Green Supplier Selection and Order Allocation Using an Integrated Fuzzy TOPSIS, AHP and IP Approach

Sadeque Hamdan
Industrial Engineering and Engineering Management
University of Sharjah
Sharjah, UAE
shamdan@sharjah.ac.ae

Ali Cheaitou
Industrial Engineering and Engineering Management
University of Sharjah
Sharjah, UAE
acheaitou@sharjah.ac.ae

***Abstract*—this paper proposes a model to solve an integrated green supplier selection and order allocation multi-period problem. The model consists of three stages; first stage uses fuzzy TOPSIS to rank and assign preference weights to a set of traditional and green criteria. Moreover, in the second stage, the criteria are grouped into two subsets, traditional and green, and then AHP is used to assign importance weights to each subset. The outputs of the first and second stage are used as an input for a bi-objective optimization model. The model assumes a deterministic demand. It also allows for shortage while ensuring that total demand will be satisfied at the end of the planning horizon even if with some delay. Comprehensive Criterion Method (CCM) is adopted to solve the bi-objective optimization and LINGO software is used to find the optimal solution.**

Keywords—supplier selection; planning; order allocation; green; multi-criteria decision making; optimization.

I. INTRODUCTION

Supply chain management aims to maximize firm's profitability and customer satisfaction through an integrated planning and control decisions [1]. Globalization increased the challenges to remain competitive in the market by focusing on reducing operational cost and enlarging overall profit [2]. Due to the increased awareness to the environmental issues, both public and private sectors face an increasing pressure to consider environmental aspects. This consideration is recognized as green supply chain management [3] , [4] , [5].

Green supply chain management (GSCM) is management of the flow of funds, information and products between and among all stages of the supply chain to find the right balance between environment and economic aspects [3], [6] . Purchasing is recognized as an essential strategic function in Supply Chain Management in order to be effective and competitive. Purchasing has six major decision processes which are make or buy, supplier selection, contract negotiation, design collaboration, procurement, sourcing analysis [1], [7], [8]. Among these six processes, Supplier selection has received considerable attention since 1960sto achieve good purchasing strategy since the right selection reduces cost and improves quality of final products [9] , [10] , [2] , [1].

Supplier selection is the most critical issue facing firms where raw materials and components represent significant percentage of total product cost [7]. Supplier selection importance has been increased also due to outsourcing initiatives where firms rely more on suppliers to lower raw material cost and improve quality [11], thus it's considered a strategic decision [12].

Supplier selection problem can be either a single sourcing problem where one supplier is selected to satisfy the firm's entire demand or multiple sourcing problem in this case more than one supplier is selected, each provides certain amount of quantities based on a set of constraints [12]. Relying on only one supplier increases disruption risk in the supply chain while depending on multiple sources incurs an increase in the fixed cost in terms of administrative cost and negotiation cost for each placed order [13]; however, multiple sourcing is preferred over single sourcing as it allows for order flexibility [12].

Supplier selection is a complex multi-criteria decision making process that considers both qualitative and quantitative factors [10], [14], [2], [12] to choose reliable suppliers. This complexity comes from the unpredictable and uncontrollable factors which may be uncertain conflict each other [14], [15]. Traditionally, supplier selection and order allocation problems focused mainly on product cost, delivery time and quality without considering environmental effects and issues [3], [4].

Recently, due to governmental regulation, increased awareness to protect environment and the growing environmental concerns, the trend is to select green vendors since company's environmental performance is measured by both its inner environmental practices and its suppliers' environmental image [12], [6].

Green supplier selection is evaluating suppliers that will be selected based on set of criteria that includes environmental aspects such as reducing wastes, using recyclable material, green knowledge transfer, eco-design and so on. Such green criteria used in supplier selection models are mainly based on company requirements and industrial best practices [16]. While evaluating and selecting green suppliers, each green criterion will be given an importance weight and then each alternative will be evaluated and ranked with respect to these criteria [17].

The rest of this paper is organized as follows: problem is described in section 2. Section 3 is literature review; section 4 describes the proposed model and then numerical examples in section 5 and finally a conclusion

II. Problem Statement

The purpose of this research is to develop a mathematical bi-objective optimization model to solve an integrated green supplier selection and planning problem. This proposed model will deal with deterministic demand, multiple-sourcing problem and will consider both traditional and green criteria separately to select best suppliers and order quantities during each period.

First of all, we use Fuzzy TOPSIS to rank alternatives based on general criteria and green criteria separately so that the alternative which is very good in traditional criteria and very poor in terms of green criteria will not rank among the best alternatives if more weight is given to green criteria. We use then AHP to assign weights for the two categories of criteria (general and green). Finally, weights obtained from Fuzzy TOPSIS and AHP are used as an input for the bi-objective optimization model which will be solved using LINGO software

III. Literature Review

We classified the literature related to our work into four categories. The first category includes works about supplier selection and order allocation. The second category studies the papers with a focus on green criteria. The third category explores the literature of green supplier selection and green supplier selection with order allocation. Finally, the last category summarizes the works about supplier selection and planning problems.

A. Supplier Selection and order allocation

Supplier selection activity is recognized as the most important and prominent part of purchasing function as it contributes in enhancing the competitive strategy and global market share by reducing operational cost such as maintenance cost, offering high quality end product, enlarging total supply chain profit and improving total supply chain performance[13], [14], [18], [19].

In today's global competition, customer expectation has increased; this expectation can't only be described by lower product cost but it also includes quality, lead time, warranties and many other criteria which make supplier selection a multi-criteria problem. For supplier selection problems, Dickson [20] proposed 23 different criteria which are used as reference in majority of supplier selection papers [14].

To balance the tradeoff between these conflicting criteria, researchers have developed many models ranging from single approaches to hybrid approaches. In a single approach, some researchers have focused on solving supplier selection and optimum quantities subjected to stochastic demand to account for uncertainty in forecast process. For example, Zhang & Zhang [13] developed mixed integer programming model to minimize product cost and fixed cost for a stochastic demand while assuming all suppliers meet qualitative criteria level.

While in the hybrid models, Amin et al, [21] were the first to consider strategic perspectives by developing a two stages integrated quantified SWOT analysis technique with fuzzy linear programming to deal with supplier selection problem. In the first stage SWOT analysis and Triangular fuzzy number are adopted for supplier selection while in the next stage, fuzzy linear programming constrained by capacity is applied to define quantities assuming demand as fuzzy number. Some researchers tried to use historical data in supplier selection, as Faez et al, [9] who developed an integrated Case Based Reasoning (CBR) with Mixed Integer programming (MIP). In this model, CBR is used to develop purchasing situations from historical data. To account for parameters vagueness, fuzzy logic is used. Purchasing situations are then considered as an input to mixed integer programming model to select supplier and quantities to be ordered.

Xia & Wu [22] proposed an integrated approach of AHP improved by rough set theory and Multi-Objectives Mixed Integer Linear Programming (MOMILP) for multi-product supplier selection and order allocation problem where suppliers offer price discounts on total business volumes. The mathematical model is constrained by limited supplier capacity and solved using MATLAB software.

While Demirtas & Demirtas [23] developed a two-stage solving supplier selection and order allocation model based on Analytical Network Process (ANP) and Multi-objective Mixed Integer Programming (MOMIP) approach. In the first stage ANP is used to generate weight for the criteria and then in the second stage a multi-objective function that maximizes purchasing value and minimizes budget and defect rates is adopted and solved by ϵ-constraint method and reservation level by Tchebycheff procedure.

Wu et al [18] extended previous work of [23] to a combination of Delphi method, Analytical Network Process (ANP) and Multi-objective Mixed Integer Programming (MOMIP) model. Supplier selection criteria are generated by experts using Delphi method which is considered an input for ANP and finally, MOMIP model to select best suppliers and the associated quantities. Kilic [15] applied fuzzy TOPSIS with mix integer linear programming to select best supplier for multi-item in a multi-supplier problem. The proposed mathematical model maximizes weight obtained from fuzzy TOPSIS.

As the models previously developed in literature didn't consider probabilistic nature of supplier selection problem, Sanayei et al [14] proposed linear programming model (LP) to maximize total additive utility based on Multi-\Attribute Utility theory (MAUT). This model accounts for risk and uncertainty within criteria and is subjected to capacity constraint, demand constraint and budget constraint.

B. Green Criteria

In today's open market, suppliers who provide environmental friendly products and services have gained more recognition and more respect for their efforts on becoming green and saving the environment. Also, researches on green supplier selection have recently been increased due to the global competition [5]

Literature reviews on green supplier selection are limited and thus this field is considered immature [11],[5]. Green aspect differs from the sustainability concept. While sustainability contains economic, social and environmental

criteria, green aspect is limited to environmental criteria. As a result, green concept is recognized as a part of sustainability concept [5].

Govindan et al [11] & Igarashi et al [5] reviewed green supplier selection articles. Igarashi et al [5] stated that both environmental qualitative and quantitative criteria have been used in supplier selection models without a clear identification of the criteria characteristics or even criterion definition. Green criteria can be structured into two groups: product oriented and organization oriented criteria. They also noticed that some of the reviewed articles used either product related criteria or organization related criteria.

Govindan et al [11] found that the mostly used approach in green supplier selection is fuzzy based single approach where the most common green criteria is environmental management system followed by green image, environmental performance and environmental competences.

C. Green Supplier Selection and green supplier selection with order allocation

To solve green supplier selection problem, researchers have applied different methods. Amindoust et al [17] applied fuzzy logic and new ranking model based on fuzzy inference system (FIS). Kannan et al [16] proposed fuzzy axiomatic design (FAD), Hsu et al [24] used DEMATEL to identify the key green criterion in supplier selection problems. Kannan et al [25] proposed framework for selecting green suppliers using fuzzy TOPSIS. Büyüközkan & Çifçi [6] developed hybrid model that uses fuzzy DEMATEL to extract the mutual relationships of interdependencies with criteria and strength of interdependence, fuzzy ANP to handle the relationships of the factors and lastly and finally fuzzy TOPSIS to select the best alternative.

However, the previously described methods rank the supplier without considering capacity limitation and without also specifying the order quantities from each supplier. Yeh and Chuang [3] aimed to minimize total product cost and total time while maximizing quality and green score in multiple supply chain stages for a multi-product green supplier selection problem by applying multi-objective genetic algorithm. Two algorithms were used to find Pareto-optimal solution set. The proposed model is constrained by production capacity limitation, demand satisfaction for both warehouses and end-customers and some other constraints for criterion score value.

Shaw et al [4] proposed fuzzy AHP and fuzzy multi-objective linear programing model to solve green supplier selection problem and deal with its vagueness due to the subjectivity in human decisions. They considered criteria such as cost, quality, rejection percentage, late delivery percentages and greenhouse gas emissions. The model aims to satisfy demand while not exceeding production capacity, limit the carbon footprint to certain level and ensure that total budget is not exceeded.

Kannan et al [12] proposed a hybrid model of fuzzy AHP, Fuzzy TOPSIS and multi objective linear programming (MOLP) approach to solve multi-sourcing green supplier selection problems. The proposed technique uses fuzzy AHP to calculate and assign weights for the criteria, then fuzzy TOPSIS to rank the alternatives according to the distance from ideal solution. Finally, fuzzy MOLP model is adopted to determine the order quantity of each supplier by optimizing total scores and total cost, based on set of constraints such as quality, demand and capacity. The proposed MOLP model is converted to a single objective function by applying max-min formulation.

Liao & Kao [26] developed a two-stage model for supplier selection and order allocation in watch manufacturing. The first stage uses Fuzzy TOPSIS to rank the criteria and the alternatives and then multi-choice goal programming (MC-GP) to optimize the problem. In 2014 Rouyendegh (Babek Erdebilli) & Saputro [27] applied Fuzzy TOPSIS and MC-GP in Fertilizer and Chemicals Company. Zouggari & Benyoucef [28] proposed four-stage simulation-based knowledge approach, while in the first stage, pairwise comparison and aggregation of decision matrix are done, in the second stage a list of the best suppliers is developed via Fuzzy AHP method. Knowledge based simulator platform is used in the third stage with an initial data of market demand and inventory control policies. The knowledge based simulator provides new values of criteria. The output from stage two and three is used as input to the final stage to obtain order allocation data using Fuzzy TOPSIS.

D. Supplier Selection and Planning

Most papers in the literature focused on single period supplier selection and order allocation problem. Since the selected suppliers for one period problem might not be the best choice in the other periods, it's important to consider multi-period problem where the most suitable suppliers are selected for each period to satisfy the constraints [8].

Rezaei & Davoodi [29] proposed multi-item, multi period mathematical model to solve supplier selection problem assuming that the received item is not necessary of a perfect quality; imperfect quality item is sold as single batch at discounted price. The proposed model maximizes total profit. The model is subjected to the following constraints; deterministic demand in which backordering and shortage are avoided, maximum storage capacity and maximum production capacity. To solve the proposed mathematical model, genetic algorithm is adopted

Razmi & Maghool [19] developed fuzzy bi-objective mixed integer multi-item, multi-period supplier selection and order sizing model under dynamic demand, capacity and budget limitation. The proposed model considers different payment methods and price discount policies such as all unit discount, incremental discount and total business volume discount. The first objective function is to minimize total purchasing cost while the second is to maximize total value of purchasing taking into account the impact of qualitative performance criteria in purchasing decision. They adopted augmented ε-constraint and reservation level by Tchebycheff to solve the bi-objective model then the efficiency of each method is obtained using additive utility function offered by decision maker.

Li et al [30] proposed two stages mathematical model to deal with material supplier selection and order allocation problem over a planning horizon in short product life cycle

environment. They applied fuzzy extended analytical hierarchy process (FEAHP) to generate risk weights for different suppliers among five criteria which are cost, quality, risk, profile and service performance. Then, in the second stage, bi-objective mathematical model is developed to minimize risk and cost. This bi-objective model is solved using dynamic programming algorithm to get supplier ranks and order allocation. The model assumes that each supplier can provide all materials with different capacities and no inventory.

Ware et al. [8] developed mix integer non-linear program (MINLP) that minimizes total cost of purchasing in order to solve dynamic supplier selection problem. The developed model considers multi-product, multi-period situation in which purchasing cost, total transportation cost, penalty cost for not meeting quality requirements and delay cost are considered in the objective function. The model is constrained by capacity limitation, demand and minimum quality level and can be solved using LINGO software.

All previously stated models consider supplier selection problem without any consideration of environmental criteria, however, the only paper discussing green supplier selection and planning was proposed by Mafakheri et al [1]. They introduced two-stage dynamic programming model for single product multi-period green vendor selection and order allocation problem. Using analytical hierarchy process (AHP) in the first stage, potential suppliers are ranked based on four main criteria (price performance, delivery performance, environmental performance and quality). The problem objectives are to maximize utility function and minimize total purchasing cost (purchasing cost and Inventory holding cost) which later combined into one objective function and solved using dynamic programming algorithm. The model is constrained by capacity limitation, deterministic demand and inventory allowance.

All the articles concerned about green supplier selection included green criteria and traditional criteria in the same category; however, this paper separates green criteria from traditional criteria and gives the decision maker the possibility to assign different importance weight to each category using AHP so that green criteria may be given higher importance if necessary.

The only article in the literature on green supplier selection and order allocation with multi-period planning horizon [1] used AHP to rank the criteria. This approach makes the model inconsistent when the number of criteria or alternatives changes. Our paper applies Fuzzy TOPSIS to overcome this issue and to account for uncertainty. In addition, the planning part in our model, accounts for fixed costs and allows the decision maker to use shortage, which is not the case in [1].

IV. MODEL

The proposed model consists of three stages. In the first stage, Fuzzy TOPSIS is used twice to calculate closeness coefficient for each alternative based on four green criteria and five traditional criteria separately. K decision makers will give their evaluation for the criteria and alternatives. Then, in the second stage AHP is applied to assign weights for each of the two categories of criteria. A higher rank decision maker is responsible for this strategic decision. In the last stage, bi-objective integer programming model to maximize scores obtained from Fuzzy TOPSIS and to minimize total purchasing cost is developed to calculate optimum order quantities.

A. *Fuzzy TOPSIS*

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was introduced in 1981 by Hwang and Yoon. TOPSIS is a multi-criteria decision making (MCDM) technique that ranks alternatives based on the shortest distance from positive ideal solution and longest distance from negative ideal solution. As decision makers prefer using linguistic scale rather than numbers and to account for vagueness and uncertainty in judgment procedure, Chen (2000) proposed Fuzzy TOPSIS. In supplier selection problems, Fuzzy TOPSIS is preferred over Fuzzy AHP as shown in the comparison done by Lima Junior et al [31]. They proved that Fuzzy TOPSIS generates consistent results when the number of alternatives or criteria changes while reversal ranking occurs in Fuzzy AHP. Fuzzy TOPSIS also perform better than Fuzzy AHP in most cases and requires less data as stated.

1) *Triangular Fuzzy Number*

Fuzzy theory was introduced by Zadeh (1965) as an extension of the classical notion of set [27]. Fuzzy numbers are powerful in describing a subjective measurement as a range rather than in an exact value [32]**.** In supplier selection problem with fuzzy environment, the mostly used fuzzy number is triangular fuzzy number format (TFN). TFNs can be defined as (l, m, u) and the membership function is defined as follows:

$$\mu_A(x) = \begin{cases} 0 \quad , & x < l \\ \dfrac{x-l}{m-l} \ , & l \le x \le m \\ \dfrac{u-x}{u-m} \ , & m \le x \le u \end{cases}$$

Several types of linguistic scales for TFN were proposed and suggested with different points. For instance, many researchers proposed different 5-point linguistic scale as Chang and Chen (1994) , Liou and Wang (1994), Chien and Tsai (2000), Lee et al. (2002), Lau et al. (2003) & Yang and Hung (2007) . Other researcher proposed 6- point linguistic scale such as Chan et al. (2000), Ertay et al. (2005). 7-point linguistic scale was proposed by Chen (2001), Herrera et al. (2005), Chen et al. (2006), Kuo et al. (2006)}[32]**.**

In this paper we will use 5-point linguistic scale proposed by Lau et al (2010). Table 1 and Table 2 include the definition of our rating scale.

TABLE 1: CRITERION RATING SCALE

Linguistic Variable	TFN
Littlie Importance (LI)	(0, 0, 0.25)
Moderately Important (MI)	(0, 0.25, 0.50)
Important (I)	(0.25, 0.50, 0.75)
Very Important (VI)	(0.50, 0.75, 1.00)
Absolutely Important (AI)	(0.75, 1.0, 1.0)

TABLE 2: ALTERNATIVE RATING SCALE

Linguistic Variable	TFN
Very Low (VL)	(0, 0, 0.25)
Low (L)	(0, 0.25, 0.50)
Good (G)	(0.25, 0.50, 0.75)
High (H)	(0.50, 0.75, 1.00)
Very High (VH)	(0.75, 1.0, 1.0)

2) Fuzzy TOPSIS procedure:

- Step 1:

Using linguistic variables, decision makers $r_j, r = 1, \dots, k$, give a weight w_i to each criterion $i, i = 1, .., n$ and a weight x_{ij} to each alternative $j, j = 1, .., m$ with respect to each criterion $i, i = 1, .., n$. These weights will be aggregated according to the following equations:

$$\bar{w}_i = \frac{1}{k}\left(w_i^1 + w_i^2 + \cdots + w_i^k\right) \quad (1)$$

$$\bar{x}_{ij} = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k\right) \quad (2)$$

Where w_i^r is criterion i weight given by decision maker r and $x_{ij}^r = (l_{ij}, m_{ij}, u_{ij})$ is alternative j weight with respect to criterion i given by decision maker r.

- Step 2:

In this step, a fuzzy decision matrix of alternatives and criteria is developed. This matrix contains the aggregated evaluation of each alternative with respect to each criterion and another matrix with weights of each criterion. The different units of measurement are then eliminated using normalization approach as follows:

$$r_{ij} = \left(\frac{\bar{l}_{ij}}{u_j}, \frac{\bar{m}_{ij}}{u_j}, \frac{\bar{u}_{ij}}{u_j}\right) \text{ for every benefit criterion i.} \quad (3)$$

$$r_{ij} = \left(\frac{l_j}{\bar{l}_{ij}}, \frac{l_j}{\bar{m}_{ij}}, \frac{l_j}{\bar{u}_{ij}}\right) \text{ for every cost criterion i,} \quad (4)$$

where r_{ij} is the normalized value of $\bar{x}_{ij}$ and $u_j = \max_i u_{ij}$ and $l_j = \min_i l_{ij}$.

- Step 3:

After normalizing fuzzy decision matrix, alternative weight must be multiplied by criterion weight to obtain weighted normalized fuzzy decision matrix as in the equation below:

$$V = [v_{ij}]_{m\,x\,n}, \text{ where } v_{ij} = r_{ij} \otimes w_i \quad (5)$$

- Step 4:

Identify fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS). FPIS is defined to be (1,1,1) while FNIS is defined as (0,0,0) to calculate distance from positive ideal and negative ideal solutions for each alternative as follows:

$$d_j^+ = \sum_i^n d(v_{ij}, FPIS) \quad (6)$$

$$d_j^- = \sum_i^n d(v_{ij}, FNIS) \quad (7)$$

Where d_j^+ and d_j^- are distances calculated using:

$$d(A,B) = \sqrt{\frac{1}{3}(l_A - l_B)^2 + (m_A - m_B)^2 + (u_A - u_B)^2} \quad (8)$$

- Step 4:

Rank the alternatives according to closeness coefficient $CC_j\ j = 1, \dots, m$ that is calculated as follows:

$$CC_j = \frac{d_j^-}{d_j^- + d_j^+} \quad (9)$$

B. AHP

In our model, AHP will be used to assign weights to the two subsets of criteria: traditional and green.

Analytical hierarchy process (AHP) is a decision making tool developed in 1970s by Saaty [33]. AHP decomposes the problem into hierarchy order starting from a goal, then main criteria, sub-criteria and finally alternative. We explain here the basic idea of AHP.

1) AHP procedure for calculating weights of categories:

- Step 1:

Construct pair-wise comparison matrix for criteria. Assign weights using the following scale:

TABLE 3: PAIR-WISE COMPARISON SCALE

1	**Equally preferred**
3	**Moderately preferred**
5	**Strongly preferred**
7	**Very strongly preferred**
9	**Extremely preferred**

- Step 2:

Normalize values obtained from the pair wise comparison using the following equation:

$$\bar{r_{ij}} = \frac{r_{ij}}{sum(rj)} \quad (10)$$

Where r_{ij} is the weight in ith row and jth column

- Step 3:

Calculate weight for each criterion

$$w_i = \frac{r_{i1} + r_{i2} + \cdots + r_{im}}{m} \quad (11)$$

Where m is number of columns in the matrix.

C. Bi-Objective Integer Programming Model

The bi-objective optimization model consists of two objective functions. The first objective aims to minimize the total purchasing cost in terms of fixed cost, variable cost, holding cost and shortage cost. The second objective function aims to maximize total green criteria weights and total traditional criteria weights.

1) Notations:

Parameters:

- T : Number of periods in the planning horizon.

- n: Total number of suppliers.
- W_1^{AHP}: Green criteria category weight obtained from AHP
- W_2^{AHP}: Traditional criteria category weight obtained from AHP
- GW_i: Green Criteria Closeness Coefficient obtain from Fuzzy TOPSIS for supplier i, i = 1,..,n.
- TW_i: Traditional criteria closeness coefficient obtained from Fuzzy TOPSIS for supplier i, i = 1...n.
- vc_{it}: Variable cost per unit product for supplier i in period t.
- FC_{it}: Fixed cost for supplier i in period t.
- H_t: Inventory holding cost per unit product in period t.
- S_t: Shortage cost per unit product in period t.
- C_{it}^{max}: Maximum capacity of supplier i in period t.
- D_t Demand in period t.

Decision variables:

- Q_{it}: Quantities to be ordered from supplier i in period t.
- Y_{it}: Binary variable indicates if supplier i in period t is selected $Y_{it} = 1$ or not $Y_{it} = 0$.
- I_t : Available inventory level at the end of period t.

2) Mathmathical model:

$$\max W = \sum_{t=1}^{T}\sum_{i=1}^{n}(W_1^{AHP} * GW_i * Q_{it} + W_2^{AHP} * TW_i * Q_{it}) \quad (12)$$

$$\min Z = \sum_{t=1}^{T}\sum_{i=1}^{n} vc_{it} * Q_{it} + FC_i * Y_{it} + H_t * \max(I_t, 0) + S_t * \max(-I_t, 0) \quad (13)$$

Subject to:

$$Q_{it} \le Y_{it}C_{it}^{max} \qquad \forall i = 1, \dots, n \ , \forall t = 1 , \dots , T \quad (14)$$

$$I_{t-1} + \sum_{i=1}^{n} Q_{it} - I_t = D_t \qquad \forall t = 1 , \dots , T \quad (15)$$

$$\sum_{i=1}^{n}\sum_{t=1}^{T} Q_{it} + I_0 = \sum_{t=1}^{T} D_t \quad (16)$$

$$Q_{it} \ge 0 \qquad \forall i = 1, \dots, n \ , \forall t = 1 , \dots , T \quad (17)$$

$$Q_{it} , I_t \ integer \quad \forall i = 1, \dots, n \ , \forall t = 1 , \dots , T \quad (18)$$

$$Y_{it} \in \{ 0 , 1 \} \qquad \forall i = 1, \dots, n \ , \forall t = 1 , \dots , T \quad (19)$$

Equation (12) maximizes the total preference of all suppliers over the planning horizon. First part of equation (12) is for the green criteria weights while the second is for general criteria such as cost, delivery time and quality. Equation (13) minimizes total purchasing cost that includes variable cost, fixed cost, inventory holding cost and penalty shortage cost. Equation (14) ensures that supplier capacity is not exceeded. Constraint (15) ensures that the demand is satisfied either from the quantity that is ordered or from the available inventory or considered as shortage. Equation (16) ensures that total demand for the entire planning horizon is satisfied even with some delay. Equation (17) ensures that the ordered quantities are positive. Equation (18) is for integrity and Equation (19) ensures that Y is either 0 or 1.

3) Solution Approach:

The bi-objective optimization model defined in equations (12) to (19) will be divided into two single objective sub problems where the first sub-problem is defined using equation (12) as objective function subject to the constraints defined in equations (14) to (19). The second sub-problem has equation (13) as its objective function subject to the same constraints. These two sub-problems are solved separately in order to obtain their optimal solutions f_{max} and f_{min} respectively. Comprehensive Criterion Method (CMM) [34] is then adopted to merge both objective functions in a single objective function. The reason for choosing this method over other methods such as utility function, inverted utility function and goal programming is to eliminate the need for decision maker opinion which reduces subjectivity and uncertainty. The normalization approach is as follows:

$$f(x)_T = \frac{f(x) - f_{min}}{f_{min}} \quad (20)$$

$$f(x)_T = \frac{f_{max} - f(x)}{f_{max}} \quad (21)$$

Equation (20) is used for the objective function $f(x)$ when it is a minimization function, while equation (21) is used if the objective function $f(x)$ is a maximization function. The combined objective function is described as follows:

$$\min f = f(x)_{T1} + f(x)_{T2} + \cdots$$

where $f(x)_{Ti}$ is the normalization of the ith objective function in the multi-objective function optimization problem that can be obtained from equations (20) and (21).

This combined objective function is then minimized subject to the same constraints defined in equations (14) to (19). The obtained solution is the optimal solution for the multi-objective problem. It is then used to evaluate each of the two objective functions separately.

V. Numerical Example

In this section, we will show through an example how our model can be implemented.

A. Criteria and alternative ranking:

Four green criteria which are environmental management systems (G1), green image (G2), eco-design (G3) and staff training on environmental targets (G4), and five traditional criteria that include quality (C1), product cost (C2), delivery time (C3), stability of finance (C4), and past performance (C5) are selected for this example. Criteria in each category are

evaluated by three decision makers DM1, DM2, DM3 as shown in Table (4) and Table (6). Then each decision maker assigned rank for each alternative with respect to each criterion as shown in Table (5) and Table (7). Closeness coefficients are obtained after applying Fuzzy TOPSIS and results are shown in Table (8).

TABLE 4: TRADITIONAL CRITERIA EVALUATION

Traditional criteria evaluation					
	C1	**C2**	**C3**	**C4**	**C5**
DM1	VI	VI	MI	I	I
DM2	I	VI	VI	I	MI
DM3	MI	I	I	VI	VI

TABLE 5: ALTERNATIVES EVALUATION ACCORDING TO TRADITIONAL CRITERIA

Alternatives evaluation according to traditional criteria						
		C1	**C2**	**C3**	**C4**	**C5**
DM 1	**S 1**	VH	VH	G	H	H
	S 2	H	VH	H	VH	VH
	S 3	G	G	L	L	G
DM 2	**S 1**	H	VH	H	H	H
	S 2	H	H	G	VH	VH
	S 3	L	G	L	G	L
DM 3	**S 1**	VH	VH	H	VH	H
	S 2	G	H	H	VH	H
	S 3	L	G	G	L	G

TABLE 6: GREEN CRITERIA EVALUATION

Green criteria evaluation				
	G1	**G2**	**G3**	**G4**
DM1	AI	I	VI	I
DM2	VI	I	I	LI
DM3	AI	MI	VI	VI

TABLE 7: ALTERNATIVE EVALUATION ACCORDING TO GREEN CRITERIA

Alternative evaluation according to green criteria					
		G1	**G2**	**G3**	**G4**
DM 1	**S 1**	VH	VH	H	H
	S 2	VH	VH	H	H
	S 3	G	L	G	VL
DM 2	**S 1**	VH	VH	VH	H
	S 2	VH	H	G	G
	S 3	G	VL	G	VL
DM 3	**S 1**	VH	VH	H	H
	S 2	VH	G	VH	G
	S 3	L	VL	G	L

TABLE 8: CLOSENESS COEFFICIENT

	Green Criteria	**Traditional Criteria**
S 1	0.5281	0.4114
S 2	0.4878	0.4205
S 3	0.2672	0.3156

B. *Categories weight:*

Since the relative weight of the two criteria categories (green and traditional) is a high level decision, a strategic decision maker is asked to assign weight for each category using AHP approach. Table (9) shows pairwise comparison done by higher rank decision maker and Table (10) shows priority values used in mathematical model.

TABLE 9: PAIR-WISE COMPARISON BY HIGHER RANK DM

Pair-wise Comparison by Higher rank DM		
	Green Criteria	**Traditional Criteria**
Green Criteria	**1.00**	3.00
Traditional Criteria	0.33	**1.00**
Sum	1.33	4.00

TABLE 10: NORMALIZATION AND PRIORITY VALUES

Normalization and priority values			
	Green Criteria	**Traditional Criteria**	**Priority Values**
Green Criteria	0.75	0.75	**0.75**
Traditional Criteria	0.25	0.25	**0.25**

C. *Supplier Selection and order allocation*

For the mathematical model, the following data were assumed:

1- Demand for all period is equal to1000 units/period.
2- Capacity from all suppliers in each period is equal to 1000 units.
3- Fixed cost for every supplier is the same in each period and is as follows: for supplier 1: 1700, for supplier 2: 1750 and for supplier 3: 1200.
4- Variable unit cost is the same in each period as follows: for supplier 1: 45 /unit, for supplier 2: 50 /unit and for supplier 3: 20 /unit.

5- Inventory holding cost is 5 /unit/period for all the periods in the planning horizon while penalty shortage cost is 100 /unit/period.

Solving the first sub-problem, constituted of equations (12) and (14)-(19), results in $f_{max} = 2993.6$, where all the quantities should be ordered from supplier 1 as shown in Table (11). Substituting the optimal solution of the first sub-problem in equation (13), results in an objective function value of 280200.

Solving the second sub-problem, constituted of equations (13)-(19), results in an optimal objective function value of $f_{min} = 127200$, where all the quantities should be ordered from supplier 3 as shown in Table (12). Substituting the optimal solution of the second sub-problem in equation (12), provides an objective function value of 1675.8.

TABLE 11: MAXIMIZING PREFERENCE OBJECTIVE FUNCTION ONLY

Maximizing preference objective function only						
Period	**1**	**2**	**3**	**4**	**5**	**6**
Quantities						
S 1	1000	1000	1000	1000	1000	1000
S 2	0	0	0	0	0	0
S 3	0	0	0	0	0	0
Inventory	0	0	0	0	0	0

TABLE 12: MINIMIZING COST OBJECTIVE FUNCTION ONLY

Minimizing Cost only						
Period	**1**	**2**	**3**	**4**	**5**	**6**
Quantities						
S 1	0	0	0	0	0	0
S 2	0	0	0	0	0	0
S 3	1000	1000	1000	1000	1000	1000
Inventory	0	0	0	0	0	0

$f_{min} = 127200$and $f_{max} = 2993.6$ are then used as goals for equation (12) and equation (13) respectively while applying Comprehensive Criterion Method (CCM) as described earlier to normalize and combine the bi-objective functions into a single objective function. Table (13) shows the optimal solution of the resulting single objective function optimization problem. The optimal value of the combined objective function is f = -0.4. Substituting the optimal solution of this single objective function problem in the objective functions defined in (12) and (13) results in Z=127200 and W=1675.8.

TABLE 13: COMBINED OBJECTIVE FUNCTION RESULTS

Multi Objective (min. Cost & max. Weights)						
Period	**1**	**2**	**3**	**4**	**5**	**6**
Quantities						
S 1	0	0	0	0	0	0
S 2	0	0	0	0	0	0
S 3	1000	1000	1000	1000	1000	1000
Inventory	0	0	0	0	0	0

The optimal solution as shown in Table 28 suggests buying from supplier 3 in each period which seems reasonable, as we have the same demand in each period and supplier 3 capacity is greater than the required demand in each period. Having zero inventory is justified in each period since the fixed cost for supplier 3 (1200) is less than holding cost for total demand in each period (5000). To increase the importance of weights objective function, Equation (23) can be used while assigning different weights to each objective function.

VI. CONCLUSION

In our model, we first applied fuzzy TOPSIS to rank criteria and alternatives. Criteria were grouped in two different categories: traditional and green. AHP was then used to assign importance weights to each category of criteria. Consequently, the alternative which is considered very good in terms of traditional criteria and very poor in green criteria will not be ranked among the best alternatives if the decision maker decides to give more importance to the green criteria category. This method gives decision maker more flexibility in identifying the importance of green aspect in their selection. In the last stage, Comprehensive Criterion Method (CCM) is used to solve bi-objective optimization model to determine the optimal quantities in a multi-period planning horizon. A numerical example is given to show how the proposed model can be applied.

VII. REFERENCES

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BIOGRAPHY

Sadeque Hamdan was born in Sharjah, United Arab Emirates in 1991. He received the B.Sc. degree in civil engineering from Univeristy of Sharjah in 2012, and he is currently doing master of science in engineering management in University of Sharjah, UAE. His mean research interests are multi-criteria decision making and supply chain management.

Ali Cheaitou is Assistant Professor in the Industrial Engineering and Engineering Management Department, College of Engineering, University of Sharjah, United Arab Emirates. He worked previously as Assistant Professor at Marseilles Business School, France, Lecturer at Ecole Centrale Paris, France and consultant in the field of ERP systems with a special focus on the modules related to Supply Chain Management. His main research interests are in production planning and inventory control, supply chain management, shipping and maritime transportation.