Chapter 2
Supplier Selection Procedure of Military Critical Items: Mutivariate, Fuzzy, Analytical Hierarchy Procedures

Christodoulos Nikou and Socrates J. Moschuris

2.1 Introduction

In the US Department of Defense (DoD) whose budgets over defense related products and services are immense, procurement functions gain status and importance as it is acknowledged that they can contribute significantly in achieving its strategic objectives (Apte et al. 2011). One major aspect of the procurement procedure is the supplier/vendor selection (Weber et al. 1991). In the armed forces area, the same importance is appointed to supplier selection as it is stated that Military Logistics include, among others, aspects of military operations that deal with the acquisition of parts, materials and services, and act as a force multiplier that attains the advantage from a given force configuration by increasing the timeliness and endurance of the force (DCDC 2007). US DoD considers as Military Critical Items (MCI) supplies vital to the support of operations that are in short supply or are expected to be in short supply and mission-essential items that are available but require intense management to ensure more rapid supply for mission success (USADoD JP4-00 2000). Consequently, MCIs supplies do play a vital role in Armed Forces capability to fulfill a mission.

The objective of this paper is to present a methodology that is able to identify a supplier who meets an agency's need in the military procurement area, by

C. Nikou (✉)
Department of Industrial Management and Technology, University of Piraeus, Greece,
17th Serifou Street, 13561 Athens, Greece
e-mail: chrisnikou@gmail.com; cnikou@unipi.gr

S. J. Moschuris
Department of Industrial Management and Technology, University of Piraeus,
80 Karaoli and Dimitriou Street, 18534 Piraeus, Greece
e-mail: smosx@unipi.gr

V. Zeimpekis et al. (eds.), *Military Logistics,* Operations Research/Computer Science Interfaces Series 56, DOI 10.1007/978-3-319-12075-1_2

avoiding crisp data in decision making process, which (data) may be insufficient to model real life situations (Kahraman et al. 2003; Shen et al. 2013). Thus, Fuzzy logic theory, proposed by Zadeh (1965), is used hereinafter to deal with the vagueness/subjectivity of human thoughts and expressions and therefore, it strengthens the comprehensiveness and reasonableness of the decision making process (Shen et al. 2013). It is applied on Analytic Hierarchy Process, which is a widely accepted method in the supplier selection area (Liu and Hai 2005; Ho et al. 2010).

For the score of this paper, real data were collected through confidential questionnaires of members of the Hellenic armed forces. To these data, we applied some descriptive statistics, as part of a usual statistical analysis that provides the necessary feedback for someone to decide if a statistical method may be applied, i.e. if it requires normality assumptions. Confidence intervals were also calculated, since they provide estimation on the data population's answers and can assist in its simplified graphical depiction. Additionally, Competitive Intelligence (CI) was put to the cadre, as there is a growing interest in that area (Rouach and Santi 2001; Blenkhorn and Fleisher 2005). CI is conducted by an organized competitive intelligence system in 60 % of companies with revenues of more than $ 1 billion (Miller 2001). PCA, aims to reduce in an efficient way, the number of data/variables under study since MCDM methods, when applied to a large number of alternatives, may generate inconsistencies (Zanakis et al. 1998).

The main contribution of this paper, in our humble opinion, is located in the methodology proposed in the military procurement area. It combines methods that confront subjectivity of human judgment and modern statistical ones that allow the efficient identification of a small set of variables from the original group of variables of the collected data. This combination is done in a professional area where to the best of our knowledge there is still work to be done with that kind of methods. Additionally, this paper suggests the use of a CI process as a tool that may increase the transparency of the supplier selection procedure.

The rest of the paper is organized as follows: In the next section we review parts of relevant literature and present our conceptual integrated framework. Then, the phases that comprise the evaluation procedure based on real data are described, and conclusions, limitations and directions for future research are cited.

2.2 Literature Review

The problem of supplier selection/evaluation is not new and a great number of conceptual and practical studies have been reported so far, since it is an area of purchasing function (Sen et al. 2010) which is increasingly seen as a strategic issue in various organizations (De Boer et al. 2001). A short review of various evaluation techniques, applied to cope with aforementioned problem, is presented in Table 2.1.

Supplier selection plays a critical role and has a significant impact on purchasing management in supply chain (Amin and Razmi 2011;Omurca 2013). Several financial data verify the importance of purchasing into the defense area. In fiscal

Table 2.1 A short review of supplier evaluation and techniques

Supplier evaluation methods/techniques	
Evaluation technique	Authors
Weighted linear models	Lamberson et al. (1976); Timmerman (1986); Wind and Robinson (1968)
Linear programming	Pan (1989); Turner (1988)
Mixed integer programming	Weber and Current (1993)
Grouping methods	Hinkle et al. (1969); Muralidharan et al. (2002)
Analytical hierarchy process	Nydick and Hill (1992); Mohanty and Deshmukh (1993); Barbarosoglu and Yazgac (1997); Cheng et al. (1996) Akakarte et al. (2001); Lee et al. 2001 Muralidharan et al. (2002); Chan and Chan (2004); Liu and Hai (2005); Chan et al. (2007); Hou and Su (2007); Guler (2008); Dagdeviren et al. (2009)
Simple multi attribute rating technique	Barka (2003); Huang and Keska (2007)
Case-based reasoning	Ng and Skitmore (1995); Choy et al. (2002); Choy and Lee (203); Choy et al. (2005)
Genetic algorithm	Ding et al. (2005)
Analytical network process	Hill and Nydick (1992); Narasimhan (1983); Sarkis and Talluri (2002); Bayazit (2006); Gencer and Gurpinar (2007)
Matrix method	Gregory (1986)
Multi-objective programming	Weber and Ellram (1993); Narasisimhan et al. (2006); Wadhwa and Ravindran (2007)
Total cost of ownership	Smytka and Clemens (1993); Degraeve and Roodhooft (1999); Degraeve et al. (2000); Bhutta and Huq (2002)
Human judgment models	Ellram (1995); Patton (1996)
Principal component analysis	Petroni and Braglia (2000); Amiri et al. (2008); Lasch and Janker (2005); Sheng and Lan (2009); Lin and Song (2009); Sen et al. (2010); Surjandari et al. (2010)
Data envelopment analysis	Narasimhan et al. (2001); Talluri (2002a); Weber and Desai (1996); Weber et al. (1998); Liu et al. (2000)
Interpret. structural modeling	Mandal and Deshmukh (1994)
Game models	Talluri (2002b)
Statistical analysis	Ronen an Trietsch (1988); Mummalaneni et al. (1996); Verna and Pullman (1998)
Discrete choice analysis exp.	Verma and Pullman (1998)
Neural networks	Siying et al. (1997)
Semi-structural questionnaire	Schmitz and Platts (2004)
Max-Min approach	Talluri and Narasimhan (2003)
Vendor performance index	Willis et al. (1993)
Standardized unitless rating	Li et al. (1997)
Outranking methods	De Boer et al. (2001)
Mathematical models	Weber and Elram (1993); Sadrian and Yoon (1994); Rosental et al. (1995); Ghodyspour and O' brien (1998)

Table 2.1 (continued)

Supplier evaluation methods/techniques	
Evaluation technique	Authors
Thurstone scaling techniques	Thompson (1991)
Vendor survey plan	Lee and Welln (1993)
Integrated fuzzy AHP	Kahraman et al. (2003); Bottani and Rizzi (2005); Bozdag et al. (2005); Haq and Kannan (2006); Chan and Kumar (2007); Kunadhamraks and Hanaoka (2008); Kong et al. (2008); Pang (2008); Sen et al. (2010); Lee (2009) Ku et al. (2009); Chamodrakas et al. (2010)
Fuzzy PCA	Lam et al. (2010)
Integrated AHP and DEA	Ramanathan (2007); Saen (2007); Sevkli (2007)
Integrated AHP and GP	Cebi and Bayractar (2003); Peercin (2006); Kull and Talluri (2008); Mendoza (2008)
Integrated fuzzy and cluster analysis	Bottani and Rizzi (2008)
Integrated fuzzy and GA	Jain et al. (2004)
Integrated fuzzy and multi objective programming	Amid et al. (2006)
Integrated fuzzy and quality function deployment	Bevilacqua et al. (2006)
Integrate fuzzy and smart	Kwong et al. (2002); Chou and Chang (2008)

year (FY) 2007, US DOD's contract obligations included $ 330 billion for defense-related supplies and services (FPR 2007). In FY 2010, US DOD estimated that overall spending on logistics, including supply chain management, mounted to more than $ 210 billion (GAO-11-569 2007). Hellenic MoD's budget calculations for FYs 2013 and 2014, in spite of the ongoing financial crisis, were of 3.36 € and 2.9 billion € respectively (PGD 2012, 2013). Suppliers, in defense area, account for 50–80 % of a major item's value (GAO-98-87 1998) and Beil (2010) reports that average US manufacturer spends roughly half of its revenue to purchase goods and services. Consequently, selecting suppliers with solid and modernized criteria could be a secure way for reducing defense budgets, in an effective and transparent way.

In this paper, we focus on a supplier selection methodology of MCIs, otherwise seen as critical safety items. The aspects that may categorize an item as an MCI relate to the safety of the personnel that uses it and its capability to fulfill the mission assigned (JLC ACSIMH 2005; DAGuidebook 2010; UK JSP 886 2010). Briefly, the lack or the malfunction of an MCI will have a major impact to the safety and accomplishment of a mission. Laios (2010) uses the portfolio analysis (supply positioning model) to classify items depending on the risk of supply, i.e. consequences from their shortage and the volume/expenditure of purchase they represent. By that MCIs may be corresponded to critical and bottleneck items, since in both cases the risk of supply is high and may jeopardize the success of a mission.

Our literature review of the relevant area in defense procurement, indicated that no single, widely accepted, approach exists for supplier selection that can fit in every case, and that supply managers may adopt different selection criteria, each time a procurement need arises (kanan and Tan 2002; Hsu et al. 2006; Ho et al. 2010; Degraeve et al. 2000). By reviewing Ware (2012), it seems that the application of fuzzy logic in supplier selection issues is something relatively new. More specifically, in the majority of the papers mentioned by Ware (2012), fuzzy AHP and Multivariate Statistical Analysis (MSA) were not applied to a significant extent. Ho et al. (2010) provide only one paper (Bottani and Rizzi 2008) as an integration of Fuzzy AHP with Cluster Analysis (a MSA sub-area). Studying uncertainty in supplier selection decisions that involve strategic (critical) and bottleneck items, is something that needs to be seriously considered (De Boer 2001). Competitive Intelligence (CI) may be used as an extra tool to reduce that uncertainty, as it could serve to highlight the critical gaps in the knowledge of decision makers and illuminate the key uncertainties (Hopple 1984).

NATO Support Agency (NSPA) procurement regulation (FD251-01 2012) states that supplier's eligibility will be based on the following factors: residency, national eligibility status, present capability and past performance, and that in vendor evaluation procedure, the Source Identification Section shall maintain a database containing information on the performance of suppliers with whom NSPA has concluded contracts, which should as a minimum cover cases of late delivery and discrepancies. No clear use of Fuzzy Logic and MSA is observed therein, while other defense related editions urge to deal with uncertainty in procurement decisions (DoD 2003; DAG 2010). Past performance is included in Bernhardt's (1994) working definition for CI. Lysons and Farrington (2006) provided a list of common vendor rating methods, where no Multivariate Statistical Methods exist. Furthermore, indicative criteria for supplier selection are referred in the regulatory for the public defense procurement, European Directive 2009/81/EC (Greek Law 3978/11 2011) which also covers procurement functions with non-EU members. By following the provisions of that Directive and the respective procedures, transnational agreements for reasons of national security/defense may be reached such as the USA/Foreign Military Sales contracts. The existence of indicative criteria allows suggestions for the public procurement supplier selection process, of methods and tools seen in the private section relevant literature, as long as the suppliers under evaluation cover the basic prerequisites set by that Directive. Public/private sector cooperation and exchange of knowledge to resolve procurement issues is a growing tendency in many countries and various public/private partnership arrangements replace conventional purchasing (Thai 2004; Choi 2010).

2.2.1 An Integrated Approach for MCI Supplier Selection

Figure 2.1 shows the steps of our methodology within the frame of a defense agency under public procurement law and the positioning of the suggested decision tools. Due to the specialized nature of the data (Armed Forces Data) the application of the framework required a panel of experts operating in military procurement area. For

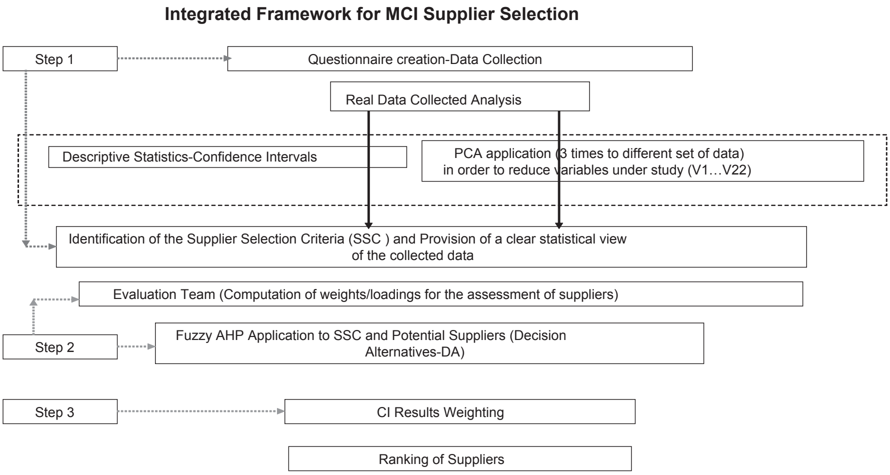

Fig. 2.1 Steps of the methodology for an integrated approach of MCI supplier selection

that scope, an Evaluation Team was created by two senior managers with a lot of experience in military procurement and the authors of this article, in order to embed every day experience in our approach. In addition to that, we took into account that multiple decision makers are often preferred in order to minimize partiality of a decision process (Bilsel et al. 2006) and the increasing importance of group decision making (Ahn 2000). The tools used to develop the suggested methodology are analyzed hereinafter.

2.2.2 Competitive Intelligence

Intelligence issues also appear in Logistics. Greek Intelligence Doctrine for land forces (GID 2005) urges for the use of a C4ISR system (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) in order to obtain intelligence that will drive, among others, to successful military logistics. Porteus (1994) provides examples of obtaining information on military procurement and Lee et al. (2009) suggest a procurement system that includes supplier selection, to enhance Business Intelligence (BI). BI includes competitive intelligence (Negash 2004). Competitive Intelligence (CI) is a systematic program for gathering and analyzing information about competitor's activities and general business trends to further a company's goals (Kahaner 1996). There is a positive relationship between CI and successful financial performance (Miller 2001) and Bernhardt (1994) reports that one of the usual CI objectives is financial issues. SWOT and financial analysis are the most used and effective tools of CI analysis (Miller 2001). In addition to that, SWOT analysis is often used to identify internal and external factors that may influence the fulfillment of strategy goals (Jiang et al. 2011).A failure to monitor supplier financial performance can result in interruptions in supply, if a financially troubled supplier is unable to deliver goods and services as agreed (Cancro and McGinnis 2003). Laios (2010) states that evaluating financial issues of a potential supplier is a demanding process and may become very important in cases of critical and bottleneck items (MCIs). In UK 2010 Bribery Act Adequate Procedures for corporate anti-bribery programs, indices 199–206 suggest the existence of an anti-bribery procedure. In the research study "Identifying and reducing corruption in public procurement in the EU" commissioned by the European Commission and conducted by PwC EU Services and Ecorys in 2013, the use of intelligence methods is suggested as a mean to reduce corruption. Consequently, we suggest that a CI system of MCIs could assist in securing the transparency of procurement actions and focusing on financial objectives, SWOT information and Corporate Trends of the potential suppliers. Therefore the key points of an MCI CI system may be the following, for each one of the potential suppliers that reached the final selection phase:

a. Its current corporate strategy and the possibility of a forthcoming change in it.
b. Its anti-corruption policy.
c. SWOT analysis for each one.
d. Financial Health information.

Ascertaining the financial health of a supplier can be subtle and challenging, because the signs of financial distress often emerge slowly and because financial data may not be publicly available or masked under the financial reports of larger firms that individual operating units belong to (Cancro and McGinnis 2004). If the Management decides to use as a CI sole source the financial statements of, balance sheet and the profit and loss statement [they provide the basic financial information for an enterprise/agency (Laios 2010)], then we suggest the evaluation of three ratios of solvency and one of profitability, derived from the abovementioned financial statements. Solvency ratios are more significant than profitability ratios (Inman 1991; Cancro and McGinnis 2003) and below-mentioned specific ratios are considered to be important for supply managers to understand basic financial information of a company and for the evaluation of potential supplier (Laios 2010; Cancro and McGinnis 2003).

e. Solvency-Current Ratio = Current Assets/Current Liabilities. A value grater than 1 may imply that the firm can cover its short-term debts.
f. Solvency-Acid Ratio = Current Assets –Inventory/ Current Liabilities. This ratio, although similar to Current Ratio, it provides a more direct estimation for the supplier's liquidity since it takes into account the time for the inventory to be turned into liquid assets. A value grater than 1 may implies a sufficient liquidity.
g. Solvency-Inventory Turnover = Cost of Gods sold/Average Inventory. A low value may imply high operating cost and inefficient inventory management.
h. Profitability-Operating Margin = Operating Income/ Net sales. It provides the net profit that derives from each $ of sales.

Possible CI objectives could also be other, hard to quantify, information. In Ware (2012) supplier loyalty is mentioned as a selection criterion that may reduce the supplier selection risks. A good reputation of a supplier in the market may ease contracting in peacetime conditions (CSI Proceedings 2006). Chan (2007) provides risk factors that strongly affect global supplier selection, such as geographical location, political stability, economy and terrorism. All this, could be a part of the SWOT analysis of each candidate supplier for a study of the influence on the contractual fulfilment of his obligations and the risk of interrupting supply. For example, political stability enhances long-term relations with suppliers which is a part of a supply strategy for critical items (Laios 2010). Conclusively, the establishment of a CI system does not imply the existence of corruption phenomena in any defense acquisition practise. It aims at reducing procurement risks that may occur throughout the life cycle of a weapon system f.e. It is more likely to support it in a long-term period a financially viable supplier with good reputation in the market.

2.2.3 Principal Components Analysis

Xia and Wu (2007), report that there is a large part of procurement experts that consider supplier selection as the most important function of a purchasing department and that decision makers cannot handle simultaneously many factors/parameters of decision. Miller (1956) stated that most decision makers cannot simultaneously handle more than 7–9 factors when it comes to decide. Consequently, it would be wise to use a reliable solution towards the direction of reducing decisional factors. Principal Component Analysis (PCA) is not new in the supplier selection area (Table 2.1) because it is considered to be an efficient way to reduce data and simplify the model under study without losing valuable information (Johnson and Wichern 2007). Algebraically, PCs are particular linear combinations of p random variables ($X_1, X_2, \ldots, X_p$) that explain most of the variability of the original variable set. Geometrically, PCs are linear combinations that represent the selection of a new coordinate system obtained by rotating the original system with $X_1, X_2, \ldots, X_p$ as the coordinate axes. The new axes represent the direction of the maximum variability and provide a simpler and more parsimonious description of the covariance structure (Jhonson and Wichern 2007). Let the random vector $X' = \left[X_1, X_2, \ldots, X_p\right]$ have the covariance matrix Σ with eigen values $\lambda_1 \geq \lambda_2 \geq \ldots.. \geq \lambda_p \geq 0$. Consider the following linear combinations:

$$\begin{aligned}
\psi_1 &= a_1' X = a_{11}X_1 + a_{12}X_2 + \ldots.. a_{1p}X_p \\
\psi_2 &= a_2' X = a_{21}X_1 + a_{22}X_2 + \ldots.. a_{2p}X_p \\
&\vdots \\
\psi_p &= a_p' X = a_{p1}X_1 + a_{p2}X_2 + \ldots.. a_{pp}X_p
\end{aligned}$$

These linear combinations $\Psi = CX$ have $\mu_\psi = E(\Psi) = E(CX) = C\mu_\chi$ and $\Sigma_\psi = Cov(\Psi) = Cov(CX) = C\Sigma_\psi C'$, where $\mu\psi$ and $\Sigma\psi$ are the mean vector and

	Supplier Quality indicators
1.Testing Capability	V1
2. Scope of resources	V2
3. Technical Expertise	V3
4. Industry knowledge	V4
5. Commitment to Quality	V5
6. Supplier's Process Capability	V6
7. Commitment tot continuous improvement	V7
8. Visionary Leadership	V8
9. Employee Fulfilment	V9

	Supplier Service Indicators
1. Ability to meet delivery due dates	V10
2. Price of materials, parts and services	V11
3. Flexible contract terms and conditions	V12
4. Geographical compatibility/proximity	V13
5. Reserve Capacity	V14

	Buyer- Supplier Strategic/Management Fit Indicators
1. Open to site evaluation	V15
2. Supplier's reputation	V16
3. Financial stability and staying power	V17
4. Honest and frequently communications	V18
5. Cultural match with Supplier	V19
6. Past and current relationship with the supplier	V20
7. Supplier is strategically Important	V21
8. Supplier's willingness to share confidential information	V22

Footnote: V means Variable

Fig. 2.2 Supplier quality, Service/delivery and stgic/mgmt fit indicators

variance-covariance matrix of *Xp* respectively. Finally we obtain $Var(\psi_i) = \alpha_i^{'}\Sigma\alpha_i$ and $Cov(\psi_i, \psi_k) = \alpha_1^{'}\Sigma\alpha_k$ with *I, k* = *1, 2....p*. The PCs are those uncorrelated linear combinations $\Psi_1, \Psi_2, \ldots, \Psi_P$ whose variances are as large as possible and the first PC is the linear combination with maximum variance. There are various statistical softwares such as SPSS, MINITAB that perform PCA calculations. In this paper we used the MINITAB statistical software. Cheraghi (2004) concluded that supplier selection dominant criteria were aspects of quality, delivery, price and service and Ho et al. (2010) mentioned that the three most popular evaluating criteria are those related to aspects of quality, delivery and price/cost. Ongoing importance of quality delivery and cost aspects enhanced us to use the supplier selection construct suggested by Hsu et al. (2006) and investigate the importance attributed to indicators mentioned therein and related to quality, service, delivery, cost and buyer-supplier management fit. Real data were evaluated from questionnaires where members of the armed forces were asked to rate the importance of above-mentioned indicators, in cases of MCIs, by their importance and rate of appearance on a five point Likert scale (Indicators depicted in Fig. 2.2). The number of questionnaires constituted the sample size (N=30) where PCA was applied (see Fig. 2.1). Each set of indicators was a different question in the same questionnaire.

Analytically, PCA was applied three times, one in each subgroup i.e. Supplier Quality, Service/Delivery and Stgic/Mgmt Fit subgroups, in an attempt to reduce indicators/Variables under study so that they reach the number suggested by Miller (1956) and therefore be made easier for a decision maker to handle. Some indicators of the 3rd subgroup, such as supplier reputation and financial stability may be important objectives of a CI system, as shown in previous subsection.

2.2.4 Fuzzy Sets Theory and Fuzzy AHP

Fuzzy logic deals with the vagueness of human thought (Zadeh 1965) which is usually an outcome of the majority of the real world situations where most decision environments are characterized by complex and imprecise information (Aggarwal and Singh 2013). Supply Chain Management issues could not be an exemption. According to Ho et al. (2010) the most well known method to operationalize supplier selection decision making is the Analytic Hierarchy Procedure (AHP). AHP includes subjective judgments, thus a fuzzy approach on that issue can overcome the possible uncertainty of these judgments (Tang and Beynon 2005) and fuzzy logic allows numerical values to belong in two categories with a different extent (Bottani and Rizzi 2008). Fuzzy AHP (FAHP) is developed from the AHP and integrates fuzzy logic into AHP, making it able to provide more sufficient information (Aggarwal and Singh 2013).

The Basic Concepts of fuzzy logic adopted in this paper are cited below and can be viewed in detail in Chang (1992, 1996), Tang and Beynon (2005), and Theodorou (2012). Triangular Fuzzy Numbers (TFNs) were selected since they are the most popular ones (Amin and Razmi 2011) and easy to handle (Lam 2010).

Definition 1 Let M E F(R) be called a fuzzy number if: (1) exists $x_o \in$ such that $\mu_M(\chi_0) = 1$ and (2) For any $a \in [0, 1]$, $A_a = [x, \mu_{Aa}(x) \geq a]$ is a closed interval. *F(R)* represents all fuzzy sets, and *R* is the set of real numbers.

$$\mu_M(x) = \begin{bmatrix} \frac{x}{m-l} - \frac{l}{m-l}, x \in [l, m], \\ \frac{x}{m-u} - \frac{u}{m-u}, x \in [m, u], \\ 0, if \quad otherwise \end{bmatrix} \tag{2.1}$$

Definition 2 A fuzzy number *M* on *R* is defined to be a triangular fuzzy number if its membership function $\mu_M(\chi): R \rightarrow [0, 1]$ equals to equation (1). *1* and *u* are the lower and upper values of the support of M respectively and *m* the modal value. The triangular fuzzy number can be denoted by *(l, m, u)*. The support of M is the set of elements $\{x \in R [l < x < u\}$.

Springer

http://www.springer.com/978-3-319-12074-4

Military Logistics
Research Advances and Future Trends
Zeimpekis, V.; Kaimakamis, G.; Daras, N.J. (Eds.)
2015, XII, 172 p. 45 illus., 36 illus. in color., Hardcover
ISBN: 978-3-319-12074-4