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Supply Chain Performance Improvement by Integrating Sustainability in Supplier Selection for a Steel Producer

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Abstract - **The purpose of this paper is to develop a framework for supplier selection considering the sustainability factors. It utilizes an integrated Triple-Bottom Line (3BL) and Analytic Network Process (ANP) approach. ANP is a flexible analytical program that enables to find the best possible solution to complex problems by breaking down a problem into a systematic network of inter-relationships of the various levels and attributes. This method therefore may not only aid in selecting the best alternative but also helps to understand why an supplier should be preferred over the other suppliers'.**

Keywords - Sustainability, 3BL, ANP and Supplier selection.

I. INTRODUCTION

Organizations now recognize the importance of sustainability and thus sustainability has become an integral part of business strategy. A widely accepted definition of sustainable development is the one from the World Commission on Environment and Development [1]: "Sustainable development is the development that meets the needs of the present generation without compromising the ability of future generations to meet their needs." Sustainability calls for proponents of human, economic, as well as environmental concerns to join together to provide an everlasting life for the human species in the global ecosystem [2]. Studies have found that an increased emphasis on sustainability in the supply chain is related to lower costs and a neutral or positive effect on value [3].

Supplier selection is increasingly recognized as a critical decision in supply chain management [4]. Most of the companies have reduced their supply base to effectively manage relationships with strategic suppliers and developed cooperative, mutually beneficial relationships with all suppliers [5]. A strategic commitment from suppliers is a vital determinant of business success as it directly and indirectly impacts performance [6].

The factors which have made the topic of supplier relationships and their selection so vital are:

- firms' increased focus on core-competencies;
- supply chain as a source of competitive advantage;
- ICT tools make it easier to find, establish, and maintain supplier relationships;
- agility requirements of a supply chain; and
- emphasis on long-term strategic relationships.

However, supplier selection is a complex multi-criteria decision problem that includes both qualitative and quantitative factors. Thus to evaluate suppliers effectively, it is necessary to identify quantitative and qualitative criteria simultaneously [7]. Studies over the years have addressed a variety of criteria that are important in supplier selection [8]. Factors that are generally accorded highest priority in supplier selection are quality, delivery, and price [9][10]. But in the literature very few studies exist that have considered factors other than those that impact the financial bottom line as an important component of the supplier selection process.

Sustainable development in Agenda 21 (UN 1993) was described as three dimensions: the social, economic, and environmental and considered the task of bringing these development processes into balance with each other. These three dimensions are also known as the triple bottom line (3BL). Thus in this paper, an approach that integrates triple bottom line dimensions of sustainability and analytic network process (ANP) is employed for supplier selection problem. In addition to advantages such as consideration of interdependence and feedback that ANP provides, the major contribution of this paper is the integration of environmental and social issues along with the economics issues in the selection of the supplier.

II. SUPPLIER SELECTION PROBLEM

Choosing the right suppliers involves much more than scanning a series of price lists, and choices will depend on a wide range of factors which can be both quantitative and qualitative [11]. The decision-making methods reported for supplier selection can be clustered into five broad categories [12]: traditional MCDM (multi-criteria decision making) techniques, mathematical programming, artificial intelligence, expert systems, and multivariate statistical analysis. From a sustainability point of view, environmental considerations were included by [13] in their Analytic Hierarchy Process (AHP) model. Noci [14] designed a conceptual approach that first identified measures for assessing a supplier's environmental performance and, secondly, suggested effective techniques for developing the supplier selection procedure according to an environmental viewpoint. For selecting suppliers for a sustainable supply chain, there is a need to consider both qualitative and quantitative criteria which may even be interdependent. However, as mentioned above, there are studies which have considered integrating environmental issues in the supplier selection process, but no study was found that has also integrated social dimensions in the supplier selection . The problem basically is of selecting suppliers which have an impact on economic, environmental, and social performance or the 'triple-bottom-line (3BL)' of the overall supply chain. Thus the major objectives of this paper are to

- Develop a framework for supplier selection for a sustainable steel supply chain.
- Integrate 3BL and analytic network process approach to select supplier.

III. SUPPLY CHAIN AND THE 'TRIPLE BOTTOM LINE'

Carter and Rogers [15] reviewed the literature and suggested that organizational sustainability, at a broader level, consists of three components: the natural environment, society, and economic performance. This perspective corresponds to the idea of the triple bottom line, a concept developed by Elkington [16][17], which simultaneously considers and balances economic, environmental and social goals from a microeconomic standpoint. Thus a sustainable organization is one that contributes to sustainable development by simultaneously delivering economic, social, and environmental benefits [18]. The 'triple bottom line' enablers for economic, social, and economic dimensions are summarized below.

Environmental dimension: This dimension addresses issues such as reduction of waste produced, material substitution through environmental sourcing of raw materials, and waste minimization of hazardous materials [3]. This requires commitment, involvement, and support from suppliers'. Therefore, companies are increasingly managing their suppliers' environmental performance to ensure that the materials and equipment supplied by them are environmentally-friendly in nature and are produced using environmentally-friendly processes [19].

Social dimension: According to Carter and Jennings [20] 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 [21]. 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" [22]. Thus in recent years, firms have embraced the importance of working collaboratively with their supply chain partners to enhance their corporate social responsibility (CSR) performance [23].

Economic dimension: In supplier selection literature, quality, delivery and net price have received the greatest amount of attention [7]. Nydick and Hill [24] considered four criteria in supplier selection: quality, price, delivery, and service. Karpak et al. [9] considered cost, quality and delivery reliability as vendor selection criteria. Bhutta and Huq [25] used four criteria to evaluate suppliers: manufacturing costs, quality, technology, and service. Bayazit [8] has also considered quality, on time delivery, price, delivery lead time, and flexibility as the factors for supplier selection.

IV. THE ANALYTIC NETWORK PROCESS

Decision-making is a difficult procedure especially when there are a number of conflicting objectives and criteria. Saaty [26] suggested the use of analytic network process (ANP) to solve the problem of dependence among alternatives or criteria. ANP can be used as an effective tool in cases in which the interactions among the elements of a system form a network structure. ANP replaces hierarchies with networks, in which the relationships between levels are not easily represented as higher or lower, dominate or being dominated, directly or indirectly [26]

The concept of supermatrix was initially introduced by Saaty [27] to serve as a general composition principle of ratio-scale priorities wherein hierarchical composition is a special case. The supermatrix approach, which became popularly known as the Analytic Network Process (ANP), has become an attractive tool for understanding more of a decision problem since it overcomes the limitation of linear hierarchic structures [28]. Analytic Network Process (ANP) is a more general form of AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives [26].

The ANP technique allows for more complex relationships among the decision levels and attributes. The ANP consists of coupling of two phases:

- the first phase consists of a control hierarchy of a network of criteria and sub-criteria that control the interactions, and
- the second phase is a network of influences among the elements and clusters.

Some of the applications of ANP project alternatives, include third part logistic providers, waste management, SWOT analysis, industrial land valuation, reverse logistics, and supply chain risks [29] [30] [31] [32] [33] [34] [35].

V. THE DECISION ENVIRONMENT: AN ILLUSTRATIVE EXAMPLE

The proposed approach was applied to a steel company which is currently dealing with numerous suppliers. As the company's goals with regard to sustainability depend on its suppliers, it is important to address the sustainability impact on supplier's selection. The company started production in early 1970's and has now become one of the leader' in steel production in the gulf region. With the enforcement of new stringent environmental legislation and the attempt to reduce its carbon footprint, the company needs to seriously consider its performance in the environmental dimension. Further, there is an expectation by the local populace that the profit-earning organization should contribute to the overall betterment of the society. These concerns have led the company to chart out a program to develop sustainability practices in all its areas of operation. As the company is not highly integrated in its upstream and downstream supply chain, it is very much dependent on its suppliers. To achieve the objectives of sustainability, the company has realized that the right type of supply chain partners, in this case, suppliers, are crucial. The following section describes the model development and its application for the company in this case study.

Step 1. Model development and problem formulation

In this research, the ANP model has been developed on the basis of literature review and a series of informal discussions with a few academicians and industry personnel. Discussion with industry and academia helped to classify the various criteria of decision-making for supplier selection with the consideration of sustainability into three levels. These categories have been named as determinants, dimensions, and enablers. This classification is adapted from other ANP based models like [30][34][35]. Determinants form the upper level of the ANP model and can be considered as the main drivers for the whole decision making process. The next level is the triple-bottom-line (3BL) dimensions that support the achievement of the upper-level determinants. The third level of variables is named as enablers which not only support their respective dimensions but also have some interdependencies among themselves. The alternatives that the decision-maker wishes to evaluate are shown at the bottom of the model. A graphical summary of the ANP model, so formed, is presented in Figure 1 (Appendix A).

Step 2. Pair-wise comparison of determinants

In this step, a series of pair-wise comparisons are made to establish the relative importance of determinants in achieving the objective. In such comparisons, a ratio scale of 1-9 is used to compare any two elements. A score of 1 indicates equal importance of the two elements whereas a score of 9 indicates overwhelming dominance of the element under consideration (row component) over the comparison element (column component). If an element has weaker impact than its comparison element, the range of the scores will be from 1 to 1/9, where 1 indicates indifference and 1/9 represents an overwhelming dominance by a column element over the row element. For reverse comparison, a reciprocal value is automatically assigned within the matrix, so that in a matrix $a_{ij}a_{ji} = 1$. This type of comparison is in agreement with the method recommended by Saaty (1980). In the formation of a pair-wise comparison matrix, group decision-making may be used to avoid the biased attitude of the decision-maker towards a particular provider. Dyer and Forman [36] have suggested several ways for including the views and judgments of group members in the pair-wise comparison of matrices. These are (i) consensus, (ii) vote or compromise, (iii) geometric mean of the individual's judgments, and (iv) a separate model. This paper utilizes the consensus approach to arrive at a value for pair-wise comparison. The matrix showing the pair-wise comparison of determinants along with the derived local priority vectors (also known as eigen-vectors or e-vectors) is shown in Table 1.

Table 1: Pair-wise comparison of determinants

	LegOb	*ComAd*	*CRes*	*BImg*	*e-vector*
Legal obligations	1	2	3	3	0.449205
Competitive advantage	1/2	1	2	1	0.228073
Corporate responsibility	1/3	1/2	1	2	0.175838
Brand Image	1/3	1	1/2	1	0.146884

CR: 0.0639

Step 3. Pair-wise comparison of dimensions

In this step, the decision-maker is asked to respond to a number of pair-wise comparisons in which two components are compared at a time in terms of an upper lever control criteria. The pair-wise comparisons of the components at each level are performed regarding their relative influence toward the control criterion. Pair-wise comparison is thus performed between the applicable criteria within a given dimension cluster. In this model, three such pair-wise comparison matrices are formed. Table 2 shows the pair-wise comparison matrix for the social dimension.

Table 2: Pair-wise comparison of 'dimensions' with respect to 'competitive advantage'

Competitive advantage	*Economic*	*Social*	*Environmental*	*e-vector*
Economic	1	2	3	0.527836
Social	1/2	1	3	0.332516
Environmental	1/3	1/3	1	0.139648

CR: 0.0516

Step 4. Pair-wise comparison matrices for enablers

This step involves performing pair-wise comparisons to consider the interdependencies among the criteria (third level). There are 13 such pair-wise comparison matrices in this stage. Table 3 lists one such comparison which represents the result of the economic dimension with 'price' as the control criterion over other criteria. The decision- maker is asked to answer the question for evaluating the interdependencies related to "when considering 'price' with respect to economic dimension, what is the relative impact of criterion "a" compared to criterion "b". Table 3 reveals that 'quality' has the strongest impact (0.637501) on the economic dimension, with 'price' as the control criterion over others. Furthermore, 'flexibility' has the weakest impact (0.063153). It shows that quality has the most influence on the requirement of price for the economic dimension. The e-vector from these matrices is thus used to form super matrices.

Table 3: Pair-wise comparison of 'enablers' under the economic dimension with 'price' as the control criterion

Price	*Quality*	*On-time delivery*	*Lead time*	*Flexi bility*	*e-vector*
Quality	1	6	5	6	0.637501
On-time delivery	1/6	1	3	4	0.200871
Lead time	1/5	1/3	1	2	0.098476
Flexibility	1/6	1/4	1/2	1	0.063153

CR: 0.0964

Step 5. Evaluation of suppliers

This step evaluates suppliers for every enabler under each of the dimension. The number of such pair-wise comparison matrices is dependent on the number of enablers that are included. In the present case, there are 13 enablers, which leads to the formation of 13 such pair-wise comparison matrices. One such pair-wise comparison matrix is shown in Table 4. In this table, the three alternatives are compared with respect to the enabler 'health & safety'.

Table 4: Pair-wise comparison of alternatives with respect to enabler 'Health & Safety'

	Supplier A	*Supplier B*	*Supplier C*	*e-vector*
Supplier A	1	3	1/4	0.210933
Supplier B	1/3	1	1/7	0.084158
Supplier C	4	7	1	0.704909

CR: 0.0312

Step 6. Influence of selecting an alternative or the feedback loop

The final set of pair-wise comparisons is made with respect to preference of each of the supplier alternatives (A, B, and C) in terms of each enabler. In other words, this comparison evaluates the influence of selecting an alternative on the enabler which in turn impacts the controlling dimension. Table 5 shows the feedback influence of Supplier C for the environmental dimension.

Table 5: Pair-wise comparison of the influence of selecting Supplier C for the environmental dimension

	Waste Red	*Waste Recyc*	*Environ Purch*	*Rev Logistics*	*e-vector*
Waste Reduction	1	1	4	5	0.416006
Waste Recycling	1	1	4	4	0.392791
Environmental Purchasing	1/4	1/4	1	1	0.098198
Reverse Logistics	1/5	1/4	1	1	0.093006

CR: 0.0023

Step 7. Super-matrix formation

The super-matrix allows for a resolution of interdependencies that exist among the elements of a system. It is a partitioned matrix where each sub-matrix is composed of a set of relationships between and within the levels as represented by the decision-maker's model. In the next step, the super matrix M is made to converge to acquire a long-term stable set of weights. For convergence to occur, the super matrix needs to be column stochastic, which means the sum of each column of the super matrix must be one. This was done utilizing Superdecisions software (www.superdecisions.com).

Step 8. Selection of the best alternative

This step provides the results of synthesizing the whole model. Table 6 represents the priorities of different supplier alternative with respect to the goal. It is evident that according to the framework Supplier B is the most preferred supplier for the supply chain to achieve sustainability. Supplier A and Supplier C are very close in their priorities.

Table 6: Priorities of the three alternatives

Alternative	Normal	Ideal
Supplier A	0.297351	0.726939
Supplier B	0.409046	1.000000
Supplier C	0.293602	0.717774

VI. CONCLUSIONS

This study proposed an integrated 3BL and ANP approach for supplier selection for a sustainable supply chain. The proposed approach evaluates alternative suppliers', in terms of economic, social, and environmental dimensions. The case of a steel manufacturer was presented for the illustration of the proposed approach. One of the major contribution of the approach is the consideration of interdependency among the dimensions and enablers. This was effectively employed for producing the priorities of the alternative suppliers'.

Although the supplier selection problem is not new and there are numerous studies and models available in literature, the novelty of the proposed model lies in its consideration of the three critical dimensions of sustainability simultaneously to arrive at a decision. Traditionally, supplier selection is based on variables such as cost, quality, lead time, and on-time delivery all of which are part of only the economic dimension. But the demand of sustainability requires improvements on the other two dimensions of social responsibility and environmental performance as well. The proposed framework thus moves from a singular focus to a multi-dimensional focus with the consideration that suppliers' are critical to improve overall performance in all dimensions of sustainability.

The 3BL-ANP approach illustrated in this research has a few limitations as well. For example, the enablers included under each dimension of sustainability are by no means exhaustive or fixed. Certain other enablers can be added and the model can be customized depending on the impact these factors have on overall priorities. Also as the proposed model was tested for a steel manufacturer, further refinements can be brought by evaluating the model in other settings such as automobile segment or computer hardware manufacturers.

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APPPENDIX 'A'

3BL AND ANP BASED FRAMEWORK FOR SUPPLIER SELECTION FOR A STEEL MANUFACTURER