



An Integrated Group Decision-making Process For Supplier Selection and Order Allocation Using Multi-attribute Utility Theory Under Fuzzy Environment

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Abstract

Supply chain management has become a key aspect that has implications for effective and efficient management of industrial relations. It has also become an important focus for firms and organizations to obtain a competitive advantage. Supplier selection is a highly important multi-criteria group decision making problem, which requires a trade-off between multiple criteria exhibiting vagueness and imprecision with the involvement of a group of experts. In this problem if suppliers have capacity or other different constraints, two problems will exist: which suppliers are best and how much should be purchased from each selected supplier. In this paper an integrated approach of multi-attribute utility theory (MAUT) is applied to represent the decision maker's fuzzy goals for the supplier selection and order allocation problem. A numerical example is proposed to illustrate an application of the proposed method.

Keywords: Supplier selection; MAUT

1. Introduction

Supply relationship management in supply chains seeks the participation of good suppliers providing low cost and high quality. A recent trend in 21st Century business is outsourcing product manufacturing. With an increase in outsourcing, offshore-sourcing, and electronic business, supply management decisions are becoming ever more complex in a global market. Supply chain vendor evaluation is a very important operational decision, involving not only selection of vendors, but other decisions with respect to quantities to order from each vendor. Supplier selection problem is a multi-criteria decision making problem which includes both qualitative and quantitative factors. In the selection process many criteria may conflict with each other, therefore decision-making process becomes complicated.

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In today's competitiveness world, most organizations attempt to meet demand, increase quality, and decrease cost. In most industries, the cost of raw materials and component parts forms the major part of production cost, e.g. up to 70% [1]. Since different criteria can be considered during the decision making process for Supplier selection decision, this problem is a more complex in presence of volume discounts and multiple items. These criteria include qualitative and quantitative factors. Therefore, this problem is important for purchasing managers and they should determine the trade-off among the several factors. Improper selection of suppliers may unfavorably affect the company's competitiveness strategy. Thus, this problem is naturally a multi-objective decision-making problem with several conflicting factors such as cost, quality, and delivery. Mathematical programming techniques can be applied to determine the optimal solutions of this problem where the criteria are formulated as the objective functions or constraints [2].

Selecting suppliers provide the lowest price in a given industry is a challenge for purchasing managers, specifically when suppliers offer multiple products and volume-based discount pricing schedules [3]. Different mixed-integer programming approaches have been applied by researchers for the SSP. Talluri presented a binary integer linear programming model in selecting an optimal set of bids that satisfy the buyer's demand requirements to evaluate supplier bids based on the ideal targets set by the buyer [4]. The outputs of the Hong et al.' model were the optimal number of suppliers, and the optimal order quantity to maximize revenue while satisfying the procurement condition and maintaining the supplier-relationship for a longer time period [5]. Ghodsypour and O'Brien developed a mixed integer non-linear programming model taking into account the total logistics costs (net price, storage, transportation, and ordering costs) and the buyer limitations (budget, quality, service, etc.) to solve the multiple sourcing problems [6]. Basnet and Leung developed a mixed integer programming model to solve the SSP with multi-period multi-product lot sizing. The objective function included the transaction cost, the purchasing cost, and holding cost for each product in the inventory in each period [7].

Xia and Wu proposed an integrated approach of analytical hierarchy process improved by rough sets theory and multi-objective mixed integer programming simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing, multiple products, with multiple criteria and with supplier's capacity constraints. These models have not considered price discount or multi-price level [8].

Kumar et al. formulated the SSP as a fuzzy mixed integer goal programming with three primary goals minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries subject to realistic constraints regarding the buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items, budget allocation to individual vendor, etc [9]. On the other hand, supplier selection requires the information about potential suppliers' credit history, performance history and other personal information, which are often not available to the public. Therefore, data available to supplier selection often incur problems such as small dataset available to the public, missing values, inconsistent values, errors, etc. In addition, companies conducting supplier performance evaluation always have a great deal of data but lack the knowledge of the data. That is to say, these data are not fully and effectively explored and used and they cannot provide predictive functions for the future decision-making.

Supplier selection problem is a multi-criteria decision making problem which includes both qualitative and quantitative factors like unit cost, delivery on-time, service quality, etc. In this problem many criteria may conflict with each other, so the selection process becomes complicated and it contains two major problems: (i) which supplier(s) should be chosen? and (ii) how much should be purchased from each selected supplier? These problems encountered in purchasing departments of firms and solving them are very significant. In the last several years, supplier (or vendor) selection problem has gained great importance and is handled by academic researchers and also practitioners in business environment. The literature on this problem exist some researches (i) focused on supplier selection problem criteria, and (ii) proposed methods for supplier selection process [10].

The emerging trend in current research is the integration of DM techniques in constructing an effective decision model to address practical and complex SS problems, particularly for the consideration of multitudinous uncertainty factors. Given the diversity and the complexity of SS research, we particularly use a methodological decision analysis framework for the selection of the collected articles. This framework provides a guide for the analysis of the literature based on four aspects: (1) decision problems, (2) decision makers, (3) decision environments, and (4) decision approaches. First, we confine our survey on structural SS and thus eliminate the literature that discusses semi-structural or non-structural decision problems. Consequently, a total of 123 articles are selected for detailed

review. Second, the literature that involves multiple decision makers as a group is specifically indicated as reference for readers. Third, we classify the selected articles into seven categories after a decision environment analysis. Fourth, the emerging decision approaches are investigated in detail. Specifically, 26 DM techniques are independently reviewed from three perspectives: MCDM techniques, mathematical programming (MP) techniques, and artificial intelligence (AI) techniques. Major integrated approaches are separately reviewed. These approaches include the integrated analytic hierarchy process (AHP), integrated analytic network process (ANP), integrated data envelopment analysis (DEA), and integrated uncertain approaches, among others [11].

For example they don't effectively take into account risk and uncertainty when assessing the supplier's potential performance because they presume that the relative importance of attributes affecting the supplier's performance is known with certainty. Multi-attribute utility theory (MAUT) has been used in international supplier selection considering one decision maker in a single sourcing environment by Min however the probabilistic nature of supplier performance still remained unanswered [12].

Organizations have two approaches to supplier selection. The first approach is to select the best single supplier, which can meet all the requirements (single sourcing). The second approach is to select an appropriate combination of suppliers when no single supplier can satisfy all the requirements. Accordingly, management should split order quantities among the available suppliers for a variety of reasons including creating a constant environment of competitiveness (multiple sourcing).

Several methods have been proposed in the literature for single sourcing supplier selection some of which are discussed. One of these methods is data envelopment analysis (DEA), DEA is a mathematical programming (MP) technique that calculates the relative efficiencies (ratio of weighted outputs (benefit criteria) to weighted inputs (cost criteria)) of multiple decision-making units. Liu et al. used DEA for rating and choosing the best supplier [13]. Talluri and Narasimhan stated that methods such as DEA have primarily relied on evaluating vendors based on their strengths and failed to incorporate their weaknesses into the selection process. They also added that such approaches would not be able to effectively differentiate between vendors with comparable strengths but significantly different weaknesses [14].

Although many researches have been proposed to deal with supplier selection problem, the probabilistic nature of the problem, qualitative and quantitative factors and uncertainty involved with it are not considered at the same time in a multiple sourcing fuzzy environment. In this study, we propose an integrated MAUT approach and a LP model to select the best suppliers and indentifying the optimum order quantities among the selected suppliers in order to maximize total additive utility.

The remaining sections of the paper are structured as follows: In the section 2, Importance of Supply chain management. Section 3, an overview and background of MAUT method is presented. Section 4 will focus on the proposed model. In Section 5, a numerical example is illustrated, Section 6 results are discussed. In the final section, some conclusions are drawn from the study.

2. Importance of Supply chain management

A supply chain, as opposed to supply chain management, is a set of organizations directly linked by one or more upstream and downstream flows of products, services, finances, or information from a source to a customer. Supply chain management is the management of such a chain [26]. Supply chain management software includes tools or modules used to execute supply chain transactions, manage supplier relationships, and control associated business processes.

Supply Chain Management (SCM) is concerned with the optimization of the resources of firms in a logistics network that delivers value to end customers.

Supply chain management (SCM) is the combination of art and science that goes into improving the way your company finds the raw components it needs to make a product or service and deliver it to customers. The following are five basic components of SCM.

A. Plan

This is the strategic portion of SCM. Companies need a strategy for managing all the resources that go toward meeting customer demand for their product or service. A big piece of SCM planning is developing a set of metrics to monitor the supply chain so that it is efficient, costs less and delivers high quality and value to customers.

B. Source

Next, companies must choose suppliers to deliver the goods and services they need to create their product. Therefore, supply chain managers must develop a set of pricing, delivery and payment processes with suppliers and create metrics for monitoring and improving the relationships. And then, SCM managers can put together processes for managing their goods and services inventory, including receiving and verifying shipments, transferring them to the manufacturing facilities and authorizing supplier payments.

C. Make

This is the manufacturing step. Supply chain managers schedule the activities necessary for production, testing, packaging and preparation for delivery. This is the most metric-intensive portion of the supply chain—one where companies are able to measure quality levels, production output and worker productivity.

D. Deliver

This is the part that many SCM insiders refer to as logistics, where companies coordinate the receipt of orders from customers, develop a network of warehouses, pick carriers to get products to customers and set up an invoicing system to receive payments.

E. Return

This can be a problematic part of the supply chain for many companies. Supply chain planners have to create a responsive and flexible network for receiving defective and excess products back from their customers and supporting customers who have problems with delivered product. Supply chain event management (SCEM) considers all possible events and factors that can disrupt a supply chain. With SCEM, possible scenarios can be created and solutions devised. In many cases the supply chain includes the collection of goods after consumer use for recycling. Including third-party logistics or other gathering agencies as part of the RM repatriation process is a way of illustrating the new endgame strategy.

Supply chain strategies require a total systems view of the links in the chain that work together efficiently to create customer satisfaction at the end point of delivery to the consumer. As a consequence, costs must be lowered throughout the chain by driving out unnecessary expenses, movements, and handling. The main focus is turned to efficiency and added value, or the end-user's perception of value. Efficiency must be increased, and bottlenecks removed. The measurement of performance focuses on total system efficiency and the equitable monetary reward distribution to those within the supply chain. The supply chain system must be responsive to customer requirements [27].

Supply chain management is a cross-functional approach that includes managing the movement of raw materials into an organization, certain aspects of the internal processing of materials into finished goods, and the movement of finished goods out of the organization and toward the end consumer. As organizations strive to focus on core competencies and becoming more flexible, they reduce their ownership of raw materials sources and distribution channels. These functions are increasingly being outsourced to other firms that can perform the activities better or more cost effectively. The effect is to increase the number of organizations involved in satisfying customer demand, while reducing managerial control of daily logistics operations. Less control and more supply chain partners led to the creation of the concept of supply chain management. The purpose of supply chain management is to improve

trust and collaboration among supply chain partners, thus improving inventory visibility and the velocity of inventory movement.

In recent decades, globalization, outsourcing, and information technology have enabled many organizations, such as Dell and Hewlett Packard, to successfully operate collaborative supply networks in which each specialized business partner focuses on only a few key strategic activities. This inter-organizational supply network can be acknowledged as a new form of organization. However, with the complicated interactions among the players, the network structure fits neither "market" nor "hierarchy" categories. It is not clear what kind of performance impacts different supply network structures could have on firms, and little is known about the coordination conditions and trade-offs that may exist among the players. From a systems perspective, a complex network structure can be decomposed into individual component firms [28]. Traditionally, companies in a supply network concentrate on the inputs and outputs of the processes, with little concern for the internal management working of other individual players. Therefore, the choice of an internal management control structure is known to impact local firm performance.

In the 21st century, changes in the business environment have contributed to the development of supply chain networks. First, as an outcome of globalization and the proliferation of multinational companies, joint ventures, strategic alliances, and business partnerships, significant success factors were identified, complementing the earlier "just-in-time", lean manufacturing, and agile manufacturing practices. Second, technological changes, particularly the dramatic fall in communication costs (a significant component of transaction costs), have led to changes in coordination among the members of the supply chain network .

In general, such a structure can be defined as "a group of semi-independent organizations, each with their capabilities, which collaborate in ever-changing constellations to serve one or more markets in order to achieve some business goal specific to that collaboration.

The security management system for supply chains is described in ISO/IEC 28000 and ISO/IEC 28001 and related standards published jointly by the ISO and the IEC. Supply Chain Management draws heavily from the areas of operations management, logistics, procurement, and information technology, and strives for an integrated approach.

3. Multi-attribute utility theory (MAUT)

As indicated in the previous section, supplier selection is a complex decision-making problem. The complexity stems from the probability nature of the problem, a multitude of quantitative and qualitative factors influencing supplier choices as well as the intrinsic difficulty of making numerous tradeoffs among these factors. One analytical approach often suggested for solving such complex problems is MAUT. The MAUT model enables the consideration of factors that have different measures and different relative importance to the decision.

Keeney and Raiffa employed the utility concept in complex decision problems involving multiple attributes and multiple conflicting objectives, and provided a systematical approach of multiple attributes utility analysis (MAUA). MAUA is targeted in solving problems of trading off the achievement of some objectives against other objectives to obtain the maximum overall utility [15]. Another possibility for dealing with imprecision within MAUT described in the literature attempts to apply the concept of pair wise and absolute dominance to eliminate inferior alternatives, leading to the so-called surrogate weighting methods [19,20]. A decision-maker is assumed to be facing the above-mentioned problem, and he/she has to choose a solution from some solution alternatives. MAUA is used to assess the decision-maker's preference structure and model it mathematically with a multiple attributes utility function. This multiple attributes utility function is then applied to help the decision maker reach an optimal decision.

Multi-attribute utility analysis (MAUA) has emerged as a powerful tool for supplier selection and evaluation. An operations research technique, MAUA has been used in a wide range of selection areas. Utility analysis affords a rational method of supplier selection which avoids many of the fundamental logical difficulties of many widely used alternative approaches. A number of papers on multi-attribute utility theory (MAUT) have dealt with incomplete information. For instance, Sage and White proposed the model of imprecisely specified multi attributes utility theory (ISMAUT) where preference information about both weights and utilities is assumed not to be precise [17].

Malakooti suggested a new efficient algorithm for ranking alternatives when there is incomplete information about the preferences and the value of the alternatives [18].

MAUT enables the decision maker to structure a complex problem in the form of a simple hierarchy and to subjectively evaluate a large number of quantitative and qualitative factors in the presence of uncertainty. Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine quantitative and qualitative factors. A utility function is a device which quantifies the preferences of a decision maker by assigning a numerical index to varying levels of satisfaction of a criterion [16].

In particular, Min highlighted three distinctive advantages of MAUT over MOP in handling multiple and conflicting criteria as follows[13]:

- (1) MAUT requires less ‘‘front-end’’ analysis than MOP, as MAUT has no constraints considering explicitly;
- (2) MAUT requires data more than MOP, as MAUT does not necessitate parameters for constraints; and
- (3) MAUT poses less computational difficulty than MOP, as MAUT is not burdened with additional constraints.

The systematic nature of MAUT in tackling complex problems with conflicting criteria makes it especially suitable for selecting the most appropriate supplier.

4. An integrated method for supplier selection and order allocation

The model presented in this section applies MAUT, which unifies quantitative and qualitative factors using the same scale to measure desirability of the suppliers. The model is intended to rate the suppliers while considering uncertainty. The obtained rates are then used as coefficients for the objective function of the proposed model. The solution obtained from the maximum total additive utility (TAU) of the model provides the optimal allocation of the order quantities among the suppliers. The process is depicted in Fig. 1, and the main steps of the algorithms are described in the following sections.

4.1. Identify the problem scope and define the objectives or goals

The purpose of this step is to identify, test and implement a solution to the problem; in part or in whole. Identify creative solutions to eliminate the key root causes in order to fix and prevent process problems. Firstly, in this step, the scope of the problem is defined in terms of the product/service to be outsourced, time frame for outsourcing, justification of decision, constraints in the supplier selection process, and available alternative sources to choose from. Then the objectives of supplier selection are derived from the various functional departments of the organization, which are aligned with the overall organizational goals and impacted by the decision: such as the assembly line, supplier quality assurance department, finance group, logistics department and the other related sections.

4.2. Define and describe a finite set of relevant attributes

For supplier selection, identification of decision attributes (criteria) is required, and then evaluation scale/metrics are determined in order to measure appositeness of a supplier. Our previous work on the weighting factor is on such probability basis. This is applicable regardless of the data distribution in the database. However, with the existing database as the training set, we can derive more certain information from attribute relevance analysis, and thus get better weighting factors to distinguish an object from others. The general idea behind attribute relevance analysis is to compute some measure that is used to quantify the relevance of an attribute with respect to a given class (category) these criteria must be defined according to the corporate strategies and the company’s competitive situation. In this way, the level of buyer–supplier integration is determined and the product type outsourced [21].

Having considered sub-criteria for each main criterion, a hierarchical form called “value tree” is structured along with a unit to measure each criterion. The objectives and goals identified in step 3.1 and the decision makers’ desires have direct impacts on the degrees to which these attributes are encountered.

4.3. Pre-selection of potential suppliers

According to Aissaoui et al. today’s co-operative logistics environment requires a low number of suppliers as it is very difficult to manage high numbers [22].

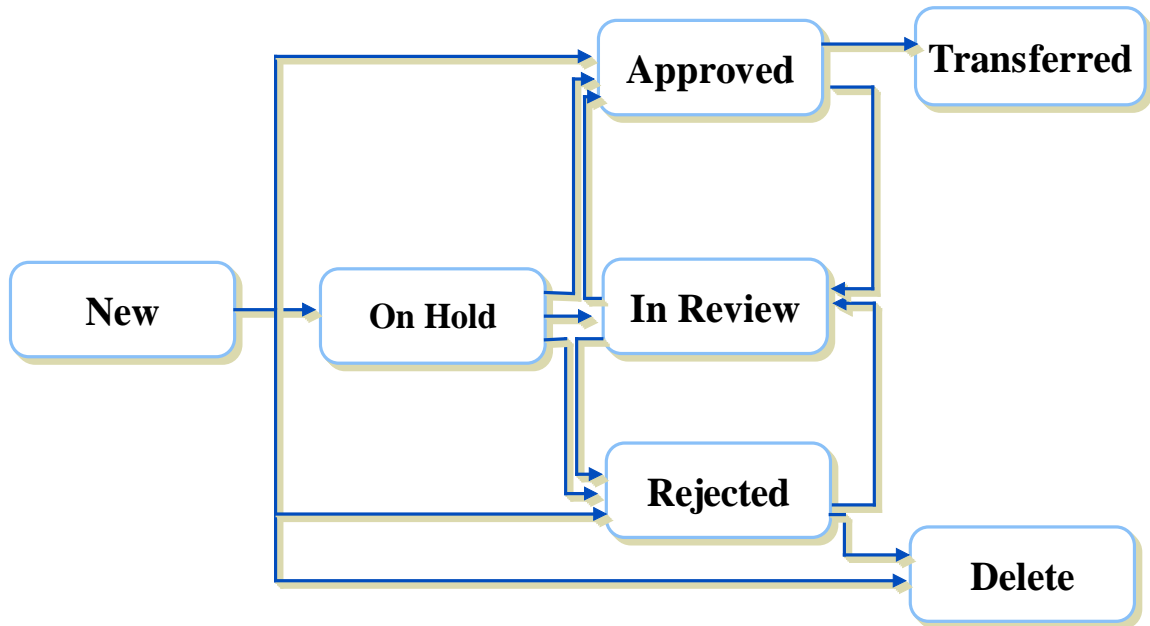


Fig: 2 Pre-selection of potential suppliers

In today’s severe competitive environment companies are forced to take advantage of any opportunity to optimize their business process, to that end they must work with their supply chain partner to improve the chain’s total performance

Among the existing supplier alternatives, it is possible to use an elimination method which excludes suppliers who cannot satisfy the selection rules. The concept is based on the fact that suppliers who do not fit the minimum level of key criterion/criteria are gradually eliminated during the selection process. To achieve this aim a brief data collection with respect to key criterion/criteria is required. De Boer et al. discussed the methods supporting pre-selection of potential suppliers [23].

4.4. Data collection

In this step literally we can guess which supplier could be better for us. The data are collected from each qualified supplier through interviews, questionnaires, personal meetings, visits to the supplier facility and external resources. The best/worst levels should be identified in this step. The extrapolation of the utility outside the measurement

boundaries cannot be reliably accomplished. The data collection could also facilitate the estimate of uncertainty concerning the supplier performance.

4.5. Utility assessment

The utility assessment step is the decisive part of the supplier selection process. During the utility assessment a series of interviews is conducted with the decision makers by an expert analyst. The parameters of the utility function are calculated directly from a lottery and trade-off questions. Detection of escape as a maintaining variable relies on the presentation of aversive events, it is important to include tasks in the supplier selection that may evoke problem behavior maintained by escape. Depending on the nature of individual attributes and the assumptions regarding preferential and utility dependencies, a multi-attribute utility function can be derived. The MAUA method is based on a two-step approach of mapping the alternatives to the overall utility values as follows:

- i. Build a utility function for each attribute by associating probabilities with the attribute levels, or a value function by a direct assessment method. The value of each attribute's performance with respect to the decision maker is evoked in terms of preference/scaling factors. Through an interview process the utility values of an individual attribute for each alternative supplier are assessed.
- ii. Find an appropriate form to make combination of single attribute utility/value functions into an overall utility value.

The derived multi-attribute utility function is utilized to calculate the final utility score for each supplier. This utility score is used to rate the suppliers. A utility function is a mapping of a multi-dimensional attribute space into a single dimensioned preference space. A simple attribute space (cost and weight) was considered above. The critical elements of this attribute space are that its dimensions correspond to the performance attributes that underlie the decision being studied, and that the limits of this space are well defined at the outset of the analysis. Based upon repeated evaluations of carefully constructed decision problems, an analyst can define a mathematical mapping of this performance space into a single dimension of preference, which establishes an ordering to all points in the attribute space. The defining characteristics of any utility function are:

Given two alternatives, A and B, and a utility function U(x)

$U(A) > U(B)$ if A is preferred to B; and

$U(A) = U(B)$ if A and B are equally preferred

4.6. Compute the overall (surrogate) utility of group decision making

Multiple decision makers are usually preferred to a single decision maker, because there is less chance of mistake when there are more than one decision makers. To calculate the overall utility when more than one decision maker is involved with the supplier selection process, as is often the case, utility scores elicited from each decision maker should be considered. Surrogate utility function (SUF) for group decisions has the weighted additive form as follows [24]:

$$U(a) = \sum_{i=1}^M c_i u_i(a) \tag{1}$$

where i is the decision maker's index, M the number of decision makers, $u_i(a)$ the utility function of i th DM, and c_i the weight of i th DM.

To use this function, it is necessary to set values for c_i , the weights assigned to individual utility functions. Bodily noted that these weights may be assigned either by a super decision maker (benevolent dictator) or through mutual agreement of the committee members. He proposes a delegation process to find c_i by solving the system of equations below [24]:

$$c = cZ \quad \text{and} \quad \sum_{i=1}^M c_i = 1 \quad (2)$$

Where Z is a delegation matrix in which each committee member within a subcommittee designates voting weights to the other members. Individual i assigns weight z_{ip} to member P of his delegation subcommittee, when $0 \leq z_{ip} \leq 1, p = 1, 2, \dots, M; z_{ii} = 0; \sum_{p=1}^M z_{ip} = 1; \text{ for all } i; \text{ and } c = [c_1, c_2, \dots, c_M]$.

WHY GROUP DECISION-MAKING?

Integration of the team (Specialization vs. Integration) As we will examine when we study organizational structure, the needs to specialized and group individuals in department by functional expertise poses some coordination, or integration, problems. One method of providing integration is the establishment of project teams.

Better decisions- It can be argued that group produce potentially superior decisions by affecting one of the three elements of decisions:

1. **Criteria-** As group membership increases there is a likelihood that more stakeholders will be represented and their interests can be incorporated into the criteria used in the decision process.
2. **Cause/Effect-** By including individuals with specialized expertise, we tend to increase the likelihood that more accurate cause/effect assumptions (theory) will be used in the decision making process.
3. **Alternatives-** Groups tend to develop a greater number of potential options and more creative options.

Commitment to decision- This applies especially to individuals responsible for implementing the decision that requires a change of behavior. Individuals contributing to a decision tend to feel greater ownership to the decision, especially when their identities are tied to it. Resistance to change and motivation to ensure that the decision is implemented properly can be increased through participation.

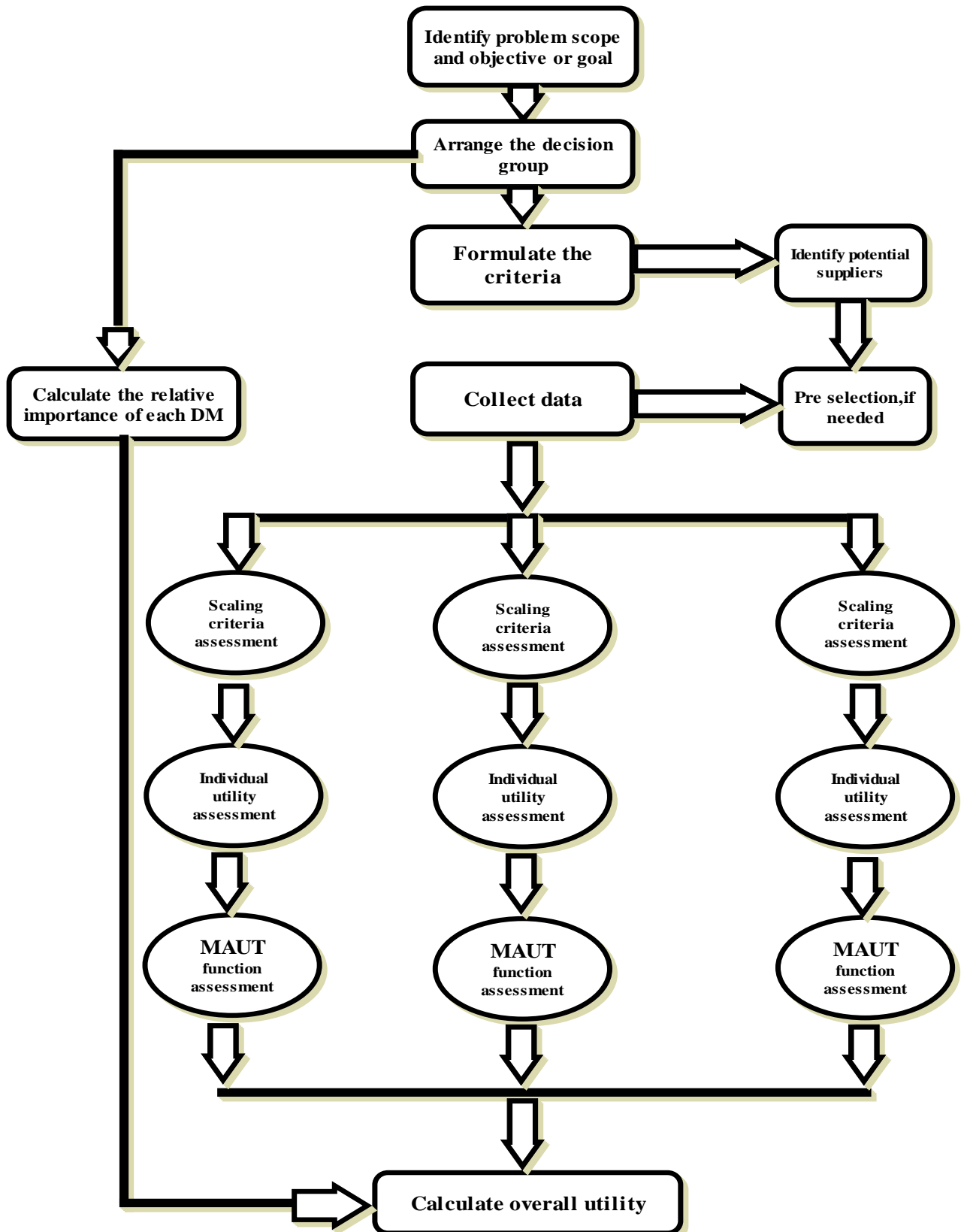


Fig. 1. An integrated method for supplier selection and order allocation.

4.7. Build a model to maximize TAU

A model is formulated to assign order quantities to the suppliers. We use the suppliers' ratings as coefficients of the objective function in order to assign optimal order quantities to the suppliers. As a result, the TAU becomes maximized while purchasing as much as we can from the most desirable suppliers. The objective function and constraints of this model are as follows:

4.7.1. Notations

U_i	Final utility (rate) of i th supplier
Y_i	Order quantity for i th supplier
W_i	Capacity of i th supplier
B_i	Total logistic cost of i th supplier
D	Demand for the period
f_i	Defect percent of i th supplier
H	Buyer's maximum acceptable defect rate
R	Total budget

4.7.2. Objective function

As U_i and Y_i , respectively, denote the ratings for and the number of purchased units from the i th supplier and maximizing the TAU as the objective function of desired purchasing as follows:

$$Max(TAU) = \sum_{i=1}^n U_i Y_i \quad (3)$$

4.7.3. Constraints

The important constraints of the problem are supplier capacity, buyer's demand and quality, which are formulated as follows:

4.7.4. Capacity constraint

As vendor i can provide up to W_i units of the product, the order quantity Y_i should be equal or less than the vendor

capacity as follows:

$$Y_i \leq W_i ; \quad i = 1, 2, \dots, n \quad (4)$$

On the other hand, the aggregate suppliers' capacity should be equal or greater than the demand. Therefore:

$$\sum_{i=1}^n W_i \geq D \quad (5)$$

4.7.5. Demand constraint

The sum of the assigned order quantities to n vendors should meet the buyer's demand as stated below:

$$\sum_{i=1}^n Y_i \geq D \quad (6)$$

4.7.6. Quality constraint

Since H is the buyer's maximum acceptable defect rate and f_i is the defect rate of the i th vendor, the quality constraint can be expressed as follows:

$$\sum_{i=1}^n Y_i f_i \leq HD \quad (7)$$

4.7.7. Cost constraints

Cost plays an essential factor in the supplier selection. Budget allocated for outsourcing or buying products is not unlimited.

Consider R as total allocated budget and B_i total logistic cost of i th supplier which involves products cost, ordering cost and shipping cost. Thus

$$\sum_{i=1}^n B_i Y_i \leq R \quad (8)$$

4.7.8. Final model

The final integrated model can be shown as

$$\text{Max}(TAU) = \sum_{i=1}^n U_i Y_i$$

Subject to :

$$\sum_{i=1}^n Y_i \geq D$$

$$\sum_{i=1}^n W_i \geq D$$

$$Y_i \leq W_i ; \quad i = 1, 2, \dots, n$$

$$\sum_{i=1}^n B_i Y_i \leq R$$

$$\sum_{i=1}^n Y_i f_i \leq HD$$

$$Y_i \leq 0 ; \quad i = 1, 2, \dots, n$$

(9)

5. Numerical example

To illustrate the model implementation, the supplier selection approach proposed in this paper is used for a typical supplier selection problem. XYZ Inc. is an automobile manufacturer, which purchases parts and materials having a large portion of the total cost. For the company to survive in the competitive environment the savings from supplies is particularly vital.

To apply the methodology, a committee of three decision-makers from different functional departments of the company is formed. As the first step the actors must be aligned with the overall organizational goals. Having discussed the overall organization goal, a reasonable set of the comprehensive objectives for supplier selection process is formulated. These objectives must be in line with the overall organization goal. The next step involves specifying attributes to measure the degree to which these several objectives are met. The supply chain operations reference (SCOR) model can be used to identify these attributes. The SCOR model is a descriptive model constructed by the supply chain council (SCC) and intended to be an industrial standard [29]. The criteria, attributes and their definitions are listed in Table 1.

The attributes are categorized into five groups and described as follows:

Reliability:

The criterion regarding to the ability of a supplier to perform its required functions under stated conditions for a

specified period of time, as the performance of the supplier in delivering the correct product with the correct quantity, to the correct place, at the correct time, and in the correct condition and packaging.

Responsiveness:

The criterion related to the quality of being responsive; reacting quickly; as a quality of people, and to the velocity at which a supplier provides products to the customer.

Flexibility:

The criterion regarding the agility of a supplier in responding to the demand changes, capable of being managed or controlled, and how he enjoy the flexibility of his working arrangement.

Cost:

The criterion regarding cost and financial aspects of procuring from suppliers.

Assets/Infrastructure

The criterion regarding the effectiveness of suppliers as how much efficient he is in managing assets to support the original equipment manufacturer (OEM) demand, and how long he could be safe for organization.

Having identified the attributes, the utility values should be assessed. The MAUT assessment is conducted through a series of interviews with three decision makers by an expert analyst. A simple additive form of a multi-attribute utility function is employed for the illustration purpose. We decided to choose Additive utility theory (AUT) because, AUT provides a more practical methodology due to easier computational analysis, and is easier to understand and explain to decision makers.

The additive multi-attribute utility function is represented as

$$U_i = \sum_{p=1}^S \left(M_p \left(U_i \left(Y_p \right) \right) \right) \quad (10)$$

Where i is the supplier index, P the attribute index, M_P the preference factor or weight of P th attribute, S the number of attributes, and U_i the overall supplier score. The evaluation of a preference/scaling factor is an iterative process [25]. A similar interview processes are used to understand the weight of each attribute for the decision maker. It is based on solving simultaneous equations derived from the fact that equally preferred options must have equal overall utility values. This is accomplished by asking the decision maker to compare a consequence of one attribute at the most preferred amount and all of the other attributes at the least preferred level to a lottery yielding having probability P and probability $1-P$, respectively. Probability P^* at which the decision maker is indifferent to this lottery is used for equating the overall utilities of two consequences to arrive at scaling factor for the attribute.

This procedure also needs a number of consistency checks and iterations for refining the results which may make it time consuming and complicated. With n attributes, $n-1$ scaling constants need to be determined using the simultaneous equations. The last factor can be calculated from the constraint, i.e. the sum of all scaling factors equals 1. This analysis can be simplified by using software tools like Logical Decision. These kinds of decision support tools can navigate the decision maker through various steps with interactive graphical interface to arrive at final values of scaling factors [12].

Table: 1 Attributes description

Category	Attribute	Description	Symbol
Reliability	Damage free Orders	Number of orders received damage free divided by total number of orders processed in the specific time period	Y1
	On time orders	Number of orders received on time divided by total number of orders in the specific time period	Y2
Responsiveness	Lead time	The average actual required time from the moment the supplier receives an order to the moment it ships	Y3
	Return product velocity	Average time required for process of returning the defective, incomplete or damaged orders and reshipping of the order to customer	Y4
Flexibility	Order increase/decrease flexibility	Average time required to achieve an unplanned sustainable 30% increase/decrease in orders	Y5
	Revise flexibility	Ability to change or revise in the production operations	Y6
Cost/Financial	Total cost	Including component cost, shipment cost, order cost etc.	Y7
	Payment terms	Suitability of terms and conditions regarding payment of invoices, open accounts, sight drafts, credit letter and payment schedule	Y8
Infrastructure	Quality system certification	Quality certifications acquired	Y9
	Company size and reputation	Including good reputation, facility size, turnover, capacity etc.	Y10

By calculating the preference/scaling factor for each alternative supplier, the utility values for each supplier are assessed. Various techniques can be applied in determining these utility values [25]. In this case, the method of direct assessment is used. The utility values for the two extreme alternatives are assigned first, typically allocating 0 for the least preferable alternative, and 1 for the most preferable alternative. As a result, for each alternative, a probability value P' is assessed when a decision maker is indifferent to lottery of choosing that particular alternative versus choosing most preferable alternative with probability P or least preferable alternative with probability $1 - P'$. This assessment is done through an interview process with the decision maker. Extracting exact preferences of the decision maker is very critical and needs expertise, aptitude and dedication on the part of analyst, as well as, decision maker. Due to space constraints only final results for the utility values of all suppliers derived from three decision makers with respect to ten attributes are shown in Table 3. When considering the inherent uncertainty for the supplier performance, the following methodology is proposed. For uncertain attributes, decision makers may face different utility values for various performance levels. The past data is used to indicate those levels

and the corresponding probability values as shown in the following formula:

$$U_i(Y_p) = \sum_{g=1}^G (P_{ipg} U_i(Y_{pg})) \tag{11}$$

Where i is the supplier index, p the attribute index, g the level index in attribute p, G the number of levels in attribute p, P_{ipn} probability of level index in attribute p.

For example the lead time performance metric (Y2) represents the average actual order lead time. For supplier S1 there is a 50% chance of being less than 7 days, a 30% chance of being between 7 days and 14 days, and a 20% chance of being more than 14 days. The DM1’s utility values for various levels explained above are assessed via interviews and depicted in Table 2[30].

Utility value for supplier S2 with respect to attribute Y2 would be:

$$(0.5 \times 0.8) + (0.3 \times 0.67) + (0.2 \times 0.3) = [12/41 \quad 15/41 \quad 14/41]$$

Table 2: DM1s utility values for each performance level of attribute Y2 with their related probability

Performance level	Probability	Utility
Less than 7 days	0.5	0.8
Between 7 days and 14 days	0.3	0.67
More than 14 days	0.2	0.3

Similar methodology is implemented for all the uncertain metrics (Table 3).

Table 4 shows the final utility values for each supplier. So far, the utility values for each supplier with respect to each attribute have been calculated. Consequently, the overall utility of the decision-making group must be computed to arrive at a single number representing the overall supplier score. This number will guide the decision by rating each supplier. Consider that Z is decision makers’ delegation matrix [30].

$$Z = \begin{pmatrix} 0 & 2/3 & 1/3 \\ 1/3 & 0 & 2/3 \\ 1/2 & 1/2 & 0 \end{pmatrix} \text{ So } a = [12/41 \quad 15/41 \quad 14/41]$$

Therefore, the final DMs importance weight will be:

Table 3: The utility values for the all suppliers derived from the three decision makers with respect to the ten attributes [30]

Attribute	DM1				DM2				DM3			
	Kj	U1(Xj)	U2(Xj)	U3(Xj)	Kj	U1(Xj)	U2(Xj)	U3(Xj)	Kj	U1(Xj)	U2(Xj)	U3(Xj)
X1	0.090	0.840	0.730	0.349	0.110	0.950	0.870	0.238	0.060	0.750	0.680	0.345
X2	0.090	0.660	0.726	0.540	0.074	0.720	0.630	0.490	0.090	0.600	0.530	0.390
X3	0.027	0.700	0.870	0.389	0.046	0.670	0.770	0.263	0.048	0.540	0.628	0.163
X4	0.107	0.250	0.612	0.420	0.106	0.150	0.523	0.320	0.072	0.300	0.580	0.480
X5	0.065	0.547	0.940	0.234	0.124	0.355	0.543	0.138	0.070	0.687	0.894	0.197
X6	0.098	0.456	0.796	0.547	0.067	0.398	0.659	0.412	0.070	0.287	0.894	0.327
X7	0.338	0.542	0.187	0.462	0.248	0.483	0.143	0.399	0.390	0.334	0.060	0.253
X8	0.085	0.274	0.367	0.203	0.106	0.189	0.434	0.115	0.130	0.256	0.382	0.195
X9	0.050	0.326	0.528	0.197	0.054	0.426	0.497	0.156	0.025	0.386	0.532	0.174
X10	0.050	0.246	0.454	0.336	0.066	0.265	0.365	0.398	0.046	0.189	0.587	0.341

$$\begin{pmatrix} 12/41 & 15/41 & 14/41 \end{pmatrix} \begin{pmatrix} .496 & .503 & .404 \\ .455 & .477 & .299 \\ .396 & .398 & .279 \end{pmatrix} \\
 = (0.447 \quad 0.457 \quad 0.323)$$

Table 4: Final utility values for all of the suppliers derived from the three decision makers

	S1	S2	S3
DM1	0.496	0.503	0.404
DM2	0.455	0.477	0.299
DM3	0.396	0.398	0.279

6. Discussion

In this section, after solving the model the impact of changes in special supplier (S1)’s cost on quantity of purchasing is analyzed, where other variables are assumed constant. In order to calculate the impact, S1’s cost is changed to an acceptable range (\$10–\$100) and then the quantity of purchase is monitored to see how it is changing. Changes in attributes for each supplier will cause change in the utility score of that supplier. This change will follow the utility functions that have been elicited in previous section.

As S1’s cost reaches to its minimum level (\$10), it became more desirable for DMs. So its utility is maximized (for cost attribute) and model proposes to purchase as much as possible from supplier 1 though to S1’s capacity constraint, which is 650. Remaining demand must be purchased from S2 because our demand is satisfied and there is no need to purchase from S3.

But by increasing the cost, the order quantity from S3 will also increase, whereas order quantity from S1 is decreased, and the order quantity from S2 remains constant. When the cost reaches 85.7, the U1 becomes less than all so the model proposes no purchase from S1 and all our needs must be procured from S2 and S3.

7. Conclusion

Supply chain management has recently received considerable attention in business management literature. Because, supply chain management is the management of the flow of goods. It includes the movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption. Interconnected or interlinked networks, channels and node businesses are involved in the provision of products and services required by end customers in a supply chain. Supply chain management has been defined as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally." Organizations increasingly find that they must rely on effective supply chains, or networks, to compete in the global market and networked economy. Many companies consider a well-designed and implemented supply chain system as an important tool. Supplier selection is a fundamental aspect of supply chain management, which heavily contributes to the overall supply chain performance.

Supplier selection is a problem with a more complex nature. The problem is a complex multi-criteria decision problem that includes both qualitative and quantitative factors, which are often assessed with imprecise data and human judgments. It appears that MAUT is well suited to deal with such decision problems. This paper presents an effective model using MAUT for solving this problem. MAUT determines the supplier’s utility from the decision makers’ viewpoints. The model is then used to determine the order quantities to be purchased from each supplier to maximize the quantity of purchase from the most desired suppliers. The MAUT model is rather simple to use and meaningful. The systematic framework for supplier evaluation and selection presented in this paper can easily be extended to analyze other managerial decision-making problems.

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