MANUFACTURING SUPPLY CHAINS AND SUSTAINABILITY: A FUZZY ANALYTIC HIERARCHY PROCESS APPROACH

Mohd. Nishat Faisal
Department of Management & Marketing
College of Business & Economics
Qatar University, P.O. Box 2713
Doha, Qatar
nishat786@qu.edu.qa
974-55677926, 974-44035042

ABSTRACT

This study aims at defining a methodology to improve sustainability in supply chains. As supply chain sustainability is a multi-dimensional characteristic with several variables and sub-variables, there is a need to understand their relative priority for a more focussed approach for improvement. To achieve this end the research presented in this paper proposes a Fuzzy-AHP based framework to prioritize sustainability dimensions in supply chains. An exhaustive literature review complimented with the experts' opinion was undertaken from the perspective of two manufacturing supply chains to formulate a hierarchical structure of sustainability in supply chains. A fuzzy analytic hierarchy process (F-AHP) is then utilized to ascertain the relative weightings which are subsequently used to prioritize these sustainability variables. Understanding the priorities would help the firms to accord importance and develop suitable strategies to improve supply chain sustainability variables according to their relative importance.
Keywords: Supply chain, Sustainability, Fuzzy, AHP

INTRODUCTION

The concepts of Sustainable Development (SD) and sustainability have appeared as alternatives to help to understand, address and reduce current, and potentially future, economic disparities, environmental degradation, and social ailments. However, these concepts are still unfamiliar to, or are misunderstood by many individuals and societies worldwide (Lozano, 2008). Brundtland Report brought the concept of sustainable development to the mainstream international political agenda by defining it as: ‘‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’’ (WCED, 1987). Sustainability means the rearrangement of technological, scientific, environmental, economical, and social resources in such a way that the resulting heterogonous system can be maintained in a state of temporal and spatial equilibrium (Ron, 1988).

The scale and time dimensions of the current sustainability problems are unprecedented in at least three aspects: firstly, never before has humanity experienced such profound effects from globalization; secondly, the importance of the human-made world and the laws that govern it, such as the market mechanisms, has grown to become comparable to that of the natural systems; and thirdly, the tools that society and science have developed to handle policy formulation, decision-making and governance have been focused on the short to medium term and are therefore inadequate from an intergenerational sustainability perspective (Todorov and Marinova, 2011).

Sustainable Development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity (Elkington, 2002). It requires that products need to be easy to recycle and built from durable nonhazardous materials. Also products need to be made under socially acceptable working circumstances, while workers share in profits and participate in decision making. Today, customers, local communities, and environmental interest groups encourage firms to consider ecological and social impacts in their decision-making in order to improve company reputation and subsequent competitive advantage (Bansal and Roth 2000). Recent research has discovered that consumers are willing to pay 'substantially more' for goods produced based on triple bottom line, and consumers will also punish producers for unethically produced goods (Trudel and Cotte 2009). Thus, the present research is built on the premise that although supply chain managers are trying hard to improve overall sustainability of a supply chain, their efforts need to be more focused and they should know which of the sustainability factors currently require more emphasis.

RESEARCH MOTIVATION

Despite the high recognition the field sustainable supply chain management has been receiving in recent years, no true sustainable supply chain has been described in the literature (Pagell and Wu, 2009). Growing interest in sustainability along a supply chain by customers, businesses and governments, and wider community awareness is driving many sectors of manufacturing industries to move towards sustainability and sustainable supply chains (Kuik et al., 2011; Beske 2012).

The major intent of this study is to propose a methodology that would help supply chain managers prioritize sustainability variables in a supply chain. First, the paper focuses on the sustainability variables using the triple bottom line approach and develops a hierarchy based framework for sustainability in manufacturing supply chains. Secondly, the study aims to answer the following questions:

- To what extent the understanding of sustainability by various partners in a supply chain is aligned?
- How can the relative importance given to various supply chain sustainability factors and sub-factors by various partners across the supply chain can be examined?.

- What are the practical implications and research limitations of the proposed framework?

LITERATURE REVIEW

United Nations Benchmark Corporate Environmental Survey Report indicate that transnational corporations (TNCs) react in different ways to global environmental challenges, which is reflected in the way they report their behavior to their stakeholders (Robbins, 1996). The reactions range from mere compliance to environmental legislation and litigation via preventive towards pro-active management styles. The most pro-active style is called sustainable development management. It occurs in ‘ethical’ TNCs, which have a global vision and practice for dealing with environmental challenges. To support decision making and influence buying behavior, stakeholders and consumers need to be informed about sustainability of the companies, products, and processes. In other words: sustainability needs to be integrated across the supply chains (Wogman et al., 2011).

Becoming sustainable is particularly a challenge for large companies and complex supply chains. Companies like Unilever Plc., Starbucks, are trying to transform their production processes towards sustainability by applying the ‘triple bottom-line approach’ in sourcing its raw materials (Wognum et al., 2011). Melnyk et al. (2010) state that supply chains must be designed and managed to deliver certain outcomes and sustainability being one of these outcomes. Firms increasingly respond to the need for sustainability in their upstream supply chain. For example, E.ON UK recently implemented a ‘responsible procurement’ policy which focuses on (1) human rights, (2) minimisation of environmental impacts and (3) maintenance of high standards of ethics and business integrity (Hollosa et al., 2012). Drawing from an exhaustive review of literature various attributes of sustainability in a supply chain can be grouped under three variables as represented in Table 1.

Table 1: Sustainability attributes and their groupings

Sustainability Attributes	**Sustainability Variable**	**Remarks**
Profits (*ECO1*)	Economic Dimension *(ECO)*	Relates to the economic viability of the supply chain.
Return on Investments (*ECO2*)		
Quality (*ECO3*)		
On-time delivery (*ECO4*)		
Market Share (*ECO5*)		
Cost Reduction (*ECO6*)		
Community Initiatives (*SOC1*)	Social Dimension (*SOC)*	Relates to the concerns that might affect the whole society.
Philanthropy (*SOC2*)		
Diversity in supply base (*SOC3*)		
Health and safety of workers (*SOC4*)		
Diversity in workforce (*SOC5*)		
Gender Equality (*SOC6*)		
Minority Support (*SOC7*)		
Education Support (*SOC8*)		

Sustainability Attributes	Sustainability Variable	Remarks
Human Rights (*SOC9*)		
Workers participation in decision making (*SOC10*)		
Waste Reduction (*ENV1*)	Environmental Dimension (*ENV*)	Represents the realms within the environment that might be affected.
Recycling (*ENV2*)		
Reuse (*ENV3*)		
Reverse Logistics (*ENV4*)		
Alternate Materials (*ENV5*)		
Efficient Energy Use (*ENV6*)		
Packaging Reduction (*ENV7*)		
Waste Minimization (*ENV8*)		
Environmental Innovation (*ENV9*)		
Ethical Sourcing (*ENV10*)		

Environmental dimension: Work on this dimension leads to an environmentally sustainable system that maintains a stable resources base, avoids over-exploitation of renewable resource systems or environmental sink functions, and depletes non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources (Harris and Goodwin, 2001). This dimension focuses on greening the supply chain. In transforming a supply chain into a green supply chain, purchasing plays a major role. Green purchasing addresses issues such as reduction of waste produced, material substitution through environmental sourcing of raw materials, and waste minimization of hazardous materials (Rao and Holt, 2005). Today, environmental purchasing, which is defined as purchasing's involvement in supply chain management activities in order to facilitate recycling, reuse, and resource reduction is being implemented by companies like Patagonia, Mercedes, Ford to minimize waste (Carter et al., 1998). Today, a 'green' image of producing environmentally friendly products has become an important marketing element, which has stimulated a number of companies to explore options for take-back and recovery of their products and thus reverse logistics in now one of the important issues in managing the supply chain (Ravi et al., 2005).

Social dimension: Today consumers' have started to value socially responsible behavior of organizations and are even ready to pay higher prices and on the other hand penalize those who have scant regard of social responsibility. Efforts to deal with this dimension lead to a socially sustainable system that results in fairness in distribution and opportunity, and adequate provision of social services including health and education, gender equity, and political accountability and participation (Harris and Goodwin, 2001). According to Carter and Jennings (2002) social responsibility is not only synonymous with business ethics, but also encompasses dimensions including philanthropy, community, workplace diversity, safety, human rights, cause-related marketing, minority support, socially responsible employment and manufacturing processes (Maloni and Brown, 2006; Cowe, 2004). A company seeking to operate in accord with the principles of sustainability or taking an ethical or citizenship approach to corporate social responsibility must consider its entire supply chain, ''not just those links which belong to its own sphere of legal responsibility'' (Hutchins and Sutherland, 2008). Diversity in supply base, diversity in workforce, community initiatives, human rights, and health and safety of workers are major principles that relates to organizations socially responsible practices among the nine principles as defined by the Institute of Supply Management (Jacobsen, 2008).

Economic dimension: This dimension ensures that an economically sustainable system is able to produce goods and services on a continuing basis. It also maintains manageable levels of government and external debt; and avoids sectoral imbalances that damage agricultural or industrial production. Quality, on-time delivery, return on investment (ROI), net profits are some of the major indicators of the economic dimension.

METHODOLOGY

The analytic hierarchy process (AHP) developed by Saaty (1980) is a multi-criteria decision-making tool that can handle unstructured or semi-structured decisions with multi-person and multi-criteria inputs. It also allows users to structure complex problems in the form of a hierarchy or a set of integrated levels. In addition to this, AHP is easier to understand and can effectively handle both qualitative and quantitative data (Durán and Aguilo, 2008). The AHP attracted the interest of many researchers for long because of its easy applicability and interesting mathematical properties (Sasamal and Ramanjaneyulu, 2008). AHP involves the principles of decomposition, pair wise comparisons, and priority vector generation and synthesis. Though the purpose of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the human thinking style. In spite of its popularity, this method is often criticized because of a series of pitfalls associated with the AHP technique which can be summarized as follows (Durán and Aguilo, 2008):

- Its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker's perception to exact numbers.
- In the traditional formulation of the AHP, human's judgments are represented as exact (or crisp, according to the fuzzy logic terminology) numbers. However, in many practical cases the human preference model is uncertain and decision-makers might be reluctant or unable to assign exact numerical values to the comparison judgments.
- Although the use of the discrete scale of 1-9 has the advantage of simplicity, the AHP does not take into account the uncertainty associated with the mapping of one's judgment to a number.

A good decision-making models needs to tolerate vagueness or ambiguity since fuzziness and vagueness are common characteristics in many decision-making problems (Yu, 2002). Due to the fact that uncertainty should be considered in some or all of the pairwise comparison values, the pairwise comparison under traditional AHP, which needs to select arbitrary values in the process, may not be appropriate (Yu, 2002). Thus the use of fuzzy numbers and linguistic terms may be more suitable, and the fuzzy theory in AHP should be more appropriate and effective than traditional AHP in an uncertain pairwise comparison environment (Kang and Lee, 2007). Fuzzy set theory bears a resemblance to the logical behavior of human brain when faced with imprecision (Cakir and Canbolat, 2008). It has the advantage of mathematically representing uncertainty and vagueness and provides formalized tools for dealing with the imprecision intrinsic to many problems (Chan and Kumar, 2007).

Although the purpose of the original AHP was to capture expert knowledge, conventional AHP did not truly reflect human cognitive processes-especially in the context of problems that were not fully defined and/or problems involving uncertain data (so-called "fuzzy" problems) (Fu et al., 2006). Laarhoven and Pedrycz (1983) therefore introduced the concept of "fuzzy theory" to AHP assessments. This so-called "fuzzy analytic hierarchical process" (fuzzy-AHP) was able to solve uncertain "fuzzy" problems and to rank excluded factors according to their weight ratios. The research presented in this chapter prefers Chang's extent analysis method (Chang 1992; 1996) since the steps of this approach are relatively easier than the other fuzzy AHP approaches and similar to the conventional AHP (Büyüközkan et al., 2008; Bozbura et al., 2007; Büyüközkan, 2009; Chan and Kumar, 2007). Fuzzy-AHP has been widely used for prioritization purposes like prioritization of organizational capital (Bozbura and Beskese (2007), key capabilities in technology management (Erensal et al., 2006), prioritization of human capital measurement indicators (Bozbura et al., 2007), adoption of electronic marketplaces (Fu et al., 2006), supply chain risks (Faisal, 2009), and supply base reduction (Sarkar and Mohapatra, 2006).

A fuzzy number is a special fuzzy set $F=\{x\in R \mid \mu_F(x)\}$, where x takes its values on the real line R_1: $-\infty<x<+\infty$ and $\mu_F(x)$ is a continuous mapping from R_1 to the close interval [0,1]. A triangular fuzzy number can be denoted as $M=(l, m, u)$. Its membership function $\mu_M(x) : R \rightarrow [0, 1]$ is equal to:

$$\mu_M(\mathrm{x}) = \begin{cases} 0, & x < l \; or \; x > u, \\ (x-l)/(m-l), & l \le x \le m, \\ (x-u)/(m-u), & m \le x \le u \end{cases} \qquad (1)$$

Where $l \le m \le u$, l and u stand for the lower and upper value of the support of M, respectively, and m is the mind-value of M. When $l=m=u$, it is a non fuzzy number by convention. The main operational laws for two triangular fuzzy numbers M_1 and M_2 are as follows (Kauffman and Gupta, 1991):

$M_1+M_2= (l_1 +l_2, m_1+ m_2, u_1+u_2)$,
$M_1 \otimes M_2 \approx (l_1 l_2, m_1 m_2, u_1 u_2)$,
$\lambda \otimes M_1= (\lambda l_1, \lambda m_1, \lambda u_1), \lambda>0, \lambda$
$M_1^{-1} \approx (1/ u_1, 1/m_1, 1/l_1)$ (2)

Let $X=\{x_1, x_2, \ldots\ldots x_n\}$ be an object set, and $U=\{u_1,u_2 \ldots u_m\}$ be a goal set. According to the method of Chang's extent analysis model, each object is taken and extent analysis for each goal, g_i, is performed respectively (Chang, 1992; 1996). Therefore, m extent analysis values for each object can be obtained with the following signs:

$$M_{gi}^1, M_{gi}^m, i = 1,2,\ldots\ldots, n \qquad (3)$$

Where all the $M_{gi}^j (j = 1,2,\ldots\ldots m)$ are triangular fuzzy numbers. A triangular fuzzy number can be denoted as M=(l, m, u) where $l \le m \le u$, l and u stand for the lower and upper value of the support of M, respectively, and m is the mid-value of M.

The steps of the improved Chang's extent analysis model, which is applied in this chapter, can be given as follows:
Step 1: The value of fuzzy synthetic extent with respect to the *i*th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \qquad (4)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, perform the fuzzy addition operation of *m* extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \qquad (5)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, perform the fuzzy addition operation of M_{gi}^{j} (j= 1,2, …..m) values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \qquad (6)$$

and then compute the inverse of the vector in equation (6) such that

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \qquad (7)$$

The principles for the comparison of fuzzy numbers were introduced to derive the weight vectors of all elements for each level of the hierarchy with the use of fuzzy synthetic values. We now discuss these principles that allow the comparison of fuzzy numbers. (Zhu et al, 1999).
Step 2: The degree of possibility of $M_2 \geq M_1$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y)] \qquad (8)$$

When a pair (x,y) exists such that $y \geq x$ and $\mu M_1(x), \mu M_2(y)$, then we have $V(M_2 \geq M_1)=1$. Since $M_1=(l_1, m_1, u_1)$ and $M_2=(l_2, m_2, u_2)$ are convex fuzzy number we have that
$V(M_2 \geq M_1)$ = hgt $(M_1 \cap M_2) = \mu_{M2}(d)$

$$\begin{cases} 1, if \ \ m_2 \geq m_1 \\ 0, if \ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_1 - u_2) - (m_1 - l_1)}, \quad \text{otherwise} \end{cases} \qquad (9)$$

Where d us the crossover point's abscissa of M_1 and M_2. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.
Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i=1,2,……k) can be defined by
$V(M \geq M_1, M_2, \ldots\ldots M_k)$
= V$[(M \geq M_1)$ and $M \geq M_2)$ and …..and $(M \geq M_k)]$ (10)
= min $V(M \geq M_i)$, $i = 1, 2, 3, \ldots\ldots, k$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \quad (11)$$

for $k=1,2,....n;\ k \neq i$. Then the weight vector is obtained as follows:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \quad (12)$$

Where A_i $(i=1,2,.........,n)$ are n elements.

Step 4: After normalization, the normalized weight vectors are,

$$W = (d(A_1), d(A_2), ..., d'(A_n))^T \quad (13)$$

Where W is not a fuzzy number.

A NUMERICAL APPLICATION

As previously mentioned, in the third step of the framework, fuzzy AHP methodology is applied for weight determination. The sustainability variables and the sub-variables are represented in Figure I.

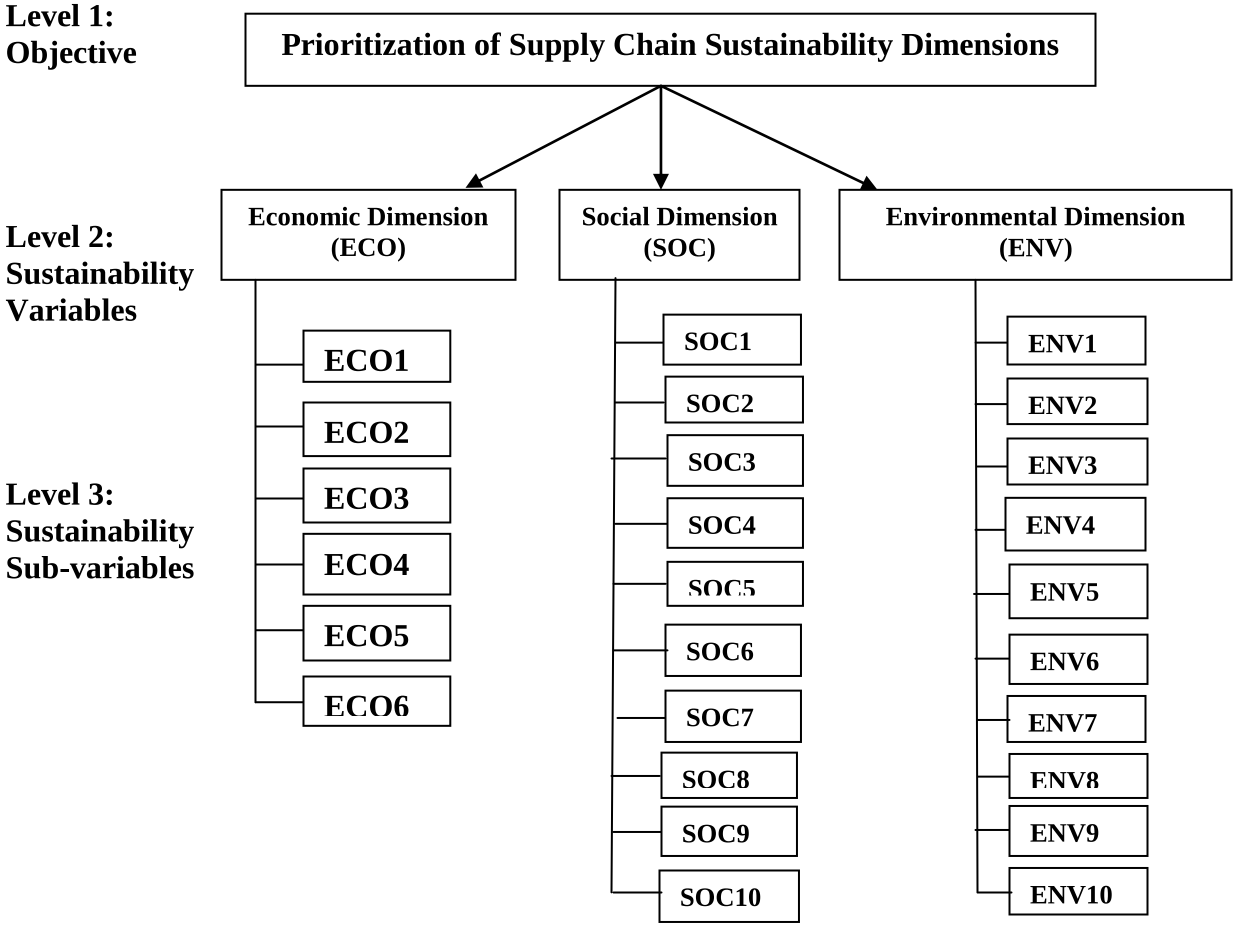

Figure I: A hierarchy based model of supply chain sustainability

In order to perform a pairwise comparison among the requirements, the linguistic scale as proposed by Büyüközkan (2009), Büyüközkan et al. (2008), Faisal (2009) is adopted in this paper. The scale is depicted in Figure II and the corresponding explanations are provided in Table 2. Figure II shows the triangular fuzzy numbers $M = (l, m, u)$ where $l \leq m \leq u$, l and u stand for the lower and upper value of the support of M, respectively, and m is the mid-value of M. Similar to the importance scale defined in Saaty's classical AHP (Saaty, 1980), five main linguistic terms are used to compare the criteria: "equal importance (EI)", "moderate importance (MI)", "strong importance (SI)", "very strong importance (VSI)" and "demonstrated importance (DI)". Further, their reciprocals: "equal unimportance (EUI)", "moderate unimportance (MUI)", "strong unimportance (SUI)", "very strong unimportance (VSUI)" and "demonstrated unimportance (DUI)" have also been considered. For instance, if criterion A is evaluated "strongly important" than criterion B, then this answer means that criterion B is "strongly unimportant" than criterion A.

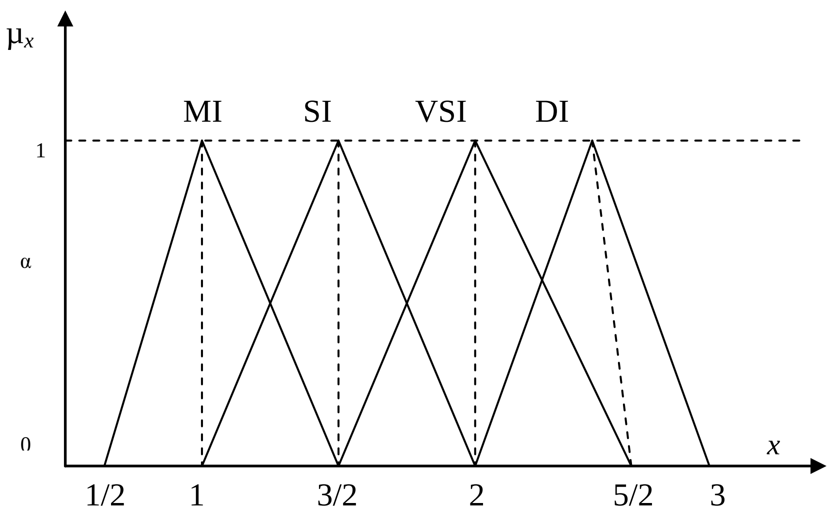

Figure II: Triangular fuzzy importance scale

Table 2: Triangular fuzzy importance scale

Linguistic Scale	**Explanation**	**Triangular fuzzy Scale**	**Triangular fuzzy reciprocal scale**
Equal Importance (EI)	Two requirements are the same importance	(1,1,1)	(1,1,1)
Moderate Importance (MI)	Experience and judgement slightly favor one requirement over another	(1/2, 1, 3/2)	(2/3,1,2)
Strong Importance (SI)	Experience and judgement strongly favor one	(1, 3/2, 2)	(1/2, 2/3, 1)
Very Strong Importance (VSI)	A requirement is favored very strongly over another; its	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)

Linguistic Scale	Explanation	Triangular fuzzy Scale	Triangular fuzzy reciprocal scale
	dominance demonstrated in practice		
Demonstrated Importance (DI)	The evidence favouring one requirement over another is the highest possible order of affirmation	(2, 5/2, 3)	(1/3, 2/5, 1/2)

Adapted from Büyüközkan (2009); Faisal (2009)

The proposed model was evaluated for two supply chains. One of them is a battery manufacturer and the other electrical goods manufacturer from India. A group of experts consisting of academics and professionals were asked to make pairwise comparisons for the sustainability variables and sub-variables mentioned in Table 1. A questionnaire (see Appendix A) is provided to get the evaluations. The overall results could be obtained by taking the geometric mean of individual evaluations. However, since the group of experts came up with a consensus by the help of the Delphi Method in this case, a single evaluation could be obtained to represent the group's opinion (Bozbura et al., 2007; Büyüközkan, 2009; Faisal 2009) as represented in Table 3 for relative importance of sustainability dimensions.

Table 3: Fuzzy evaluation matrix with respect to sustainability for Tier I supplier in Battery Supply Chain

	(SOC)	(ENV)	(ECO)
Social Dimension (SOC)	1, 1, 1	1/2, 1, 3/2	2/5, 1/2, 2/3
Environmental Dimension (ENV)	1, 3/2, 2	1, 1, 1	1/2, 1, 3/2
Economic Dimension (ECO)	3/2, 2, 5/2	2/3, 1, 2	1, 1, 1

The values of fuzzy synthetic extents with respect to the sustainability variables are calculated by applying formula (4) as below

S_{SOC} = (1.9, 2.5, 3.16) (0.076, 0.1, 0.132)
(0.144, 0.25, 0.417)

S_{ENV} = (2.5, 3.5, 4.5) (0.076, 0. 1, 0.132)
(0.19, 0.35, 0.594)

S_{ECO} = (3.16, 4, 5.5) (0.076, 0.1, 0.132)
(0.24, 0.4, 0.726)

The degrees of possibility are calculated using these values and formula (9) as below:

$V(S_{SOC} \geq S_{ENV}) = 0.694$

$V(S_{SOC} \geq S_{ECO}) = 0.541$

$V(S_{ENV} \geq S_{SOC}) = 1$

$V(S_{ENV} \geq SSQ) = 0.876$

$V(S_{ECO} \geq S_{SOC}) = 1$

$V(S_{ECO} \geq S_{ENV}) = 1$

The weight vector of the main factors of the hierarchy can be calculated by using the formulas (10) and (11) as below:
d' (SOC)= V ($S_{SOC} \geq S_{ENV}, S_{ECO}$) = min (0.694,0.541) =0.541
d' (ENV)= V($S_{ENV} \geq S_{SOC}, S_{ECO}$)= min (1, 0.876) = 0.876
d' (ECO)= V ($S_{ECO} \geq S_{SOC}, S_{ENV}$) = min (1,1)= 1
W'= (0.541, 0.876, 1) T
Hence, via normalization, the normalized vectors for the sustainability dimensions, social, environmental and economic, are obtained as below:
$W_{objective}$= $(0.22, 0.36, 0.42)^T$
In a similar way, the importance weights of the sub-variables within social dimension are calculated as follows
$W = (d(\text{SOC1}), d(\text{SOC2}), d(\text{SOC3}), d(\text{SOC4}), d(\text{SOC5}), d(\text{SOC6}), d(\text{SOC7}), d(\text{SOC8}), d(\text{SOC9}), d(\text{SOC10}))^T$
$W_{SOC} = (0.0579, 0.1323, 0.0587, 0.1398, 0.1231, 0.1766, 0.0555, 0.1316, 0.0479, 0.0763)^T$.
In a similar way, the importance weights of the sub-variables within economic dimension are calculated as follows
$W = (d(\text{ECO1}), d(\text{ECO2}), d(\text{ECO3}), d(\text{ECO4}), d(\text{ECO5}), d(\text{ECO6}))^T$
$W_{ECO} = (0.22, 0.15, 0.10, 0.10, 0.15, 0.28)^T$.
In a similar way, the importance weights of the sub-variables within environmental dimension are calculated as follows
$W = (d(\text{ENV1}), d(\text{ENV2}), d(\text{ENV3}), d(\text{ENV4}), d(\text{ENV5}), d(\text{ENV6}), d(\text{ENV7}), d(\text{ENV8}), d(\text{ENV9}), d(\text{ENV10}))^T$
$W_{ENV} = (0.0537, 0.0893, 0.05819, 0.1131, 0.1138, 0.1399, 0.1322, 0.1318, 0.1423, 0.0257)^T$.
Finally, considering the obtained results, composite priority weights for supply chain sustainability can be calculated as given in Table 4.

Table 4: Composite priority weights for supply chain sustainability for Tier I supplier in battery supply chain

Dimension	**Local weights**	**Sub-variables**	**Local weights**	**Global weights**
Social Dimension	0.22	SOC1	0.0579	0.0127
		SOC2	0.1323	0.0291
		SOC3	0.0587	0.0129
		SOC4	0.1398	0.0307
		SOC5	0.1232	0.0271
		SOC6	0.1766	0.0388
		SOC7	0.0555	0.0122
		SOC8	0.1316	0.0289
		SOC9	0.0479	0.0105
		SOC10	0.0763	0.0168
Economic Dimension	0.42	ECO1	0.2201	0.0924
		ECO2	0.1504	0.0631
		ECO3	0.1000	0.0420
		ECO4	0.1000	0.0420
		ECO5	0.1496	0.0628
		ECO6	0.2799	0.1175

Dimension	Local weights	Sub-variables	Local weights	Global weights
Environmental Dimension	0.36	ENV1	0.0537	0.0193
		ENV2	0.0893	0.0321
		ENV3	0.0582	0.0209
		ENV4	0.1131	0.0407
		ENV5	0.1138	0.0409
		ENV6	0.1399	0.0504
		ENV7	0.1322	0.0476
		ENV8	0.1318	0.0474
		ENV9	0.1423	0.0512
		ENV10	0.0257	0.0093

Similar calculations were made for the focal company and Tier II supplier for the battery supply chain and for the focal company, Tier I and Tier II supplier for the electrical goods manufacturing company. The results are presented in Table 5.

Table 5: Composite priority weights for supply chain partners for case supply chains

	Social Dimension	Economic Dimension	Environmental Dimension
Focal Company (Battery SC)	0.30	0.37	0.33
Tier I supplier (Battery SC)	0.22	0.42	0.36
Tier II Supplier (Battery SC)	0.14	0.69	0.21
Focal Company (Electrical Goods SC)	0.28	0.39	0.33
Tier I supplier (Electrical Goods SC)	0.25	0.47	0.28
Tier II Supplier (Electrical Goods SC)	0.10	0.74	0.16

DISCUSSION

Implementing triple-bottom-line initiatives is in response to growing pressure on businesses to pay more attention to the environmental and resource consequences of their products and services offerings (Sarkis 1998). This study aims at defining a methodology to improve the quality of prioritization of supply chain sustainability variables. To achieve this end, this paper proposes Fuzzy-AHP to prioritize sustainability variables and sub-variables in a supply chain. It considers the three sustainability variables and sub-variables as proposed by the triple bottom line (3BL) approach. The proposed methodology was tested for two case supply chains that included the 'focal company', a firm that governs the supply chain, is in direct contact with the consumer, and usually designs the product or service and Tier I and Tier II suppliers for these focal companies. Table 5 provides the values for the three sustainability dimensions for the focal company, Tier I and Tier II suppliers for the two case supply chains. A careful analysis of the results from Table 5 reveals that for both the case supply chains, focal companies understand the concept of sustainability and the need to integrate it in managing their supply chains. This is evident from values of the relative priorities of the three dimensions of sustainability which seems more or less equal. But as we drift away from the focal companies and move towards Tier I suppliers' it is evident that economic dimension gains priority over other two dimensions and for Tier II suppliers' the social and environmental dimension are almost non-existent. This lopsided approach by the suppliers' might result in major embarrassment for the whole supply chain as previous research has established that consumers' will punish producers for unethically produced goods (Trudel and Cotte 2009). Thus there is an urgent need to view sustainability from a supply chain perspective. This requires joint efforts by the supply chain partners to improve overall sustainability of the supply chain. In this regard the well-established dimensions' like collaborative planning, trust based relationships requires attention.

CONCLUSIONS

The model presented in this chapter would help the practitioners to assign relative importance to various sustainability variables in a supply chain and then prioritize resources to achieve them. Variables of the proposed methodology which would help the managers to improve sustainability across the supply chains are:

- The suggested methodology is based on fuzzy-AHP which takes in account the fuzziness of the human decision making.
- The proposed method considers all of the variables and sub-variables simultaneously and gives the correct and complete evaluation of sustainability of supply chains.
- The proposed method also helps in prioritizing variables and sub-variables individually which contributes towards the sustainability of a supply chain. This way it can be decided upon those areas which should have the maximum focus so as to improve the overall sustainability of the supply chain.
- The proposed model can be modified to include some other variable or sub-variables related to supply chain sustainability.

The proposed methodology can be applied for different supply chains to prioritize variables related to supply chain sustainability. Further, it would aid the managers to take a more focused approach in improving supply chain sustainability.

LIMITATIONS OF THE PRESENT WORK AND SCOPE FOR FUTURE RESEARCH

The present study is an effort to propose a model for prioritizing sustainability factors and improve alignment sustainability dimension in a supply chain. But in its present form the study has few weaknesses. First, the study proposes a methodology which to be generalized is required to be tested for other supply chains to make it more robust. Secondly, the methodology needs to be compared with some existing methodologies for sustainability measurement. In future research, a case study approach can be used to compare the perspectives of multiple partners operating in the same supply chain. In addition, further research could also take contextual variables, like length of the supply chain, into account. Additional research is required not merely at the level of single manufacturing and production system, but to take into account multiple collaborative manufacturing networks to improve the overall sustainability of a supply chain. The topic of sustainability is still developing in context of supply chain and thus it is hoped that succeeding studies can adopt a wider range of constructs to make the whole model more holistic.

APPENDIX

Sample questions from the questionnaire used to facilitate comparisons of supply chain sustainability variables.

QUESTIONNAIRE

Read the following questions and put check marks on the pairwise comparison matrices. If an attribute on the left is more important than the one matching on the right, put your check mark to the left of the "Equal importance" column, under the importance level (column) you prefer. On the other hand, if an attribute on the left is less important than the one matching on the right, put your check mark to the right of the importance "Equal Importance" column, under the importance level (column) you prefer.

QUESTIONS

With respect to the overall goal "prioritization of the supply chain sustainability variables",

Q1. How important is economic dimension (ECO) when compared with social dimension (SOC)?

Q2. How important is social dimension (SOC) when compared with environmental dimension (ENV)?

Q3. How important is environmental dimension (ENV) when compared with economic dimension (ECO) ?

Questions	Supply Chain Sustainability Variable	Demonstrated Importance	Very Strong Importance	Strong Importance	Moderate Importance	Equal Importance	Moderate unimportance	Strong unimportance	Very Strong unimportance	Demonstrated unimportance	Supply Chain Sustainability Variable
1	ECO				√						SOC
2	SOC					√					ENV
3	ENV						√				ECO

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