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CSR and Environmental Criteria in Supplier Selection

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Abstract. The supplier selection issue in today's world does not simply depend on price anymore. Other non-price criteria such as quality, delivery and overall capability are gradually gaining equal importance. Because of the globalization of trade, the world is becoming an increasingly open and global marketplace where the intense competition is urging companies to reduce the cost and development time of a new product. Companies are forced to take every possible factor into consideration when making the strategic decision to minimize costs and product development time. That means besides taking price into consideration, companies now also has to assess the overall capability of the suppliers, such as production capability, technological capability, company reputation and other factors that are hard to be quantified, in order to make the most informed decision to strive for a balance between lowering profits and rising costs. Different companies have their own ways in carrying out the supplier selection process that aligns with their corporate strategy. This paper is interested in what criteria are used in supplier evaluation and the ranking of the criteria importance. In particular, the focus is the incorporation of corporate social responsibility (CSR) and environmental responsibility (ER) requirements into supplier selection. With the increasing awareness of CSR and ER, large international corporations have been paying more attention in selecting suppliers that are capable of adhering to the practice of sustainability. Hence, this paper aims to find out what criteria or performance indicators are adopted by companies to assess their suppliers, and how much importance CSR and ER contributes to the final decision of the selected supplier. A multi-agent system is implemented with a multi criteria decision making model to incorporate the criteria identified for evaluating supplier performance and selecting the most suitable supplier.

Keywords: Supplier selection; Corporate social responsibility; Environmental responsibility; Multi-agent system; Multi criteria decision making

1. INTRODUCTION

Within a supply chain network, supply chain partners share skills, resources, costs and benefits to achieve market opportunities and gain more value for products and services. Naturally, identifying the appropriate collaborative partners is a vital prerequisite and contributor to the success of a supply chain.

Supplier selection in procurement is one of the most studied problems in supply chain management. Many criteria have been identified in supplier evaluation and selection for a supply chain. In general, the supplier selection problem involves multiple criteria including attractive price, high quality, in time delivery, perfect post-sale service and so on.

Because of the globalization of trade, the world is becoming an increasingly open and competitive global marketplace. Companies are under tremendous pressure to reduce the cost and development time of new products. Many companies find it necessary to allocate more resources in outsourcing in order to become more competent in cost, core competence, and activity specializations. They are forced to take every possible factor into consideration when making the strategic decision to minimize costs and product development time. That means besides taking the traditional criteria such as price and quality into consideration, companies now also has to assess the overall capability of the suppliers, such as production capability, technological capability, company reputation and other factors that are hard to be quantified, in order to make the most informed decision to strive for a balance between lowering profits and rising costs.

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Different companies have their own ways in carrying out the supplier selection process that aligns with their corporate strategy. This paper is interested in the establishment of a supplier selection model. In particular, the focus is the incorporation of corporate social responsibility (CSR) and environmental responsibility (ER) requirements into supplier selection. With the increasing awareness of CSR and ER, large international corporations have been paying more attention in selecting suppliers that are capable of adhering to the practice of sustainability. Hence, this paper aims to find out what criteria or performance indicators are adopted by companies to assess their suppliers, and how much importance CSR and ER contributes to the final decision of the selected supplier.

2. RELATED WORK

With the proliferation of outsourcing in the global business environment, the supplier and supply chain partner selection problem has attracted more and more attention from researchers in supply chain management. Be that as it may, price is still steering the final decision to which supplier should be chosen. However, the lowest bid price may not always be a good indicator of the most suitable supplier because suppliers using a discounted price to win the bid often have difficulties in maintaining the quality at such low price in long term. This would only result in sabotage of the product quality and the buyer-supplier relationship. Companies today are able to foresee these risks, thus they feel the need to consider the overall capability of suppliers in their supplier selection procedure. In this regard, researchers have attempted the supplier chain partner selection problem with optimization algorithms, with the consideration that price is not the only criterion in partner selection problem. Thus, supplier selection problem can be modelled as a multiple attribute decision making (MADM) problem that involves assessing trade-offs between conflicting criteria.

With the proliferation of environmental concerns and regulations, it has been recognized that it is important to strike a balance between the environmental/sustainability issues and industrial/economic development. Governments and enterprises have begun to include sustainability requirements in the design, manufacture and consumption of products.

2.1 Selection Criteria

In consideration of the criteria for supplier selection, the pioneer work by Dickson (1996) has been one of the most cited studies. He conducted a questionnaire survey to purchasing agents and managers of 273 of US companies to identify the important factors for vendor selection participated in the survey. Among the 23 criteria identified for vendor selection, the product quality was ranked as most important, it was followed by on-time delivery, performance history of supplier and warranties and claimed policies, and so on. Price was not a consistently important factor, it only ranked at the 6th place among the 23 criteria.

According to the literature survey by Weber et al. (1991), which reviewed 74 academic articles published between 1966 and 1990, rankings of the 23 criteria as listed in Dickson (1996) had changed. Price, which was only ranked at 6th (considerable importance) in Dickson's 1966 study, was ranked as the most important fact as it was recognized as the mostly discussed criterion in 79% of the papers reviewed in this survey. In the 2nd and 3rd places were, respectively, delivery and quality. Besides, production facilities and capability, geographical location and technical capability also showed increasing importance. It illustrated that while Dickson's (Dickson, 1966) 23 criteria still covered most of the criteria presented in academic literature, the evolution of the industrial and global trade environment had modified the degrees of importance of these criteria.

Cheraghi et al. (2004) extended the findings of Webber et al. (1991) to encompass research on the supplier selection published between 1990 and 2001, altogether 113 articles were reviewed. Interestingly, the top 5 ranked criteria were quality, delivery, price, repair service, technical capability. Their result revealed that increased competition and globalization of market facilitated by Internet-based technologies had combined to dramatically change the ranking of factors. In addition, new criteria had to be added. They concluded that supplier selection criteria would continue to change based on an expanded definition of excellence to include traditional aspects of performance (quality, delivery, price, service) in addition to non-traditional, evolving ones (JIT communication, process improvement, supply chain management).

2.2 Sustainability and CSR factors

With the increasing awareness of social and environmental responsibilities in recent years, companies are required to integrate both of them into their manufacturing and purchasing decisions in addition to the traditional criteria. Many companies have begun to consider new type of supplier selection criteria such as carbon emission in green requirements and CSR compliance. The conflict of environment and product manufacturing and consumption is fundamental. Introducing CSR and environmental criteria into the supply chain brings in a new set of trade-offs, with qualitative and quantitative factors, which would complicate the supplier selection decision.

Although researchers have listed different criteria and presented different mathematical approaches to evaluate and select vendors, the research that concerns environmental and CSR issues is still rather limited. Many companies follow one or more common Environmental management system (EMS) criteria when determining their environmental supply chain partner selection criteria. Commonly adopted EMS include ISO 14000 series, REACH, RoHS, and WEEE, etc. Regarding CSR requirements, there are a wide range of codes and standards, for instance, International Labor Organization (ILO) Convention, the UN Global Compact, OECD Guidelines for Multinational Enterprise, Social Accountability 8000, and ISO 26000.

Besides, enterprises are also required to follow their supply chain partners' self-developed CSR and environmental standards, as well as the local environmental management laws and regulations in their partners' regions and countries.

Noci (1997) proposed four major evaluation criteria for the proactive green strategy of an organization in the supplier selection process. They were Green Competence, Current Environmental Efficiency, Supplier's Green Image, and Net Life Cycle Cost.

Handfield et al. (2002) identified 5 requirements that environmental criteria should meet. Measures should be able to minimize waste and impact on the environment and relatively easy to assess, easy to modify, the system should consider multiple attributes simultaneously. According to these requirements, environmental criteria were categorized into six attributes, namely Packaging/Reverse Logistics, Environmental Programs at Supplier's facilities, Product Attributes, Labeling/Certification, Compliance to Government Regulation, and Waste Management.

Humphreys et al. (2003) identified seven environmental categories, as follows: Environmental Costs (pollutant effects), Environmental Costs (improvement), Management Competencies, Green Image, Design for Environment, Environmental Management Systems, and Environmental competencies.

Lu et al. (2007) identified that materials, energy use, solid residue, liquid residue, gaseous residue, and technology are very important environmental criteria in five lifecycle stages (pre-manufacturing, manufacturing, distribution/packaging, use/maintenance and end-of-life stages).

Tuzkaya et al. (2009) identified 6 major criteria: "Pollution Control", "Environmental and legislative management", "Green Product", "Green Image", "Environmental costs", and "Green Process management". Lee et al. (2009), similarly, defined 6 major criteria: "Quality", "Technology capability", "Pollution control", "Environment management", "Green Product", "Green Competence" with comprehensive sub-criteria for evaluation of supplier's environmental performance.

Awasthi et al. (2010) proposed 12 environmental criteria: Use of environmental friendly technology, Use of environmental friendly material, Green market share, Partnership with green organization, Management commitment, Adherence to environmental policies, Green R&D projects, Staff Training, Lean process planning, Design for environment, Environment certification, and Pollution control initiatives.

Baskaran et al. (2011) proposed criteria for social responsibility, for instance, Discrimination, Abuse of human rights, Child labor, long working hours, and society/ unfair competition. Kuo et al. (2010) used Delphi method to identify supplier selection criteria that have six dimensions including "Quality," "Cost," "Delivery," "Service," "Environment", and "Corporate social responsibility". Buyukozkan et al. (2011) also integrated a dimension of social responsibility with environmental responsibility and economical performance.

Hsu et al. (2011) developed a model to establish the casual relationship of 13 carbon management criteria and identified the key criteria influencing the supplier selection. It helps companies to identify which areas of carbon management can be improved.

Tseng (2011) developed the criteria based on the perspective of a company's green management and there were 10 out of 16 criteria considering environmental responsibility (Green Technology Capabilities, Green Purchasing Capabilities, Green Design, Life Cycle Assessment, Internal Green Production Plans, Green Production, Green Certificates, the Reduction of Hazardous Materials in the Production Process, and Environmental Management Systems).

Shaw et al. (2012) used a combined approach of fuzzy-AHP and fuzzy multi-objective linear programming to integrate greenhouse gas emission as a constraint while selecting a supplier with traditional criteria (cost, quality rejection percentage, late delivery percentage and demand).

Wang et al. (2012) proposed an ontological agent-based platform to establish an ecological virtual enterprise (VE). In the selection of VE partners (i.e. suppliers), the VE initiator would like to incorporate environmental criteria as well, in addition to the general supplier selection criteria such as price, quantity, lead time, etc. The environmental criteria may include factors such as environmental management, green image, green product and pollution control. The complete set of selection criteria, including the environmental criteria, can be categorised as quantitative or qualitative. While quantitative criteria are measured by numerical values, qualitative criteria are expressed by linguistic descriptions.

2.3 Multi-Criteria Decision Making

As so many criteria have been identified in supplier evaluation and selection, the selection of suppliers can be viewed as a multi-criteria decision making (MCDM) problem. There are some popular MCDM methods, for example, optimization method, AHP method, ELECTRE method, Cluster analysis (CA), and TOPSIS method (Aissaoui, Haouari, & Hassini, 2007; Ho, Xu, & Dey, 2010; Wallenius et al., 2008). Optimization method is used to select the optimal alternative. It is suitable for selecting optimal partners in final selection phase rather than ranking all interested partners in pre-selection phase. AHP method is popular in MCDM problem, but when the number of interested partners is large, a lot of pairwise work should be done, and when a new interested partner enters, the pairwise work need to be redone from beginning. ELECTRE method is a non-compensatory method and a lot of pairwise work should be done when the number of interested partners is large. In addition, CA is used to group the interested partners with similar attributes rather than rank all interested partners. TOPSIS is a rank method that is easy to understand and implement. Moreover, it allows the straight linguistic definition of weights and rating under each criterion, without of need of cumbersome pairwise comparisons and the risk of inconsistencies (Bottani & Rizzi, 2006).

3. PRELIMINARY SET OF SUPPLIER SELECTION CRITERIA

This section introduces the preliminary set of supplier selection criteria with the incorporation of ER and CSR issues. Our approach to establish the list of criteria involved two elements. First, a literature review was carried out to collect supplier selection criteria from academic publications. Subsequently, interviews were conducted with purchasing professionals to consolidate the relevant set of selection criteria.

In the first place, the literature survey was conducted to involve collection of supplier selection criteria from relevant academic literature published in major journals covering purchasing and supply chain management. Relevant articles from the last 21 years (1990-2011) were reviewed to compare with the criteria list first defined by Dickson (Dickson, 1966). Finally, 40 articles were found to be more relevant to our scope that qualitative, quantitative, CSR and ER criteria were included in their articles.

The second element of our approach involved interviews with purchasing managers and representatives in the manufacturing industry. The purpose was to make use the kind of Delphi study to invite small groups of industry experts to identify the relevance of the various selection criteria. So far, three groups of experts have been involved : (i) a field study and survey was carried out towards 19 companies located in Liaoning and Jilin provinces in China; (ii) a small group of six Hong Kong-based purchasing representatives of three multinational manufacturing firms were invited to provide information on the existing practices of evaluating supplier selection criteria and incorporating CSR requirements into supplier selection; and (iii) 7 electrical and electronics enterprises having operations in China's Pearl River Delta (PRD) region were invited to identify the relevant supplier selection criteria, including environmental and CSR requirements, for purchasing items.

As a result, a set of 21 criteria are identified for supply chain partner selection in the local manufacturing industry.

The criteria are categorized into three groups: General criteria, corporate social responsibility related, and Environmental responsibility related criteria. With regard to the product life cycle, the different criteria are geared to the various phases of product phase, i.e. product phase, design phase, production phase, and end-of-life phase.

Definitions of each issue (criterion) and reasons of picking these criteria are given. Negotiation space and Related Issues, if possible, are described in each criterion.

3.1 General Criteria

This category includes general criteria describing the basic characteristics of the finished goods, including Product Price, Quality, Delivery, and Reserved Capacity.

Product Price: it refers to the supplier's bidding price of the product.

Quality: it refers to the conformance and reliability of product.

Delivery: Delivery refers to the required day that the ordered product will arrive at the door of buying organization.

Reserved Production Capacity: it refers to the supplier that reserves an amount of production capacity to respond sudden change in demand.

3.2 Criteria related to CSR

The pressure exerted on companies to practice corporate social responsibility comes from both internal and external stakeholders such as customers, employees, unions, shareholders, business partners, governments, NGOs and the media. Several related criteria are identified to evaluate suppliers' corporate social responsibility practices.

Discrimination: The treatment of supplier's labor should not be based on their membership in a certain group or category

Occupational Health and Safety: relates to the concerns the labor safety and their health including both the physical and mental health. It could include the ergonomic, safety measure, and other instruments that ensure the labor safety.

Child Labors and Rights: refers to the employment of children in any work that deprives children of their childhood, interferes with their ability to attend regular school, and that is mentally, physically, socially or morally dangerous and harmful.

Internal Training Program: refers to the training that is given inside the company, rather than trainings given by external training program or seminars.

3.3 Criteria related to Environmental Responsibility

The following environmental criteria are related to the design phase of the product life cycle.

Material Selection: refers to the appropriate material that contributes to product functionality and minimizes environmental impact. Commonly used material is considered, such as Aluminum, Copper, Iron and Steel, Lead, Zinc, Plastics and so on.

Design for Process: refers to the chosen manufacturing method that generates the least pollutant emissions.

Design for Disassembly: refers to designing a product that is easier to be disassembled to component status through selecting the right material, altering the product architecture (Modular Design), and use of fastener.

Design for Recycling and Reuse: allows a used product to be disassembled into components for recycling and reuse.

Packaging: refers to the packaging used for protecting the product. Commonly used packaging material are various, for instance, Corrugated Fiberboard, Recycle and Remolded HDPE, Chipboard, Paper Dunnage/ Wraps, Molded Starch Peanuts in Bags, Padded 100% Packaging Paper Bags, Suspension Style Packaging, EPU (Polyurethane Foam), Plywood Crates, Wooden Pallets, EPS (Polystyrene Foam), EPE (Polyethylene Foam), EPP (Polypropylene Foam), Plastic Bubble Wrap, Stretch/ Shrink Wrap or Bags, Pressure Sensitive Tape, Corrugated Plastic, Commingled Foam/ Corrugate, Commingled Foam/ Wood, ESD Static Shielding Bags, Foam-in-place, Foam in bag, Padded bags with plastic bubble core, PVC Plastics, and Foams with CFCs/ HCFCs.

The following criteria are related to the production phase of the product life cycle.

Greenhouse Gases Emission: Greenhouse Gases (GHG) Emission includes the by-product in the manufacturing process such as CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. They are unified into CO_2 equivalent.

Air Pollution: Air Pollution refers to the gases emission such as NO_x, SO_x, and VOCs.

Waterborne Pollution: Waterborne Pollution refers to the pollutant emitted that affects the water system, e.g. Chemical oxygen demand, Ammonia, Sulfur dioxide, and Nitrogen

Waste: Waste refers to the waste that are not appropriate to be recycled and disposal is the only treatment method.

Energy Consumption: Energy Consumption refers to the consumption of energy or power, in the form of electricity. Conventional and Renewable energy source are included, e.g. fossil fuel, solar, wind, tides, and etc.

The following criteria are geared to the End-of-Life phase in the product life cycle.

Disposal: Disposal refers to the content of product that is unable to be recycled and reused in the service provider's site. This content will be ultimately transported to landfill.

Recycle Rate: Recycle Rate refers to the percentage of product unit to be collected and recycled by the service provider.

Reuse Rate: Reuse Rate refers to the percentage of reused product without significant repair and refurbishment.

Figure 1 depicts the categorization of the 21 Criteria.

4. THE PROPOSED SELECTION MODEL

In today's global supply chain scenario, it is quite common to have a large number of interested suppliers. It will then be rather complex for the purchasing company to make use of the diverse number of supplier selection criteria to evaluate a large number of initial bids from the various interested sellers. A two-stage supplier evaluation and selection model is therefore proposed in this study. The first stage is a pre-selection process is conducted to screen a smaller number of potential suppliers from the large set of interested suppliers; the selected potential suppliers and the purchasing company will engage in the negotiation-based final selection in the second stage. The complete process is to be implemented in a multi-agent system (MAS).

4.1 MAS framework

In this proposed project, a prototype MAS framework will be designed and developed to model the supplier selection model. The MAS will incorporate two categories of agents, functional agents and information agents. Functional agents are the type of agents representing the various functions in the supply chain. They usually belong to different organization units or departments. In this

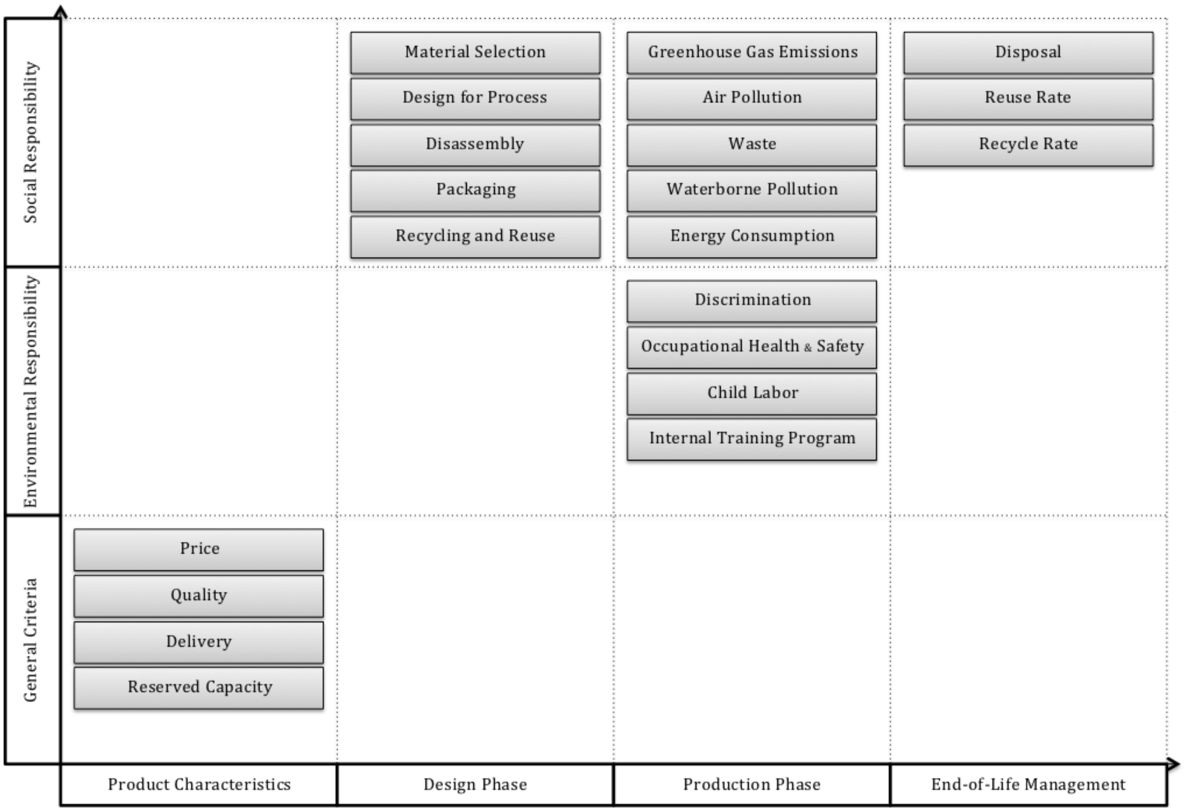

Figure 1: The categorization of 21 defined criteria

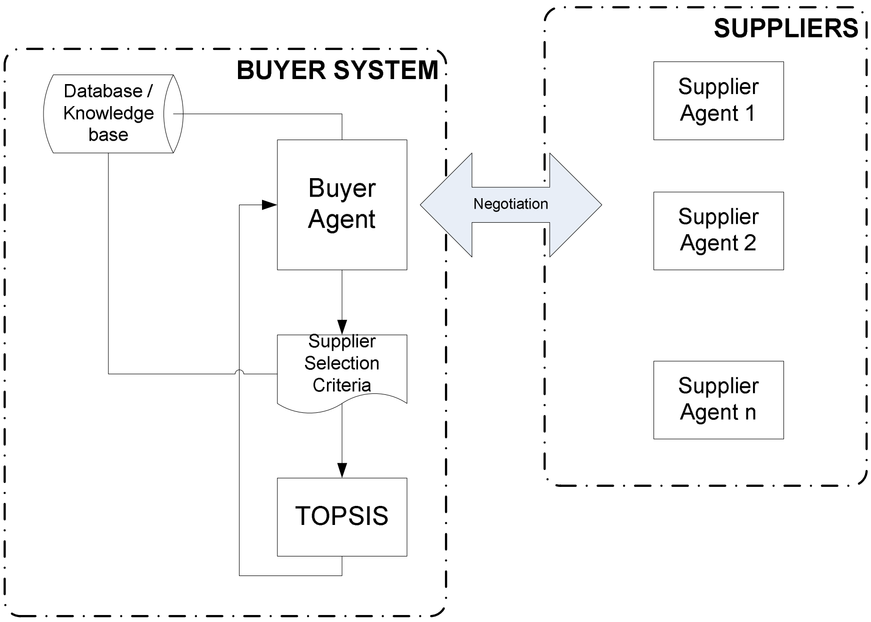

Figure 2: Main structure of the MAS

research, typical functional agents are the buyer agents and seller agents representing the buyers and sellers of the supply chain. On the other hand, information agents do not belong to particular functions or organization units. They have to represent different categories of information and data, regarding the partner companies, products, schedules, and so on. In addition, there will be a group of information agents to deal with the specific knowledge and data relevant to CSR and ER impacts of individual supply chain partners. The main structure of the MAS adopted in this paper is depicted in the Figure 2.

4.2 Pre-selection based on TOPSIS

In comparison with other MCDM methods such as MAUT, AHP, ELECTRE et al., the TOPSIS (technique for order preference by similarity to an ideal solution) is a rank method that is easy to understand and implement. The TOPSIS method considers both positive-ideal and negative-ideal solutions, and can rank alternatives based on the actual situations of candidate alternatives. In addition, the TOPSIS method allows the straight linguistic definition of weights and rating under each criterion, without the need of cumbersome pairwise comparisons and the risk of inconsistencies as in other method such as AHP. In this study, the TOPSIS method is adopted in the supplier pre-selection process to rank the interested suppliers and form a shortlist of qualified and competitive potential suppliers for future final selection process.

The TOPSIS method was firstly developed by Hwang et al. (1981) for solving the MCDM problem. It is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS).

Assume there are n criteria and m alternatives (suppliers), the decision matrix $(D)=(x_{ij})$, where x_{ij} represents the rating of m alternatives by n criteria.

$$D=\begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \quad (1)$$

Step 1: Normalized the Decision matrix and obtain a normalized decision matrix (R) by following equation:

$$r_{mn}=\frac{x_{mn}}{\sqrt{\sum_1^m x_{mn}^2}}, m=1,2,...,M \ \& \ n=1,2,...N \quad (2)$$

$$R=\begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} \quad (3)$$

Step 2: Obtained the weighting, denoted as $W=(w_1,w_2,\ldots,w_n)$ and weighted normalized decision matrix (V) is as follows:

$$V=\begin{pmatrix} w_1 r_{11} & \cdots & w_1 r_{1n} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & \cdots & w_1 r_{mn} \end{pmatrix} \quad (4)$$

Step 3: Determine the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS):

$A_n^*=\{v_1^*,v_2^*,...,v_m^*\}$ find the PIS of the n criteria by taking the maximum value for desirable criteria, or by taking the minimum values for non-desirable criteria.

$A_n^-=\{v_1^-,v_2^-,...,v_m^-\}$ find the NIS of the n criteria by taking the minimum value for desirable criteria, or by taking the maximum values for non-desirable criteria.

Step 4: Calculate the Euclidean Distance of each alternative from PIS and NIS:

$$d_m^*=\sqrt{\sum_{n=1}^{N}(v_{mn}-v_n^*)^2}, m=1,2,...M \quad (5)$$

$$d_m^-=\sqrt{\sum_{n=1}^{N}(v_{mn}-v_n^-)^2}, m=1,2,...M \quad (6)$$

Step 5: Estimate the closeness coefficient of each alternative (supplier):

$$C_m=\frac{d_m^-}{d_m^*+d_m^-}, m=1,2,...,M \quad (7)$$

Step 6: Rank the supplier and select the alternative (supplier) with highest value of C_m.

As an illustrative example, assuming that after the agent negotiation phase, the negotiation results with suppliers, represented by S1, S2 and S3 are converted to the decision matrix (D), as shown in Table 1. The normalized matrix (R) is weighted into Weighted normalized decision matrix (V), assuming that each criterion has equal importance (weighting) in this example. Accordingly, the

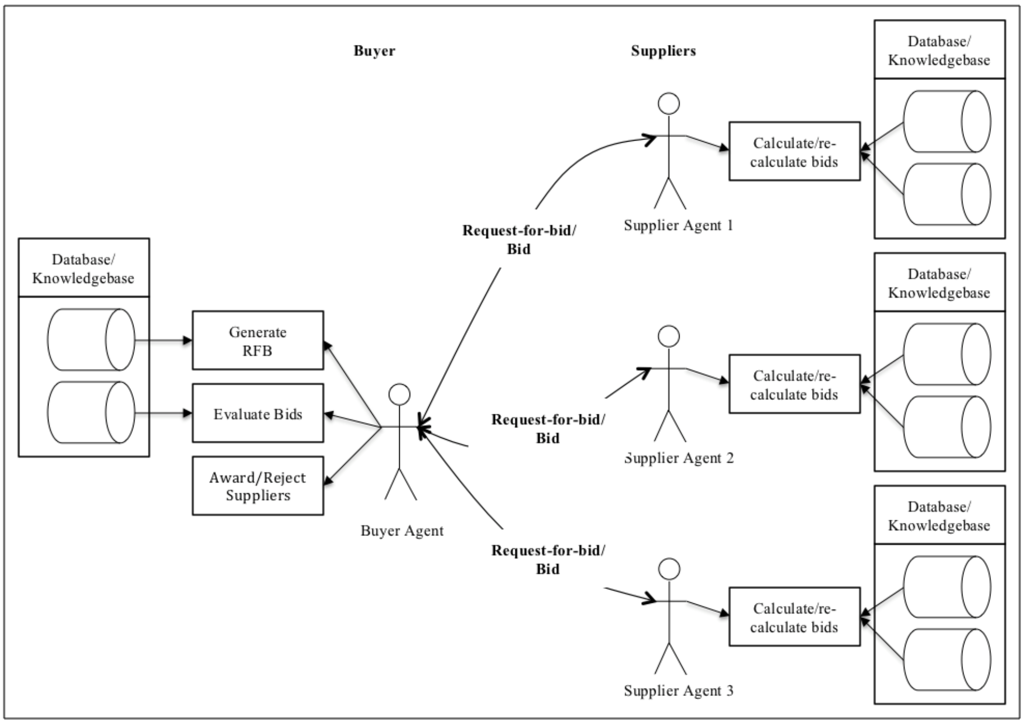

Figure 3: Use case diagram of buyer-seller negotiation

Table 1: Initial Data for supplier selection

N.	Criteria	S1	S2	S3	Per product
1	Price	78	65	80	USD
2	Quality	1	1	1	Binary (Yes /No)
3	Delivery	14	15	13	Delivery days
4	Reserved Capacity	6000	6500	6500	Reserved Quantity of a product
5	Discrimination	0.8	0.6	0.8	Linguistic Rating
6	Occupational Health & Safety	0.8	0.8	1	Linguistic Rating
7	Child Labor	0.6	0.6	0.8	Linguistic Rating
8	Internal Training Program	0.8	0.6	0.6	Linguistic Rating
9	Material Selection	0.4	0.6	0.8	Linguistic Rating
10	Design for Process	0.8	0.6	0.8	Linguistic Rating
11	Disassembly	0.6	0.8	0.6	Linguistic Rating
12	Packaging	0.8	1	1	Linguistic Rating
13	Recycling and Reuse	0.6	0.6	0.8	Linguistic Rating
14	Greenhouse Gas Emissions	45	55	42	CO2e
15	Air Pollution	4.3	4.2	4.1	Air Volume in m3
16	Waste	6600	6500	5000	Chemical Oxygen Demand (mg/L)
17	Waterborne Pollution	320	350	330	Polluted Water in gram
18	Energy Consumption	5500	5400	5400	KJ in the life cycle
19	Disposal	140	130	130	Content not be recycled in gram
20	Reuse Rate	0.6	0.55	0.65	%
21	Recycle Rate	0.32	0.3	0.4	%

Table 2: Normalized matrix (R), Weighted normalized matrix (V), and PIS & NIS

N.	Criteria	Normalized (1)			Weighted (2)			(3)		
		S1	S2	S3	S1	S2	S3	1/0	PIS	NIS
1	Price	0.603	0.503	0.619	0.029	0.024	0.029	0	0.024	0.029
2	Quality	1.000	1.000	1.000	0.048	0.048	0.048	1	0.048	0.048
3	Delivery	0.576	0.618	0.535	0.027	0.029	0.025	0	0.025	0.029
4	Reserved Capacity	0.547	0.592	0.592	0.026	0.028	0.028	1	0.028	0.026
5	Discrimination	0.800	0.600	0.800	0.038	0.029	0.038	1	0.038	0.029
6	Occupational H&S	0.800	0.800	1.000	0.038	0.038	0.048	1	0.048	0.038
7	Child Labor	0.600	0.600	0.800	0.029	0.029	0.038	1	0.038	0.029
8	Internal Training Pgm.	0.800	0.600	0.600	0.038	0.029	0.029	1	0.038	0.029
9	Material Selection	0.400	0.600	0.800	0.019	0.029	0.038	1	0.038	0.019
10	Design for Process	0.800	0.600	0.800	0.038	0.029	0.038	1	0.038	0.029
11	Disassembly	0.600	0.800	0.600	0.029	0.038	0.029	1	0.038	0.029
12	Packaging	0.800	1.000	1.000	0.038	0.048	0.048	1	0.048	0.038
13	Recycling and Reuse	0.600	0.600	0.800	0.029	0.029	0.038	1	0.038	0.029
14	GHG Emissions	0.545	0.666	0.509	0.026	0.032	0.024	0	0.024	0.032
15	Air Pollution	0.591	0.577	0.563	0.028	0.027	0.027	0	0.027	0.028
16	Waste	0.627	0.617	0.475	0.030	0.029	0.023	0	0.023	0.030
17	Waterborne Pollution	0.554	0.606	0.571	0.026	0.029	0.027	0	0.026	0.029
18	Energy Consumption	0.584	0.574	0.574	0.028	0.027	0.027	0	0.027	0.028
19	Disposal	0.606	0.563	0.563	0.029	0.027	0.027	0	0.027	0.029
20	Reuse Rate	0.600	0.550	0.650	0.029	0.026	0.031	1	0.031	0.026
21	Recycle Rate	0.320	0.300	0.400	0.015	0.014	0.019	1	0.019	0.014

Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) of S1, S2 and S3 are determined, where 0 represents not desirable criteria, and 1 vice versa. Table 2 shows the results of step 1-3.

The Euclidean Distances of each supplier are calculated (Table 3) and the closeness coefficients of each supplier are estimated, as shown in Table 4.

Table 3: Euclidean Distance of Suppliers

Supplier	d_m^*			d_m		
	S1	S2	S3	S1	S2	S3
Total	0.030	0.028	0.015	0.018	0.018	0.033

The ranking of suppliers is S3 > S2 > S1. Thus, S3 has the highest preference and is the most appropriate supplier in the example.

Table 4: Closeness coefficients and Supplier's ranking

Supplier	S1	S2	S3
C_m	0.371	0.384	0.694
Ranking	3	2	1

4.3 Negotiation-based Final Selection

The partner selection problem will be abstracted as a buyer-seller relationship in the MAS. The buyer agent represents the buyer and the potential suppliers are represented by the seller agents. Partner selection is to be effected through agent negotiation. In this regard, the buyer agent has to negotiate with a number of seller agents until the optimum choice of supplier(s) can be sought. Hence, agent negotiations in the proposed model are to be represented by one-to-many negotiations on multiple interdependent issues. The use case diagram in Figure 3 represents the negotiation-based final selection model. As in any supply chain, supply chain partner selection will involve the purchasing company's preferred set of criteria including price, delivery, quality and so on. In this study, the set of 21 criteria, including general, ER and CSR issues, are to be involved. Inter-dependences between the various criteria will also be considered. Accordingly, a multi-issue utility function will then be established for green supply chain partner evaluation and selection. In most of the MAS-based SCM studies, simply linear utility functions are commonly established in the negotiation model. Due to the more complex inter-dependences in the green supply chain, a non-linear utility function will be established in this research.

5. CONCLUDING REMARK

This paper is on the identification of supplier selection criteria with the incorporation of corporate social responsibility (CSR) and environmental responsibility (ER) requirements. The aim is to find out what criteria or performance indicators are adopted by companies to assess their suppliers, and how much importance CSR and ER contributes to the final decision of the selected supplier.

Based on literature survey and solicitation of expert opinion with a Delphi-like method, a set of 21 criteria are identified for supply chain partner selection in the local manufacturing industry. The criteria are categorized into three groups: General criteria, corporate social responsibility related criteria, and Environmental responsibility related criteria.

A multi agent system model is to be implemented to incorporate the criteria identified for evaluating supplier performance and selecting the most suitable supplier. The MAS will be equipped with a two-stage supplier evaluation and selection model. The first stage is a pre-selection process is conducted to screen a smaller number of potential suppliers from the large set of interested suppliers; the selected potential suppliers and the purchasing company will engage in the negotiation-based final selection in the second stage.

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