 2003). Supplier selection is one of these problems, requiring trade-offs among multiple criteria that are tangible and intangible (Cebi & Bayractar, 2003).

Additionally, the ability to evaluate procedures with measurement tools has been shown to be as of great importance in both defensive and non-defensive sectors. In a study commissioned by the Center of Advanced Purchasing Studies (Fearon & Bales, 1997), it was concluded that enhanced attention and tailored measurement tools are crucial for the success of a company in its vital areas of functioning. In the Armed Forces area, a Critical Application Item (CAI) is an item that is essential to weapon system performance or operation, or the operating personnel determined by the military services (USDLAI 3200.4). The mission statements of major military SCM (Supply Chain Management) agencies such as the US Defence Logistics Agency, NATO Support Agency and Hellenic Army General Staff/Ordnance Directorate, refer to the capability of providing high, added-value integrated logistics in a timely manner. That capability becomes very important in Aviation CAI cases due to their gravity for the success of a mission and the safety of the personnel involved.

The objective of this paper is to present a way of modeling article 66 of the law 3978, (2011), (article 47 of the ED 2009/81), that deals with the evaluation criteria of the supplier to whom a contract may be awarded, using an integrated AHP-GP approach. This approach is very common in supplier selection literature of the private sector (Ho, Xiaowei, & Prasanta, 2010) and provides measurable results. For the application of the integrated model, an expert team (ET) was made up of a senior procurement officer that specialized in CAIs, a procurement manager from the Hellenic Aerospace Industry (HAI) and a senior procurement member from the Hellenic Purchasing Institute. The ET determined the criteria to be used in the approach and performed the calculations of weights/loadings, with the assistance of the authors. Additionally, the ET made an effort to enrich the approach by introducing a supplier risk constraint and presented a real world application.

The main contribution of this paper is focused on the methodology proposed in the military procurement area under the law 3978, (2011). It is hoped that the current study will enrich the defence literature by exploring and applying scientific and systematic theories of group-decision support in the supplier selection problem in the defence area. The paper combines widely used methods that simulate real world problems with real Aviation CAI data in a professional area where, to the best of our knowledge, there is still work to be done. Additionally, risk management is an integral part of a supply chain (Zhen, Lee, & Choy, 2010) and supply chain disruptions may have long-term, negative effects on a firm's financial performance (Tang, 2006). As a consequence, this paper incorporates supplier risk factors that may safeguard the Defence Agency from unexpected supply shortages in potential crisis times. Finally, by using GP, optimal use of financial resources is achieved and, therefore, a prudent public financial policy is secured.

The paper is organized as follows: In the next section, parts of relevant literature are reviewed and the areas of AHP and GP are introduced briefly. Afterwards, the development of the integrated AHP-GP model is presented and it is applied to real data. Finally, concluding remarks, limitations and directions for future research are cited.

LITERATURE REVIEW

Supply chain consists of all links from suppliers to customers of a product or service. Goffin, Szwejczewski, and New (1997) stated that supply management is one of the key issues of supply chain management, because the cost of purchased items represents a major part of the total cost of the final product/service. Supplier selection is one of the most important decision-making problems, since selecting the right suppliers significantly reduces purchasing costs and improves corporate competitiveness (Ghodsypour & O'Brien, 2001). The supplier selection issue may involve conflicting quantitative and qualitative factors (Ghodsypour & O'Brien, 1998). The vast majority of qualitative factors is intangible and difficult to measure and evaluate (Sarkis & Talluri, 2002). This fact leads many authors to argue that a supplier selection problem can be modeled and solved using multi-criteria decision-making analysis.

The supplier selection problem has been extensively studied using a number of novel and well-developed approaches (e.g. Fuzzy Logic, Data Envelopment Analysis, Neural Networks, and Genetic Algorithms). In Appendix B, there is a short list of approaches/ methods used during the supplier selection process. Analytic

Hierarchy Process (AHP) was introduced by Saaty (1980). It is a systematic and highly flexible multi-criteria decision-making (MCDM) methodology that increases the efficiency of attributing weights to criteria (Radcliffe & Schniederjans, 2003; Laios, 2010). It provides the advantage of a more effective decision-making process (Kerr & Tindale, 2004) as bias and partiality in the decision-making process are minimized (Bilsel, Buyukozkan, & Ruan, 2006). It may also incorporate qualitative and quantitative factors in the decision-making process (Percin, 2006). The analytical hierarchy process includes three general steps (Deng, Yong, Yong, & Mahadevan, 2014). Initially, a hierarchical structure is established by recursively decomposing the decision-making problem. Then, the pairwise comparison matrix is constructed to indicate the relative importance of alternatives and, finally, the priority weights of alternatives are calculated. The use of pairwise comparisons to collect data from the decision maker provides significant advantages (Schniederjans & Wilson, 1991). It allows the decision maker to focus on the comparison of just two objects, making the process independent from extraneous influences. Additionally, pairwise comparisons generate meaningful information about the decision-making problem and improve consistency, especially if the process involves group decision making. A great number of researchers use AHP, alone or combined with another method, in the supplier selection process (Badri, 2001; Lee, Sungdo, & Kim, 2001; Badri & Abdulla, 2004; Liu & Hai, 2005; Hsu, Kannan, Leong, & Tan, 2006; Dagdeviren, Yavuz, & Kilinc, 2009; Sen, Selcuk, & Basligil, 2010; Pani & Kar, 2011; Deng et al.,2014).

Goal Programming (GP) has been applied in many distinct areas (Tamiz, Jones, & Romero, 1998; Ignizio & Romero, 2003). GP is a procedure for handling multiple-objective situations within the general framework of linear programming. Each objective is viewed as a goal. Then, given the usual resource limitations or constraints, the decision maker attempts to develop decisions that provide the “best” solution in terms of coming as close as possible to reaching all goals (Badri, 2001). GP differs from conventional methods of optimization due to the philosophy of ‘‘Satisficing’’ (Ignizio & Romero, 2003). This philosophy in a GP model implies that the model is focused on minimizing the non-achievement of the problem goals (Romero, 2001). It was firstly used by Ignazio, (1976) as a frame for the formulation of a GP model. A GP model permits an added priority structure, reflecting the added mathematical weighting (Radcliffe & Schniederjans, 2003).

Mathematical Programming and AHP are two of the most popular approaches for the supplier selection issue (Kar, 2014) and weights derived by the application of the AHP can be successfully incorporated into a GP model (Gass, 1986). The integrated AHP-GP approach may combine the features of the two methods by incorporating successfully mathematically-adjusted weightings on selecting decision-making criteria not already reflected in the AHP preference weights (Schniederjans & Garvin, 1997). So far, several integrated approaches in supplier selection have been presented (Ghodsypour & O'Brien, 1998; Badri, 2001; Radcliffe & Schniederjans, 2003; Cebi & Bayraktar, 2003; Wang et al., 2004; Percin, 2006; Kar, 2014; Deng et al., 2014).

Military Logistics is a fully integrated system involving four main elements – acquisition, distribution, sustainment, and disposal (US DoD-DISAM, 2007). Part of the acquisition process is the supplier selection phase which, in general, is one of the most important decision-making problems (Cebi & Bayractar, 2003). US federal agencies are urged to install a process that will monitor the performance of the acquisition function in order to support the agency's missions or achieve acquisition goals (GAO-05-218G, 2005). In a study made by the RAND Corporation for the US Army (RAND Corporation, 2012), flexibility was a key idea for several aspects of Procurement. GP appears to be suitable for defence procurement as it is a flexible and pragmatic MCDM methodology (Tamiz, Jones, & Romero, 1998). Additionally, an AHP-GP approach offers flexibility, as it can respond quickly to a dynamic decision- making process (Percin, 2006).

The military logistics literature review showed that mathematical modeling exists as a concept. However, to the best of our knowledge, no clear use of an integrated AHP-GP approach is observed therein. USDoD-4140SCMR, (2003) refers to the mathematical representations of an operation or management system in order to achieve optimum solutions to stated problems. This fact enhances the idea to implement AHP-GP in the defence area, as not only are flexibility and measurable procedures required for a well-managed acquisition program (USDoDI-5002, 2008) but the idea of ''Satisficing'' is suitable for military planning due to non-existence of ideal combat conditions as well. Mathematical representations are also reported in acquisition planning (Defence Acquisition University, 2010) in order to establish the monitoring of financial figures. Flexibility is also a prerequisite for the supply strategy of the Greek Land Forces Logistics Doctrine (Hellenic MoD, 2002), where it was stated that the main characteristic of the unified army support management is the efficient and financially viable army support. NATO Support Agency (NSPA)'s Procurement Regulation 4200 (2013) also sets a financial ''constraint'' by stating that "A principal objective of the NSPA is to obtain, through international competitive bidding, the most economical prices for material and services. The most economical proposal meeting the technical and contractual requirements stipulated in the Request for Proposal (RFP) shall normally be accepted" (p. 2).

Therefore, the purpose of this study is to propose an integrated AHP-GP model for a decision-making problem (supplier selection) and show how mathematical programming techniques could evaluate the multiple objectives in determining the best compromise solution. The building, the solution and the application processes of the proposed integrated model are presented in the following sections.

DEVELOPMENT OF THE INTEGRATED AHP-GP MODEL

Formulation of the Criteria and Sub-Criteria of the Model

The analysis of this Model assumes known and certain demand for 3 CAI products defined by the Operational Branch. The demand is to be met by four suppliers selected from an original set that satisfies the prerequisites of articles 56-60 of law 3978, (2011). A limited number of CAI products were selected in order to minimize endless replications and calculations that do not contribute to the general idea of the model, since its methodology/logic remains the same regardless of the number of the CAI products that will be used. It is based on pairwise comparisons of criteria/sub-criteria and alternatives (AHP) as well as on calculations of linear equations (GP), a procedure that remains unchangeable for any number of the CAI products.

One of the critical challenges faced by procurement managers is the selection of the best supplier (Sarkis & Talluri, 2002), because the outcome of this process greatly influences corporate competitiveness (Choy et al., 2004). This task, which will be performed by the ET, is quite difficult, because numerous criteria affect the outcome of the selection process. Several research papers review the criteria and methods affecting supplier selection (Dickson, 1966; Dempsey, 1978; Weber, Current, & Benton, 1991; Degraeve, Lambro, & RoodHoft, 2000; De Boer, Lambro, & Morlacchi, 2001; Cheraghi, Dadashzadeh, & Subramanian, 2004; Ho, 2007; Ho, Xiaowei, & Prasanta, 2010; Ware, Singh & Banwet, 2012). The ET, based on its experience and academic background, after reviewing the papers mentioned above, inferred that quality, delivery, cost/price, service and risk are the factors that influence, to a large extent, the supplier selection process. The first four criteria represent the basic supply targets (Laios, 2010). For that reason, the ET defined them as the basis for determining which of the criteria of article 66 of the law 3978, (2011) will be included in the supplier selection process of the CAI items. The criteria used in our model were associated with each one of the five criteria mentioned above. These criteria were further decomposed to sub-criteria according to the AHP hierarchical structure. The sub-criteria were developed by the ET in order to take into account qualitative and quantitative factors as well as trade-offs between them. For example, risk was corresponded to security of supply which refers to the provisions of the ED 81/2009 (law 3978, (2011)). The goal is to mitigate the risk to the essential security interests of a State and to ensure the reliability of the supplier to provide support for the purchased item (e.g. establishing multiple sourcing). Security of supply was further decomposed into three sub-criteria that include subjective (reputation in the operating sector, warranty policy) as well as measurable factors (fiscal situation-easily judged by financial statements).Table 1 shows the criteria and the sub-criteria used in our study.

TABLE 1
Decision-Making Criteria and the Respective Sub-criteria

Criteria of Article 66	Correspon-ding Criteria	Sub-Criteria of the Corresponding Criteria
Quality /Technical Merit/Functional Characteristics	Quality	1. Conformance to Specification (Q1) 2. Existence of a Corrective and Preventive Action System (Q2) 3. Number of Quality Staff (Q3)

TABLE 1 (Continued)

Criteria of the Article 66	Correspon-ding Criteria	Sub-Criteria of the Corresponding Criteria
Delivery Date and Delivery Period or Period of Completion	Delivery	4. Delivery Lead Time (D1) 5. Supplier Proximity (D2) 6. Delivery Incoterms (D3)
Price/Cost Effecti-veness/Running-Lifecycle Costs	Cost/Price	7. Minimum Order Quantity Price (C1) 8. Freight Cost (C2) 9. Competitiveness of the Cost (C3)
After Sales Service and Technical Assistance	Service	10. Flexibility and Responsiveness (S1) 11. Technical Expertise to Support Problems (S2) 12. Willingness of Sharing Information (S3)
Security of Supply	Risk	13. Reputation in the operating sector (R1) 14. Fiscal Situation (R2) 15. Warranty policy (R3)

Application of the First Part of the Integrated Approach (AHP Methodology)

AHP is an extremely suitable technique for decision making (Kar, 2014), allowing managers to determine preferences of criteria for selection purposes (Sarkis & Talluri, 2002). Figure 1 depicts the supplier selection hierarchy on which the AHP will be implemented. The priorities derived will be used to provide the final supplier scores in the integrated model. The overall objective is on the top of the Hierarchy (the Goal: Select the Best Supplier) and the main criteria and the sub-criteria that may influence the decision-making process are located in the second and third level of the model. The alternative suppliers (Supplier 1 to 4) are depicted in the lowest level.

The ET performed pairwise comparisons for all possible combinations of criteria/sub-criteria by assigning numerical values based on their relative importance with respect to the alternatives and their corresponding parent elements in Figure 1. Saaty's (1980) nine point scale of intensity was used for the calculation of the numerical values (Table 2).

FIGURE 1
Hierarchical Structure of the Supplier Selection Model

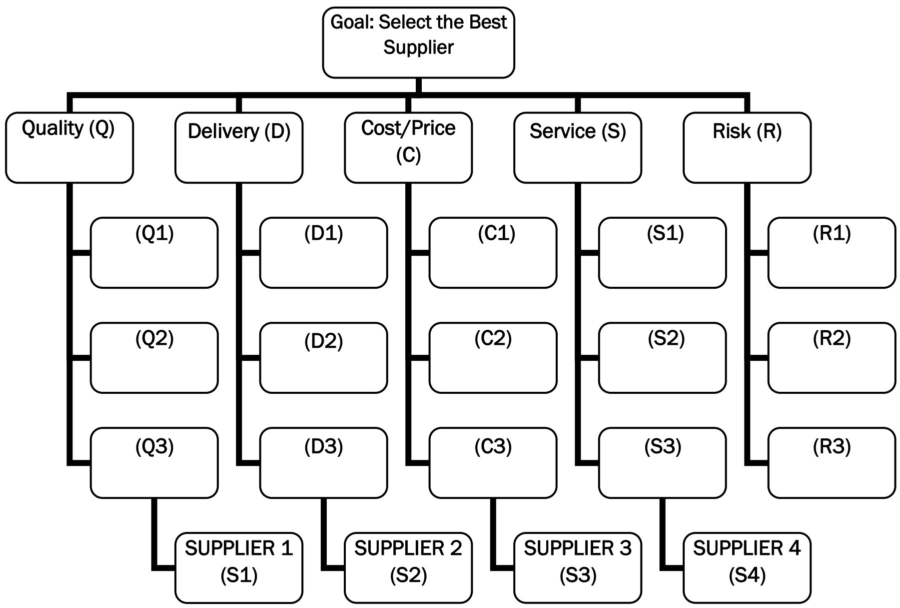


TABLE 2
Saaty's Nine-Point Intensity of Importance Scale

Definition	Intensity of Importance
Equally Important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values	2,4,6,8

Source: Saaty (1980).

Expert Choice software was used to calculate all the comparisons of criteria/sub-criteria and alternatives. Table 3 synoptically depicts the priorities/preferences of the ET for the main criteria after the application of the afore-mentioned software.

TABLE 3
The Priorities of the ET among the Main Criteria

Criterion	Expert Choice Results in Priorities among Criteria
Quality	0.454
Delivery	0.283
Cost/Price	0.065
Service	0.115
Risk	0.084

It is concluded that Quality is the most important criterion (L: 0.454) followed by Delivery (L: 0.283), Service (L: 0.115), Risk (L: 0.084), and Cost/Price (L: 0.065). Consistency Ratio (CR) evaluates the degree of validity in basic AHP pairwise comparisons and shows if a comparison matrix suffers from inconsistencies. It is defined as $C.R. = \frac{C.I.(Consistency\ Index)}{R.I.(Random\ Index)}$ whereas $C.I. = \frac{\lambda_{\max} - n}{n-1}$, $\lambda_{\max} =$ the largest eigenvalue of an n dimensional comparison matrix and R.I.is related to the dimension of the matrix as shown in Table 4 (Render & Stair, 2000; Kar, 2014; Deng et al., 2014).

TABLE 4
Random Index

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

In this case, the C.R. of the main criteria matrix is at 0.10 which shows that the judgment matrix is consistent enough (Saaty, 1980; Winston & Albright, 2006; Kar, 2014; Deng et al., 2014).

The next steps are to calculate the priorities of the sub-criteria with respect to the main criteria and to compare all the alternatives to each criterion for the final results. Table 5 presents the results of the incorporation of the hierarchical structure (shown in Figure 1) to the software, i.e. the priorities of the sub-criteria and the outcome of the synthesizing process for all the derived priorities. Synthesis yields the final supplier scores by weighing and combining priorities throughout

TABLE 5
Criteria, Sub-Criteria Priorities and Final Supplier Scores

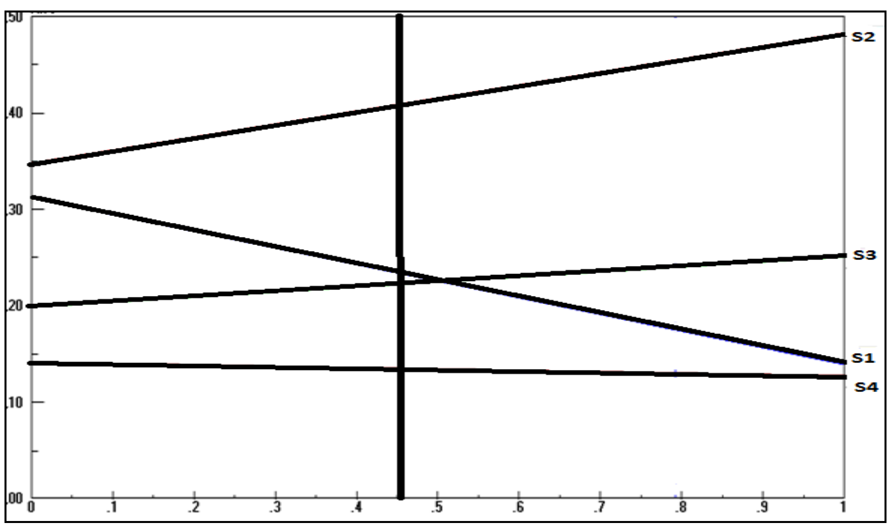
Criteria	Criteria Loadings/Priorities (shown in Table 3)	Sub-criteria Loadings/Priorities	Supplier Scores (Synthesis outcome)
Quality	0.454	Q1:0.731, Q2:0.188, Q3:0.081	Supplier 1:0.234 Supplier 2:0.408 Supplier 3:0.223 Supplier 4:0.135
Delivery	0.283	D1:0.687, D2:0.186, D3:0.127	
Cost/Price	0.065	C1:0.186, C2:0.127, C3:0.687	
Service	0.115	S1: 0.731, S2:0.188, S3:0.081	
Risk	0.084	R1:0.292, R2:0.615, R3:0.093	

the AHP model (Saaty, 2008). The model presents a notable degree of consistency (0.09). Supplier 2 is the most preferred supplier with a score of 0.408 followed by Supplier 1 (0.234), Supplier 3 (0.223), and Supplier 4 (0.135). These scores will be used in the second part of the Integrated Approach as weights in an objective function (Utility function).

Then, a sensitivity analysis was made to show a way of determining how sensitive the results (i.e. suppliers scores) are to changes in the priorities of the objectives (i.e. criteria, sub-criteria). The Gradient Sensitivity Graph (GSG) based on the results of the Expert Choice software, summarizes and shows graphically, the loadings/priorities of the alternatives (here suppliers) with respect to one objective at a time and how easily the rating of the alternatives may change if the loadings of the priorities change too. In this kind of graphs, conclusions are derived by the intersections of diagonal and vertical lines which are used in order to depict more easily the potential changes of loadings/priorities.

Figures 2 and 3 present the GSGs of the 4 suppliers (S1...S4) with respect to the criteria of Quality and Delivery, selected by the 5 criteria of Table 3 (page 94 above) for simplification purposes in order to avoid repetitions of calculations under the same logic that do not contribute anything to the model. More analytically, the X-Axis of these figures, through the vertical line, depicts the Priority scores/Loadings of the Quality and Delivery criteria respectively, having as a starting point their arithmetic values, seen in above-mentioned Table 5 (page 95 above). For example, in Quality GSG the starting point of the vertical bar is at 0.454. The Y-Axis of those figures, through the diagonal lines, depicts the Priority scores/Loadings of the Suppliers, seen in Table 5 and indicated graphically by the intersection of each suppliers line (S1...S4) with the vertical one. If the vertical lines of the criteria are moved, then new Suppliers' scores will appear, depicted graphically by the afore-mentioned intersection. For example, in Figure 2, S3 score shown previously arithmetically in page 95 above (Table 5, Supplier 3 score equals with 0.223), is indicated graphically by the intersection of the S3 line with the vertical one. Moving on a step further, the possible alterations in Suppliers' rating, if the loadings of the quality and delivery criteria (seen graphically in X-Axis) changed respectively, i.e. if the respective vertical lines of the X-Axis were moved to the right or

FIGURE 2
The GSG of the Best Supplier (Quality Criterion Presented)

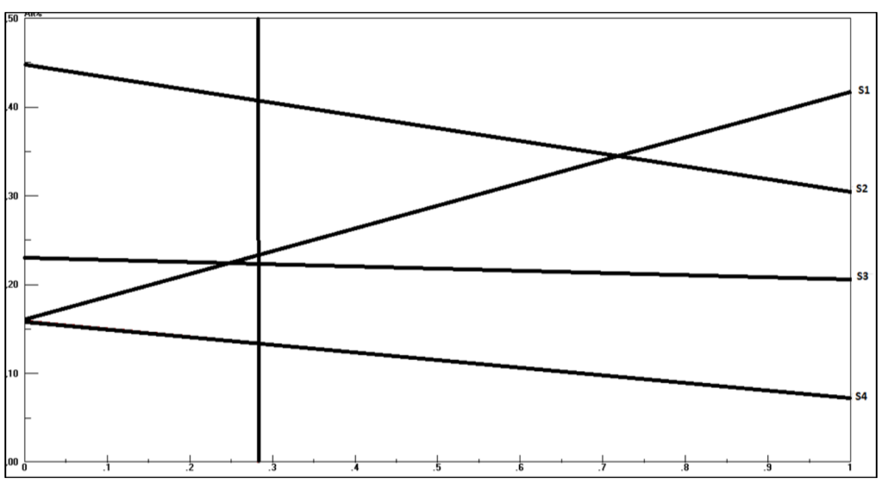


Notes: The X-Axis, through the vertical line, depicts the Priority score/ Loading of the Quality criterion. The Y-Axis, through the diagonal lines, depicts the Priority scores/ Loadings of the Suppliers and the alterations in their rating, if the Loading of the Quality criterion changes.

left side of the graphs, they (the new ratings) would appear by the new intersections of the Suppliers' lines. In the point where 2 diagonal lines of the Suppliers intersect, a change in their rating is observed therein.

For example, the observation of the 2 above-mentioned GSGs ends up to the conclusion that some alternatives intersect each other, if the vertical lines (criteria loadings) are commuted towards a direction, so the increase of an objective's priority will have an effect on the ranking of suppliers. In quality GSG (Figure 2) it is clear that if the vertical bar is dragged from its current position to the right side, after 0.48 approximately, (where the S3 line intersects with S1 line) S3 continues higher from the S1 line and consequently priorities change, S3 becomes the second most preferred supplier. Respectively, in delivery GSG (Figure 3), if the vertical bar is dragged to the far right side, after 0.72 approximately, then S1 becomes the most preferred alternative. An adequate conclusion that may be deducted from the comparison of the 2 GSGs, is that supplier scores seem to be more sensitive in delivery GSG (they may change more

FIGURE 3
The GSG of the Best Supplier (Delivery Criterion Presented)



Notes: The X-Axis, through the vertical line, depicts the Priority score/ Loading of the Delivery criterion. The Y-Axis, through the diagonal lines, depicts the Priority scores/ Loadings of the Suppliers and the alterations in their rating, if the Loading of the Delivery criterion changes.

easily), as more intersections appear at potential movements of the vertical bar.

The first part of the integrated approach (AHP Methodology) was presented analytically for only one product. The procedure for the remaining two CAI products is the same, with the only difference being the ET rankings for these products. Due to space limitations, we do not replicate the process. Table 6 shows the overall results for all three products.

TABLE 6
Final Supplier Scores in the First part of the Integrated Approach

AHP Scores for Suppliers	Supplier				Sum of Scores
	1	2	3	4	
Critical Product 1	0.234	0.408	0.223	0.135	1
Critical Product 2	0.398	0.230	0.250	0.122	1
Critical Product 3	0.250	0.300	0.140	0.310	1

Application of the Second Part of the Integrated Approach (Goal Programming)

Goal Programming (GP) will incorporate additional criteria that may differentiate the results for the best supplier. A Non-Archimedean GP, the Pre-Emptive GP, which sets objectives in order of priority (Ghodsypour & O'Brien, 2001; Ignizio, 1976), has been selected to incorporate the AHP weightings (supplier scores) into the Integrated Approach. GP uses additional criteria by pre-emptively restating several levels of preferences within a model and makes it possible for the decision makers to incorporate adjusted weightings on selecting decision-making criteria (Bhagwat & Sharma, 2009). The additional criteria should be considered as constraints in the programming model (Ghodsypour & O'Brien, 2001).

Development of the GP Model

The existence of more than one supplier is a way to mitigate supply risk (Christofer, Mena, Khan, & Yurt, 2011). Laios (2010) stresses the importance of multiple sourcing when procurement of critical items takes place. Consequently, the agency has selected as a procurement strategy in CAI products the co-operation with at least 2 suppliers out of 4. We considered a procurement situation where *i =1, 2. . . , I* (*i=3*) items/products are to be purchased from *j=1, 2, J* suppliers (*j=4*).

The first step of the development of the GP model is to determine the decision-making variables and to define objective functions (goals) and constraints in terms of the decision-making variables (Bhagwat & Sharma, 2009). The decision-making variables, the notations, the objective functions, and the constraints of the GP model are the following:

a. The Decision-Making Variables:

1. X_{ij} : The amount/quantity of the i_{th} product to be procured through supplier *j*.
2. Y_{ij} : A binary variable which equals to ''1'' if supplier *j* is chosen for the product *i* and to ''0'' otherwise.

b. The Notations:

$P_{i,j}$ = Perfect rate of the i_{th} product from j_{th} supplier. The ET considered this rate as the percentage of perfect order concept (POC) for each supplier. The POC is a complex index that indicates to a large extent the efficiency of a supply chain (Monczka et al., 2010; Laios, 2010). Perfect rate is a quality related attribute (Ho, Xiaowei, & Prasanta, 2010).

$PH_{i,j}$ =Performance history rate of the i_{th} product from j_{th} supplier. The ET considered this rate as the percentage of the long term co-operations that the potential 4 suppliers have had so far, according to written statements. Long-term co-operations may be seen as an important objective in procurement strategies of critical products (Harrison & Hoek, 2011). Additionally, past performance is suggested as a supplier selection criterion for the US Army (RAND Corporation, 2012).

$R_{i,j}$ =Reliability rate of the i_{th} product from j_{th} supplier. Reliability is defined as the probability of an item to perform a required function under stated conditions for a specified period of time and is divided in mission and logistics reliability (LR) (USA DoD-

RAM Guide, 2005). LR deals with all the failures in logistics that affect a system's operational support (USA DoD-RAM Guide, 2005). The ET considered this rate as the maximum percentage, stated by the suppliers, of the LR failures that may occur when supplying their products and may affect the operation of Military Logistics (defined in Lyssons & Farrington, 2006).

$Q_{i,j\,\min}$ = Minimum Order Quantity of the i_{th} product from j_{th} supplier.

$U_{i,j}$ = AHP score of Supplier *j* for product *i*.

D_i = Demand of raw material *i*.

c. The objective functions (Equations 1-4) are cited in order of maximizing the quality, history and utility, objective functions and minimizing reliability objective function. The coefficients of the 4th objective function are retrieved from the supplier scores from the first part of the integrated approach (AHP application).

Quality function: $Z\max = \sum_i \sum_j P_{i,j} * X_{i,j}$ (1)

Performance history function: $Z\max = \sum_i \sum_j PH_{i,j} * X_{i,j}$ (2)

Reliability function: $Z\min = \sum_i \sum_j R_{i,j} * X_{i,j}$ (3)

Utility function: $Z\max = \sum_i \sum_j U_{i,j} * X_{i,j}$ (4)

d. The constraints (additional criteria) that apply to the objective functions are:

$UnitPrice_{i,j} * X_{i,j} \leq$ Budgetary limit for each product (5)

$$\sum_j Y_{i,j} \geq 2 \quad (6)$$

$$\sum_j X_{i,j} = D \quad (7)$$

(X_i of the j_{th} supplier with the highest score in perfect rate) ≥
[$0.25 * \sum$ (of the suppliers quantities for the ith product] (8)

[Unit price of the ith product* X_i (of the jth supplier with the highest score in perfect rate)] $\leq$ (0.75% of the budgetary limit). (9)

Minimum and maximum order quantity (MOQ) for each supplier as in Table 7 (10)

$X_{i,j} \geq 0$, integer $\forall$ *i,j* (11)

$Y_{i,j} = 0$ or 1 $\forall$ *i,j* (12)

The ''quality'' objective function has been selected as the primary objective, due to its great importance in the accomplishment of a mission and its great popularity among supplier selection criteria. The primary objective of the US DoD acquisition function is to acquire quality products (systems) that satisfy user needs and to induce measurable improvements in mission capability and operational support in a timely manner and at a fair and reasonable price (USA DoD-RAM Guide, 2005). Quality is the most popular supplier selection criterion (Kahraman, Cebeci, & Ulukan, 2003; Cheraghi, Dadashzadeh, & Subramanian, 2004; Ho, Xiaowei, & Prasanta, 2010). The ''performance history'' and ''reliability''objective functions have been added to the model, due to their importance in procurement strategies of critical products and to their contribution in the overall success of a mission. Moreover, the importance of the ''performance history'' objective was demonstrated by Tadelis, (2012), who stated that the public sector buyer must find a way to use information about the past performance of potential suppliers as selection criteria.

In addition to that, the '' reliability'' objective function supports the implementation of article 36 ''Security of Supply'' of the law 3978, (2011). It conduces to the accomplishment of a mission, since it minimizes the possibilities of rendering a system incapable of operation, due to a deficient item/product. For example, by knowing the maximum percentage of a supplier's LR failures, the agency can adapt its demands and respective ordering levels accordingly, so that inventory can respond to high and unexpected needs resulting from a crisis time. The utility function serves as the bridge between the two steps of the Integrated Approach, by using supplier scores as coefficients in that Objective Function. The main constraints added in the model are the agency's demand, minimum and maximum order quantity for the suppliers' quantitative limitations and respective financial limitations imposed by the legal frame of the national law 3871, (2010). The aforementioned law determines public financial function and permits procurement action only for those items/services not exceeding a predetermined budgetary level. An effort has been made to increase transparency measures and enhance competition, by setting a limit on the economic amount of the supply that can be allocated to one supplier (constraint 9). In our case, a restraining budgetary limit of a certain amount for each product has been set by the HAI member in coordination with his financial controller.

The ET also decided to introduce a minimum limit of 25% for the quantity to be purchased from the supplier who has the highest score in the ''Perfect Rate'' decision-making variable. This limitation serves as a triple purpose incentive. Firstly, it indicates to potential suppliers the existence of a quality oriented procurement policy that rewards the most conforming supplier with a percentage that overcomes the 25% of the total quantity under procurement. This ensures that it is likely for him to get a contract for a bigger quantity than the respective contract if this limitation did not exist. Quality has two major perspectives. The first is the quality of conformance, which is defined by the absence of defects (Cheraghi, Dadashzadeh, & Subramanian, 2004). In our case the absence of defects means safe use for the weapons systems that use the purchased CAIs. The second perspective demonstrates the organization's willingness to safeguard the personnel that will be affected by the purchase of CAIs (e.g. the aviation pilots after the installation of the CAIs on their helicopters). This may serve as an incentive for potential suppliers to invest in actions that will improve their quality performance, regardless of the investment cost. This is also demonstrated by Leenders, Johnson, Flynn, and Fearon (2006) who argue that there is a tendency in public procurement to avoid suppliers with the lowest offer.

Furthermore, the ET evaluated the fact that the existence of alternative suppliers in critical products serves as a risk management strategy (Harrison & Hoek, 2011). Consequently, ET set up an additional cost constraint (constraint number 9) to avoid comments of favoritism. Table 7 shows the supplier data provided by the HAI procurement manager where the names of the suppliers have not been given due to confidentiality. Table 8 (in page 103) describes synoptically the application of the basic, objective functions, notations and constraints to the data of the Table 7, aiming at making the model clearer to a potential reader.

TABLE 7
Supplier Selection Real Data

Product/ Budget Limitation	Supplier	P-Rate	PH Rate	R-Rate	MinOQ	MaxOQ	Demand	Unit Price (€)
€1/2000	1	0.75	0.4	0.12	2	15	15	95
	2	0.77	0.32	0.08	4	15		98
	3	0.76	0.45	0.10	3	15		98
	4	0.78	0.6	0.14	2	15		97
€2/3000	1	0.64	0.5	0.09	4	20	20	105
	2	0.71	0.55	0.08	6	20		103
	3	0.68	0.6	0.05	4	20		108
	4	0.69	0.48	0.07	5	20		104
€3/4000	1	0.85	0.38	0.05	2	30	30	110
	2	0.83	0.4	0.04	2	30		115
	3	0.82	0.35	0.04	2	30		112
	4	0.81	0.44	0.05	2	30		113

Moreover, In order to assist further the understanding of the model, it is also added explanatory that in Table 8 the first 4 lines depict the objective functions (G1 to G4) and their purpose (Max for maximization and Min for minimization), and the rest depict notations and constraints, whereas X1 to X12 are the quantities of the i_{th} (i=3) product to be procured through the 4 suppliers. For example, the 5th constraint is shown by C2, C6 and C10 lines, the 7th constraint for the 3 critical products is shown by C1, C5 and C9 lines, and respectively the 9th constraint, by the C4, C8 and C12 lines.

After the determination of the decision-making variables, the definition of the objective functions (goals) and constraints in terms

TABLE 8
The Basic GP Equations of the Supplier Selection Model

Max:G1	0.75X1+0.77X2+0.76X3+0.78X4+0.64X5+0.71X6+0.68X7+ 0.69X8+0.85X9+0.83X10+0.82X11+0.81X12	X1	≥2, ≤15
Max:G2	0.41X1+0.32X2+0.45X3+0.6X4+0.5X5+0.55X6+0.6X7+ 0.48X8+0.38X9+0.4X10+0.35X11+0.44X12	X2	≥4, ≤15
Min:G3	0.12X1+0.8X2+0.1X3+0.14X4+0.09X5+0.08X6+0.05X7+ 0.07X8+0.05X9+0.4X10+0.04X11+0.05X12	X3	≥3 ≤15
Max:G4	0.408X1+0.234X2+0.23X3+0.135X4+0.398X5+0.23X6+ 0.25X7+0.22X8+0.25X9+0.3X10+0.14X11+0.31X12	X4	≥2, ≤15
C1	1X1+1X2+1X3+1X4=15	X5	≥4, ≤20
C2	95X1+98X2+98X3+97X4≤2000	X6	≥6, ≤20
C4	97X4≤1500	X7	≥4, ≤20
C5	1X5+1X6+1X7+1X8=20	X8	≥5, ≤20
C6	105X5+103X6+108X7+104X8≤3000	X9	≥2, ≤30
C8	103X6≤2250	X10	≥2, ≤30
C9	1X9+1X10+1X11+1X12=30	X11	≥2, ≤30
C10	110X9+115X10+112X11+113X12≤4000	X12	≥2, ≤30
C12	110X9≤3000		

of the decision-making variables, the ET enter the data in WINQSB software. The optimum solution provided in Table 9 shows that, in order to achieve the optimal compromise between conflicting objectives, products should be procured by different suppliers.

TABLE 9
The results of the Integrated Approach Using WINQSB Software

Decision-Making Variable ($X_{I,J}$)	Solution Value (unit)
$X_{1,1}$	2
$X_{1,2}$	4
$X_{1,3}$	3
$X_{1,4}$	6
$X_{2,1}$	4
$X_{2,2}$	7

TABLE 9 (Continued)

Decision-Making Variable ($X_{I,J}$)	Solution Value (unit)
$X_{2,3}$	4
$X_{2,4}$	5

Note: Maximized objective function value for Perfect Rate= 1193.2; Maximized objective function value for Performance History= 329.15; Minimized objective function value for Reliability = 145.93; Maximized objective function value for Utility= 2643.8.

Finally, WINQSB software was used to perform sensitivity analysis of the Right Hand Side (RHS) for each constraint. The purpose of this analysis was to evaluate the Efficiency of the model, as mentioned in the law 3871, (2010). Sensitivity analysis shows the range of feasibility for the optimal solution achieved in this model. Table 10 presents the minimum allowable feasibility range of the Constrains 2, 6 and 10 that associate with the maximum financial amounts for products 1 to 3.We can see that the optimal solution remains the same even if C2 is diminished up to €1,458 (savings €582 for product 1), C6 is reduced up to €2,093 (savings €907 for product 2) and C10 is limited to €3,320 (savings €680 for product 3). The overall savings is 21.69% of the initially available financial amount (€10,000).

TABLE 10
Sensitivity Analysis for RHS of Cost Constraints

Critical Application Item (CAI)	Constraint	Right hand Side (RHS)	Allowable Minimum RHS	Savings
1	C2	€2,000	€1,458	€582
2	C6	€3,000	€2,093	€907
3	C10	€4,000	€3,320	€680
Total Savings for all products				€2,169

CONCLUSIONS

The AHP-GP approach is useful in several real world applications of non-defensive areas. This process provides transparency as well as financial benefits, as we can see from applications in quality control systems (Badri, 2001), supplier selection in the food industry (Cebi &

Bayractar, 2003) and in industrial spare-parts (Karpak, Kumcu, & Kasuganti, 1999). In our opinion, the overall significance/usefulness of this integrated AHP-GP approach is that it demonstrates the applicability of AHP-GP in the defence area, taking into account the three main factors of EU procurement directives. These factors are legality to operate as a supplier, the minimum economic and financial standing, and the technical capacity to perform and comply with the standards of the organization. Specifically, the approach is applied according to EU directive for defence procurement, incorporating the prerequisites of articles 56-60 of law 3978, (2011) as the first filter for the suppliers that will participate in the competitive bidding. The approach moved on a step further by covering not only financial and technical aspects of the supplier selection process, but also key features of the Smart Acquisition Process, introduced by a UK Strategic Defence Review (UK Ministry of Defence, 1998). These features are referred, for example, to the willingness to share information and the need for identification, evaluation and implementation of trade-offs between performance, time and cost.

Furthermore, this approach, based on systematic and scientific tools (AHP and GP), represents an attempt to establish a rigorous supply system that will eventually bring into effect the above-mentioned benefits. This fact will strengthen the idea of co-operation with the suppliers among public procurement managers. This idea is also enhanced by a rigorous supplier selection system that develops effective supplier relationships (GAO-05-218G, 2005), especially in the case of critical products where suppliers are urged to collaborate with the buyers (Laios, 2010). Towards this direction the UK MoD needed a new basis for its relationship with industry built on competition that treats potential suppliers not as adversaries but as possible partners working together for mutual benefit (Baily, Farmer, Jessop, & Jones, 2005).

We also believe that the managerial implications of this model lie on its actual results. Managers can conclude that this model would not only be useful and applicable in real world-applications characterized by budgetary constraints, but it would also help them to prioritize their goals (translated to criteria) and evaluate them in a scientific way. The model integrates multiple qualitative and quantitative criteria, simplifies the selection process, achieves optimal use of funds, and leads to cost savings and economies of scale. It allows the best use of funds available, so that within a certain financial frame set by managers, maximum coverage of the ‘‘Risk’’ criterion is accomplished. This criterion is of high financial importance, as it includes actions such as multiple or alternative sourcing offering opportunities for cost savings.

Results are also easy to present in the Top Hierarchy, since they refer to financial sums. Additionally, if the Top Hierarchy decides to include or exclude some criteria, the flexible nature of the model permits quick response. The model uses multiple decision making by an ET, by capturing their knowledge and integrating it into a simple process without their continuous involvement in the selection of the best supplier. This conclusion bolsters the ascertainment that the model of this study is capable of providing a reliable and effective supplier selection process, thus making employees more confident when presenting their results to their managers. However, the correct application of the model is based on accurate measurement of the parameters/criteria and the definition of the suitable constraints, all provided by the ET. Therefore, constant involvement of the ET in the early stages of the selection process is considered to be necessary.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

While this study has provided the framework for the identification of an effective supplier, by no means has it answered all questions concerning this issue. The study has been conducted in the defence area and the model was developed and then tested with the use of three CAI products. A different set of criteria and constraints set by the ET would alter the results significantly, due to the fact that it would change the priorities and the ‘‘margins’’ of the criteria (the upper and lower limit at which they can be considered acceptable). The logic and the consecutive steps of the model, in order to reach a result, remain unaffected by the number of products involved. An increase in the number of products raises the calculations required for an optimal solution. Therefore, it may be quite difficult to find a solution if a large number of products is involved. An additional limitation for this model is that it was designed for critical items where quality plays the most important role. Consequently, its constraints would be ineffective in other procurement cases with different characteristics, e.g. procurement of leverage or routine items, where price or discount policies matter. Finally, limitations of

Greek National Safety Regulations and Statistical confidentiality (Principle No 5 of the European Statistics Code of Practice) were taken into account.

Possible future inquiry would be to develop a fuzzy approach for this AHP-GP model and to extend it by data envelopment analysis or genetic algorithm that may permit exceptionally stable solutions (Ignizio & Romero, 2003). Moreover, some of the criteria and sub-criteria may be eliminated or some other criteria may be included to the AHP model. Future research could also compare the results of this approach with others like VIKOR and TOPSIS (Opricovic & Tzeng, 2004) in order to examine the suitability of each approach in a procurement environment. Finally, it has to be pointed out that the proposed integrated model can be easily adapted to any kind of application and can be easily expanded as well.

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APPENDIX A
Departmental Organization of the Hellenic MoD

The detailed organization of the Hellenic Ministry of National Defence is defined by Law 2292/1995 (including some possible modifications) while, at the same time, it is being reconsidered in the framework of the Armed Forces' reorganization and modernization. Based on that law, the main branches and members of MOD that contribute to the formation and implementation of the National Military Strategy and control the Armed Forces, are the following:

- The Minister of Defence.
- The Deputy Minister or Ministers of National Defence.
- The Council of Defence.
- The Joint Chiefs of General Staffs Council.
- The Chief/ Hellenic National Defence General Staff.
- The Higher Councils of the Services of the Armed Forces (Higher Naval Council- Higher Air Council- Higher Military Council).
- The Chiefs of General Staffs of the three Services.
- The Armed Forces of the country (Army, Navy, Air Force)
- The Staff of the Minister of Defence.
- The General Secretariat for Financial Planning and Defence Investments.
- The Unified Administrative Sector, which is considered to be the resultant of the Civil Personnel belonging to the Staffs.

The Minister of Defence, as the political director of the MoD, is responsible towards the Government, for the Armed Forces command and control, aiming at the implementation of the National Defence Policy. The political leadership of the Ministry consists of the Deputy Minister or Ministers of Defence along with the Minister of Defence, which carry out their duties, as they are determined by the Prime Minister in accordance with the Minister of Defence.

The Joint Chiefs of General Staffs Council is composed of the Chiefs of Army, Navy and Air Force General Staffs of National Defence. Its duty is to submit proposals and pronouncements to the Minister of Defence, concerning issues like the national military strategy and the military evaluation of the situation. The Chief/Hellenic National Defence General Staff conducts the HNDGS (Hellenic National Defence General Staff) and is the main adviser to the Governmental Council on Foreign Policy and National Defence and to the Minister of Defence on military issues. Through the Chiefs of General Staffs, he carries out the operational commanding of the Joint Headquarters and the units that come under them, and also constructs the National Military Strategy.

The Higher Councils of the Branches of the Armed Forces (Higher Military Council, Higher Naval Council and Higher Air Force Council) decide or opine about issues that concern their Branch such as organizational, operational, armament, administrative, financial issues etc. The Chiefs of General Staffs are responsible for the perfect organization, manning, armament, training, evaluation and preparation for war, readiness and utilization of their Branches.

The Staff of the Minister of Defence is a consultative organ of the MoD that has no hierarchical relation to the General Staffs. It subserves the Minister's and the Deputy Ministers' missions. The General Secretary for Financial Planning and Defence Investments is an independent organ of the Ministry of Defence that implements the decisions of the Minister in financial sectors like financial planning and economic policy. The Unified Administrative Sector aims at regulating issues that are related to civil personnel of the Armed Forces.

Source: Hellenic MoD Departmental Organization (2014).

APPENDIX B
A Short Review of Supplier Selection Approaches/Methods

Evaluation-Selection technique	Authors
Mixed Integer Programming	Ware, Singh & Banwet (2014)
Analytic Hierarchy Process	Al Harbi (2001); Ware, Singh & Banwet (2014)
Case-Based Reasoning	Ng & Skitmore (1995)
Analytical network process	Wadhwa & Ravindran (2007)
Total cost of ownership	Degraeve, Lambro, & RoodHoft (2000)
Principal component analysis	Petroni & Braglia (2000)
Data envelopment analysis	Liu, Ding, & Lall (2000)
Optimization models	Apte, Rendon, & Salmeron al. (2011)
Statistical analysis	Verma & Pullman (1998)
Standardized Unitless Rating Outranking Methods	De Boer (1998)
Mathematical models	Deng et al. (2014)
Integrated Fuzzy AHP	Sen et al. (2010)
Fuzzy PCA	Lam, Tao, & Lam (2010)
Integrated AHP and DEA	Sevkli (2010)
Integrated AHP and GP	Kar (2014)
Integrated fuzzy and Cluster Analysis	Bottani & Rizzi (2008)
Grouping Methods	Hinkle, Robinson, P. J., & Green (1969)
Genetic Algorithm	Ding, Benyoucef, & Xie (2005)