Employing dynamic fuzzy membership functions to assess environmental performance in the supplier selection process

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The development of this system is intended to illustrate that a fuzzy system can aid management in assessing a supplier's environmental performance in the supplier selection process. A user-centred hierarchical system employing scalable fuzzy membership functions implement human priorities in the supplier selection process, with particular focus on supplier's environmental performance. Traditionally, when evaluating supplier performance, companies have considered criteria such as price, quality, flexibility etc. These criteria are of varying importance to individual companies pertaining to their own specific objectives. However, with environmental pressures increasing, many companies have begun to give more attention to environmental issues and in particular their suppliers' environmental performance. The framework presented in this paper was developed to efficiently introduce environmental criteria into the existing supplier selection process and reflect its relevant importance to individual companies. The system presented attempts to simulate the human preference given to particular supplier selection criteria with particular focus on environmental issues when considering supplier selection. The system considers environmental data from multiple aspects of a suppliers business, and based on the relevant impact this will have on a Buying Organisation, a decision is reached on the suitability of the supplier. This enables a particular supplier's strengths and weaknesses to be considered as well as considering their significance and relevance to the Buying Organisation.

1. Introduction

Pressure from governments, institutions and consumers (McAleer et al 2000) has forced many companies to improve their environmental performance (Azzone and Bertele 1994, Azzone et al 1997). Over the last number of years, organisations have responded by implementing a number of programmes. Firstly, managers introduced end-of-pipe initiatives aimed at reducing emissions, waste and energy consumption (Hunt and Auster

1990). At the end of the 1980s, clean technologies were introduced along with programmes for reducing the environmental impact of key steps in the production process (Welford and Gouldson 1993). At the beginning of the 1990s, enterprises changed their operating procedures and introduced eco-auditing frameworks for modifying products and services (Franke 1995). Organisations are facing a fourth phase in which environmentally conscious firms, mainly large companies, are developing environmental programmes aimed at organising their supply chains (Gupta 1995). A survey of purchasing trends indicated that these programmes have a significant role to play in developing an organisation's environmental policy (Carter and Narasimhan 1996). This is supported by (The UK Round Table on Sustainable Development 1997) which recommends that: ‘All organisations – but especially large companies and public sector organisations – should use procurement as a way of encouraging those in the supply chain to improve environmental performance’. It is now widely acknowledged that environmental issues must be considered as strategic in a growing number of industries because of market pressures and the threat of environmental regulations (Welford and Gouldson 1993, Murphy and Gouldson 2000).

A methodology for supplier selection based on fuzzy logic is presented. The system employs scalable fuzzy membership functions that implement human priorities in the supplier selection process. Fuzzy logic provides a method by which human reasoning can be emulated and decisions can be made with vague and imprecise information. The manipulation of the magnitude of the fuzzy membership functions enables the authors to employ human priorities on the system to varying degrees and at varying stages of the decision-making process. A hierarchical fuzzy system is presented that considers all supplier selection factors and their degree of importance to the supplier selection process. The hierarchical fuzzy system presented in this paper enables the user to implement preference and priorities at varying levels on the system. This facilitates the creation of a suitable system for the user. The system reflects the focal organisation’s requirements in the supplier selection process. The user is prompted to identify in linguistic terms the priorities they have for various supplier selection factors, and the priorities they have for the contributing sub-factors. These priorities are manifested within the fuzzy logic system (FLS) as scaling factors for the membership functions of each input in the hierarchical FLS. Hence, a robust system that reflects the preferences of the focal organisation’s human decision-making process is constructed. A detailed analysis of the environmental sub-system is performed, and results obtained from this system are presented.

2. Decision-making methodologies

Knowledge-based or expert systems have been employed extensively to decision-making problems in numerous industries. However these systems suffer from several practical disadvantages to their implementation. They are time-consuming and laborious to create since every eventuality that could occur has to be mapped out in advance, only then do they have any degree of flexibility. Human experts often make seemingly simple decisions that are difficult to implement in expert systems. Of the many other decision-making methodologies that have been implemented for supplier selection, two methodologies are the most common. These are namely, the analytic hierarchy process (AHP) (Saaty, 1980) and the multi-attribute utility theory (MAUT) (von Neumann & Morganstern, 1944).

The AHP involves the pair-wise comparison of criteria. The mathematical rigor of this technique has been called into question by some researchers (Belton & Gear, 1984). The problem with AHP known as the ‘rank reversal problem’ occurs when the addition new criteria can alter classification of all candidates.

The MAUT is restricted to quantitative data and relies on pre-defined levels for attributes (Bevilacqua, 2002). This technique is claimed to be the most objective of conventional decision-making methodologies (Bevilacqua, 2002). The utility theory works by aggregating the utility of an event with the probability of a particular resource allocation being successful. Neither of these methodologies can be considered as generic in the sense that they need to be developed for each individual supplier selection task, for example in tuning the pre-defined levels for criteria with the case of MAUT or in the classification by AHP when changing criteria.

This paper outlines the development of a generic fuzzy hierarchy, which with a few minor adjustments of scaling factors, could be used to select suppliers for any type of business. Even structural changes to the fuzzy hierarchy such as ignoring certain criteria are possible, by simply setting scaling factors for membership functions to zero. There are in addition some very persuasive reasons for using fuzzy logic in decision-making tasks:

1. **Higher level of knowledge representation:** fuzzy models encode expert knowledge in a way much akin to the way an expert can verbalise their expertise. This is facilitated by the fact that fuzzy rules are defined in terms of linguistic variables e.g. low, high, excessive, reduced etc.
2. **Multiple expert handling:** fuzzy models can cope with multiple conflicting, cooperating and collaborating experts (Cox, 1992). Conversely, conventional expert systems are unable to handle directly opposing views (Cox, 1992).

3. **Highly complex modelling capability:** fuzzy logic systems are universal approximators (Kreinovich, 1998) meaning that given sufficient rules, appropriate training, appropriate membership functions, sufficient data etc, they can handle any linear or non-linear problem to an arbitrary degree of accuracy. The intrinsic non-linearity of many outwardly simple business problems has led to the general failure of conventional expert systems (Cox, 1992).

3. Supplier selection process

Historically, several methodologies have been developed for evaluating, selecting and monitoring potential suppliers (Ellram 1987, Weber et al 1991) that take into account factors dealing with, for example, quality, logistics and cost. However, none of these methodologies have considered the importance of environmental factors, such as life cycle analysis or design for environment in the decision-making process. Further evidence collected by (Birou and Fawcett 1994) of US and European firms supports this view, indicating that few companies included environmental attributes in evaluating suppliers. Due to the increasing realisation of the importance of integrating environmental factors into assessing supplier's performance, a number of researchers have begun to identify some possible environmental indicators and criteria (B&Q 1993, Lamming and Hampson 1996, McIntyre *et al* 1998, Wathey and O'Reilly 2000). Early case studies indicate that companies have applied different approaches to deal with environmental issues. These initial case studies do not have a generic model for incorporating environmental criteria into the supplier selection process.

Subsequently, within the literature a more systematic approach has been developed by the identification of several environmental categories and criteria. (Sarkis *et al* 1996) consider the environmental criteria by grouping them into five categories namely, design for the environment, life cycle analysis, total quality environmental management, green supply chain and ISO 14000 environmental management system requirements. However, they only use these criteria to evaluate the existing internal company operations for their environmental performance, rather than using the criteria to evaluate suppliers. In addition, a number of quantitative factors like the emission level of pollutants and issues related to the introduction of new technology have not been considered.

(Noci 1995) identifies two scoring systems for the evaluation of recycling-based programmes. These two systems measure the changes of physical and economic performance of different recycling-based programmes. The change of physical performance relates to the change in waste water, air emissions and energy consumption in relation to the implementation of each programme. The changes in economic performance are affected by four major types of costs:

1. Change in costs due to product quality;
2. Costs for recycling materials making up end of life product;
3. Incremental environmental costs related to the production of recyclable products; and
4. Costs due to environmental taxation.

However, these criteria are focused internally within a company and are not applied to the supplier selection process. In addition, qualitative criteria such as the development of an environmental management system are not considered.

(Azzone and Noci 1996) proposed an operating framework for the identification of significant evaluation criteria to support decision-making on programmes aimed at introducing new 'green' products. They identify four evaluation criteria:

1. 'External' environmental effectiveness: identify whether the introduction of the designed product is consistent with the main requirements of a 'green' customer;
2. Environmental efficiency: refer to the amount of environmental impact on the state of natural resources resulting from the production process;
3. 'Green' image: identify how different product development options modify the corporate image;
4. Environmental flexibility: refer to the firm's capacity to modify its products and processes to meet new market requirements.

However, criteria such as the implementation of an environmental management system and ISO 14000 certification are not considered. In addition, as already indicated these criteria are applied to the product development process rather than supplier selection.

(Noci 1997) refined his previous environmental research to focus on supplier selection decisions. He identifies several environmental criteria and classifies them into four environmental categories including 'green' competencies, current environmental efficiency, supplier's 'green' image and net life cycle cost. Within these four categories, 'green' competencies and supplier's 'green' image are viewed as qualitative evaluation criteria while the other two categories are classified as environmental operating measures for the supplier (i.e. quantitative items). As defined by the author, net life cycle cost is called a quantitative impact, which can be expressed in monetary terms and is related to the change of operating costs and forecast revenues related to the introduction of 'green' programs. Current environmental efficiency is called a quantitative item that can be expressed in physical terms but cannot be easily converted into financial terms and relates, for example, to air emissions. Qualitative evaluation criteria relate to the intangible effects of each criterion such as a change in the company's image by consumers or customers due to the introduction of new green products into the market (Azzone and Noci 1996). However, this proposed framework has omitted some important key criteria. For example, issues related to design for environment and the implementation of an environmental management system have not been considered in the study. In addition, this study does not provide a detailed explanation of the supplier selection process, but rather a limited and brief overview of how the framework would be applied.

(Enarsson 1998) proposed an alternative instrument for the evaluation of suppliers from an environmental viewpoint by adopting a quality improvement perspective. The framework of the instrument is an Ishikawa fishbone diagram which has been developed and used in quality-assessment work within companies. Four main factors have been identified for appraisal of suppliers as listed in table 1.

[Insert table 1 about here]

The fishbone diagram covers several environmental criteria; however all are qualitative environmental criteria which require subjective judgement made by the decision-makers. Quantitative environmental criteria such as the amount of waste generated, the air emission level and the level of investment in environmental programmes are not considered. The key work by researchers on developing environmental frameworks and their limitations are summarised in table 2.

[Insert table 2 about here]

4. The development of a supplier selection system

This paper provides a supplier selection system using fuzzy logic and considering environmental issues; a fuzzy system has not been employed to consider environmental issues in the supplier selection process. The system is created in a generic form as the supplier selection process is often a very personal process. The system is a combination of a number of self-contained fuzzy systems with each system receiving a number of fuzzy or numerical inputs and providing a defuzzified output. This output can then be used to rank the supplier or as input to a further fuzzy system. Each factor under consideration in the supplier selection process requires a fuzzy system; the overall system presented in this paper considers seven supplier selection factors as illustrated in figure 1.

[Insert figure 1 about here]

The detail involved in the entire system is too vast for this paper and so only the environmental sub-system has been presented. A similar process exists for each of the other six sub-systems illustrated in figure 1. The ‘Environmental Issues’ sub-system has many criteria, which have been established through consolidating and classifying the environmental factors from the various authors reviewed in Section 2. This gives rise to the proposed environmental framework shown in figure 2. For each of the five criteria, several sub-criteria are identified. The sub-criteria ‘environmental costs (pollutant effects and improvement)’ is grouped under the heading ‘quantitative environmental criteria’. The other four named ‘green image’, ‘design for environment’, ‘environmental management systems’, and ‘environmental competencies’ are in a separate group termed ‘qualitative environmental criteria’. ‘Environmental costs (pollutant effects)’ are costs due to the treatment of pollutants, such as solid waste disposal. ‘Environmental costs (improvement)’ are costs and investments related to improvements in a supplier’s environmental performance. For example, an improvement cost could include investment in environmentally friendly technology which may result in less energy consumption, waste reduction or less pollutant generated etc. All these criteria are quantitative factors and can be expressed in monetary terms. On the other hand, qualitative criteria such as the environmental management system within a company, and its green image, require subjective decisions to be made during their evaluation.

[Insert figure 2 about here]

Each separate sub-system is a self-contained FLS and therefore is interchangeable within the overall hierarchy. The approach enables the user to establish a system that best represents the focal organisation’s decision-making process. The importance the buyer places on particular criteria or sub-criteria will determine its priority setting, this determines the weights applied to the various membership functions in the fuzzy sub-systems. The reliability of data (Faruk et al 2001, Lamming and Cousins 2002, Bowen et al 2002, Faruk et al 2002) can also be considered as a weighting element and can be combined with the level of importance to form a weighting for each criteria. This process is extended throughout the fuzzy hierarchy as illustrated in figure 3. In figure 3 it can be seen that the ‘Environmental Issues’ criteria has five sub-criteria which are ‘Environmental Costs’ which is given the highest priority, next is ‘Environmental Competencies’ followed by ‘Green Image’, ‘Environmental Management Systems’ and finally ‘Design for Environment’. Sub-criteria ‘Environmental Costs’ is then shown to have three priority levels with ‘Pollutants’ being the highest priority followed by ‘Consumables’ and ‘Improvements’. Within each of the three criteria the sub-criteria can be seen (figure 3) and their relevant priority within their own criteria.

[Insert figure 3 about here]

The degree of complexity of the system is set by the user; the more complex the system the more the user can impart their personal priority settings onto the system therefore better reflecting their supplier selection process. The system is generic to this point and the same system framework can be used by the buyer to analyse any supplier or product. After this level the system becomes more specific and is tuned to a particular supplier type or product. The user can select or create a profile for a supplier or product and establish the relevant inputs for the system at its lowest level. In this instance the sub-criteria identified in figure 3 is considered the lowest level of the system therefore inputs are identified for each of the sub-criteria. The supplier profile selected in this instance is ‘Metal preparation and treatments’. To establish the main pollutants within this industry the Toxic Release Inventory (TRI) (Toxic Release Inventory 2004) a U.S. government database was consulted and the top ten pollutants in each of solid waste, liquid emissions and atmospheric emissions are established as shown in figure 4.

[Insert figure 4 about here]

The priorities at this level are not initially established by the user, each element of waste is prioritised by how hazardous it is to the environment. The quantity of waste is scaled so as to reflect the threat to the environment as in some instances the release of a very small amount of a particular waste substance can be extremely detrimental to the environment. The buyer may choose to adjust the priorities to highlight a problem they have with a particular substance. The same process is repeated for each of the sub-criteria, the detail to which sub-criteria is analysed is controlled by the buyer. They may choose to simply rate the sub-criteria at a high level without detailed analysis. The level of analysis will be determined by the user and by the type of industry or product that is under investigation.

5. The development of a fuzzy based system

Fuzzy systems were developed due to the understanding that measurements, process modelling and control can never be exact for real and complex processes. Also there are uncertainties such as incompleteness, randomness and ignorance of data in the process model.

The seminal work by Zadeh introduced the concept of fuzzy logic to model human reasoning from imprecise and incomplete information by providing a computational framework for vague information (Zadeh 1965, Zadeh 1968, Zadeh 1973). Fuzzy logic can incorporate human experiential knowledge and give it an engineering meaning to control ill-defined systems with non-linearity. There are many interpretations of fuzzy modelling. For instance, a fuzzy set is a fuzzy model of human concept. In this study, a fuzzy model is understood as an approach to form a system model using a descriptive language based on fuzzy logic with fuzzy predicates. Fuzzy models consist of linguistic explanations about the system behaviour. Apart from fuzzy control, there are many studies on fuzzy modelling. Those are divided into two groups. The first group deals with fuzzy model of the system itself or a fuzzy model for simulation (Tong 1980, Pedrycz 1984, Filev 1991). The second group deals with fuzzy modelling of a plant for control (Takagi and Sugeno 1985, Chi and Yan 1996). In this system we are using linguistic terms to define how important particular sub-factors or criteria are in the supplier selection process.

In his seminal paper of 1965, Zadeh intimates that set membership is the key to making decisions when faced with uncertainty (Zadeh, L., 1965). Membership functions define the degree to which an input has membership to a fuzzy set. Membership functions are associated with the terms that appear in the antecedent (premise) and consequent (action) of rules. The rule base represents the linguistic knowledge of one or more human experts. Rules are typically of the modus ponens variety e.g. IF liquid emissions are *high* and air emissions are *low* THEN suitability is *satisfactory*. Rule bases in fuzzy logic systems (FLSs) usually contain many such rules. There are typically four parts to a FLS: fuzzifier, rules, inference engine, and output processor as illustrated by figure 5. In a FLS, numerically precise (crisp) inputs are converted into fuzzy representations usually in the range [0,1] by the fuzzifier. This procedure is dependent on the height, position and choice of the type of membership functions used. These inputs then activate (fire) all the rules in the rule-base that contain that fuzzy representation in their antecedent (premise). The inference engine and the rule base describe the way in which rule antecedents (inputs) are mapped to rule consequents (outputs). Hence, FLSs simply map an input space to an output space. Scaling the membership functions weights the relative importance of different inputs and hence affects the firing levels of rules.

[Insert figure 5 about here]

Each fired rule constructs an output set which is then converted to a crisp output through the process of defuzzification. Here the different firing levels will have biased the crisp output of the defuzzification process producing different outputs depending on the scaling factors for the membership functions. The amount of variation is not large, as the rule-base is still the same, but when comparing the scores between different suppliers, changes in input weights are significant in terms of ranking position.

In the proposed fuzzy hierarchical system presented in this paper the levels of the hierarchy are determined by the buyer, these are the scaling factors which weight the membership functions and hence bias the FLS. A hierarchical level can contain one or more of the seven factors but if more than one factor exists then their relationship must be defined with a rule base and then the factors are combined with each level's FLS to produce one output from that level. The overall structure of the system as illustrated in figure 6 shows that only suppliers that meet a defined benchmark will proceed to the next level, this reduces the need to process data for suppliers that are obviously unsuitable and would save time investigating supplier data.

[Insert figure 6 about here]

A more detailed look at the fuzzy system developed for the environmental factor and how the ranking system is implemented for this will establish the basic building block of the system. The environmental factor is a self-contained fuzzy system which contains other fuzzy sub-systems that represent the other levels of inputs present in the supplier selection process. As shown in figure 7 the system uses the sub-factors as inputs to the 'Factor fuzzy system', the criteria as inputs to the 'Sub-Factor fuzzy system' and the sub-criteria as inputs to the 'Criteria fuzzy System'. The output of the lower fuzzy systems becomes an input to the higher fuzzy system at all levels as can be seen in figure 7. The system uses dynamic scaling of the fuzzy membership functions to prioritise the inputs to each fuzzy system and to enable the degree of influence held by each input to be altered. Each input within the 'Environmental factor' contributes to a specified degree to the overall output of the 'Environmental factor'. The degree of influence for each input is set within each fuzzy system at each level and once set does not require adjustment unless buyer's position and priorities change. If the buyer does not wish to set any priorities then the system can be set to equal priorities (setting all scaling factors to 1) and all priorities at all levels will be set equal.

[Insert figure 7 about here]

5.1 Fuzzy inference method

The fuzzy inference method used in this system is the Takagi-Sugeno-Kang (TSK) which was introduced in 1985 (Sugeno 1985, Sugeno and Kang 1988, Sugeno and Yasukawa 1993). The TSK method was selected rather than the Mamdani's fuzzy inference method (Mamdani and Assilian 1975), as it is more computationally efficient and it works well with optimisation and adaptive techniques (Cherkassky 1998).

5.2 Input membership function

Once the basic structure of the system has been established the next stage is to determine the membership functions for the inputs to each fuzzy system. In this paper three major factors are considered when determining the membership functions for each input.

- The first is the total range of all the membership functions, the universe of discourse. The system determines how each supplier in the database performs in relation to the strongest and weakest suppliers.
- The second factor is how the data is dispersed between the strongest and weakest benchmarks.
- The last is the priority level given to the input in the system; this will determine the maximum degree of membership possible for each membership function.

5.3 Membership range

The range of the membership functions in any factor, sub-factor, criteria or sub-criteria is determined by the strongest and weakest value retrieved in the input data. All the input data is normalised with the strongest input value set as 1 (x-axis) and the weakest value set as 0 (x-axis). The authors have consulted a team of experts and selected five membership functions across each universe of discourse. Increasing the number of membership functions may improve the model accuracy but will increase computational demands. The five membership functions have been termed 'Very Poor', 'Poor', 'Average', 'Good' and 'Very Good'. Assuming that the input is equally dispersed, the membership functions were evenly divided across the range. Using these membership functions, each supplier in the sector under analysis is assigned a membership function based upon its position in the range. The degree of membership of each function would relate to the shape of the membership function used, in this case a triangular shaped membership function. The Triangular curve is a function of a vector x, and depends on three scalar parameters a, b, and c as given by:

$$f(x;a,b,c)=\begin{Bmatrix} 0,\ x \le a \\ \frac{x-a}{b-a},\ a \le x \le b \\ \frac{c-x}{c-b},\ b \le x \le c \\ 0,\ c \le x \end{Bmatrix} \tag{1}$$

5.4 Width of individual membership functions to cover data dispersion

If data is dispersed evenly across the membership range then the fuzzy membership functions are divided evenly over the range with partition of unity. The even division of the membership function over the range enables the membership functions to have partition of unity. However from analysis of the data it was apparent that a small number of suppliers were present at the extremes of the membership range and that the data was not evenly dispersed across the membership range. In these circumstances the fuzzy membership functions are altered. In the range were data is concentrated the width of the fuzzy membership functions is narrowed and in the areas of sparse data the width of the membership function is widened. This widening and narrowing of the membership functions attempts to create an even distribution of companies in each membership function. In order to mathematical calculate how the membership functions are narrowed or widened for each membership functions three points are found in the range. The three points correspond to the 'b' parameter or the peaks of mf2, mf3 and mf4. The 'b' parameter of mf1 and mf5 are set to 0 and 1 respectively. The other three 'b' parameters or peaks are calculated using the following formulas:

$$mf2(b) = \frac{\sum_{i=1}^{n} x_i}{2(n)} \tag{2}$$

$$mf3(b) = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3}$$

$$mf4(b) = \left(\frac{1 - \frac{\sum_{i=1}^{n} x_i}{n}}{2} \right) + \frac{\sum_{i=1}^{n} x_i}{n} \qquad (4)$$

Where:

n = number of inputs for x

5.5 Priority levels and scaling

The fuzzy system for each factor, sub-factor and criteria is presented along with the inputs that are relevant to that fuzzy system and the user is prompted to supply a priority level for each input in relation to the other inputs of that fuzzy system. These priorities are set once for each buyer and do not require amendment unless the buyer's priorities change. The authors in consultation have selected five levels of priority within the system:

- Very High Priority
- High Priority
- Medium Priority
- Low Priority
- Very Low Priority

The standard membership function allows a degree of membership from 0 to 1. The proposed scaling of the membership functions replaces this membership function for each input with a scaled membership function. This scaling changes the membership functions in accordance to the priority level given to the input. The calculated scaling values of this system are as follows:

Very High Priority	1.0
High Priority	0.8
Medium Priority	0.6
Low Priority	0.4
Very Low Priority	0.2

The triangular function defined in equation (1) is altered to enable the degree of membership of a function to be changed. The triangular curve is still a function of the vector 'x', but now depends on four scalar parameters a, b, c and d. The 'd' parameter determines the maximum degree of membership for the membership function. The triangular function is given by:

$$f(x;a,b,c)=\begin{Bmatrix} 0,\ x \le a \\ \dfrac{(x-a)d}{b-a},\ a \le x \le b \\ \dfrac{(c-x)d}{c-b},\ b \le x \le c \\ 0,\ c \le x \end{Bmatrix} \tag{5}$$

The five membership functions for the five priority levels Very High Priority, High Priority, Medium Priority, Low Priority and Very Low Priority are illustrated in figure 8.

[Insert figure 8 about here]

This scaling determines how influential a particular input can be; as the degree of membership for the input is limited this limiting factor determines how influential the input is on the output of its fuzzy system. This scaling determines the influential levels of inputs to outputs throughout the whole system.

5.6 Rules for the fuzzy systems

Each fuzzy system produces an output from their respective inputs. This output is determined by the rules employed by the fuzzy system. The combination of rules that are fired and the firing strength of the rule determine the output from the fuzzy system. The number of rules defined in this system is a product of the number of membership functions in each input.

$$\textit{The number of rules} = p^n \tag{6}$$

Where:

p = Number of membership functions
n = Number of Inputs

6. Environmental system results

This section reviews the results achieved with the presented system. The effectiveness of the system is illustrated by the comparison of two sets of results, the first set of results illustrate the results obtained when no priorities are implemented on the system while the second set of results implies priorities. The supplier data for both results are identical the only change on the system is the change of priorities given to each category, sub-category, criteria and sub-criteria within the varying levels of the system hierarchy. This changing of priorities enables the system to adapt, to more closely reflect the position and priorities of different Buying Organisations. The difference in the priority settings will cause the system to identify different suppliers depending on the Buying Organisation's priorities. The data used has been obtained from a number of sources including the (Toxic Release Inventory 2004), (TRI) from the U.S. Environmental Protection Agency, the (Investor Responsibility Research Centre 2004), (IRRC) on-line database and the Annual Reports Service provided by (WILink 2004) and (StockHouse 2004) supplier names have been replaced to protect their identity. The suppliers investigated are required to provide metal production and auxiliary metal work functions such as welding and painting.

6.1 Database of suppliers normalised data

The database used for the demonstration of the system consists of fifty actual suppliers which have been given the names Supplier 1 to Supplier 50 to protect their identities. The relevant data for each supplier has been normalised on the basis that production is similar and that each supplier is producing a singular product that is common throughout all companies. This enables the potential of the system to be illustrated for the purposes of this paper. All input data has been normalised to provide a value between 0 and 4 with 0 representing no environmental damage while 4 is the highest level of environmental damage within each data set. The quantitative data has been normalised so that the most environmentally damaging supplier assumes the highest point in the scale '4' while the most environmental friendly supplier assumes the bottom of the scale '0'. The qualitative data has been rated by experts based on the data available with integer values in the range 0 to 4.

6.2 Environmental system results per fuzzy system

The results presented are for Buying Organisation 1 which has set priorities and for Buying Organisation 2 which has no set priorities. The results show the output from the four fuzzy systems that account for the four sub-criteria Solid Waste, Liquid Emissions, Air Emissions and Water Waste from the criteria Pollutants. The average is used to determine the position of all the membership functions, therefore a supplier's position in relation to the average ratio will determine which membership functions it will fall under. This can be illustrated in a simple example. If five inputs have the value 0.4, 0.5, 0.3, 0.1, 0.7 the average is 0.4 and any value from 0.4 down will be considered 'Average', 'Poor' or 'Very Poor' however if the input values have values 0.8, 0.9, 1.0, 0.8, 0.5 the average is 0.8 and anything from 0.8 down will be considered 'Average', 'Poor' or 'Very Poor'. Therefore a supplier that achieves a value of 0.5 may in the first instance be part of the membership functions 'Average' and 'Good' while in the second instance be part of the membership functions ‘Average’ and ‘Poor’.

The results from the Pollutant Fuzzy System are shown in full in Appendix A. The Pollutant fuzzy system will be analysed in detail in this paper, while the results from the other fuzzy systems under sub-factor Environmental Cost are presented in Appendix B and C. The output results from the Pollutant Fuzzy System are shown in figure 9.

[Insert figure 9 about here]

[Insert table 3 about here]

Table 3 identifies the suitability of suppliers based on the ‘Pollutant’ factor for both Buying Organisation 1 and 2. The most suitable supplier for Buying Organisation 1 is Supplier 4 while Supplier 10 has been identified as the most suitable supplier for Buying Organisation 2. Supplier 10 while being first for Buying Organisation 2 only appears in third position for Buying Organisation 1 appearing behind Supplier 18. This can be identified with the fact that Supplier 10’s strong attributes, sub-factors ‘Liquid Emissions’ and ‘Water Waste’ have been decreased to Very Low Priority and Low Priority for Buying Organisation 1. While in sub-factor ‘Air Emissions’ the priority is increased to Very High Priority and Supplier 10 is beaten both by Supplier 4 and Supplier 18. Similar movements can be seen throughout the two listings and are accounted for by the changing in priority levels, such as Supplier 36 which is the join best in ‘Air Emissions’ increases its position from 42nd to 38th due to the fact that Air Emissions is set to very high priority for Buying Organisation 1. The reason that further progress is not made by Supplier 36 is the fact that in Solid Waste Supplier 36 has performed very badly and as this is also increased to high priority. This illustrated how doing well in a very high priority will positively influence a supplier’s case for selection but will not be the only determining factor. This system achieves a balance that enables an input to be more influential but without complete control. This enables a simulated human reasoning were one aspect may influence a decision more but not to the extent that it overrides the influence of other aspects.

The three outputs from the Pollutant Fuzzy system, Consumables Fuzzy System and Improvements Fuzzy Systems become inputs to the Environmental Cost Fuzzy System this system gives a crisp rating for the sub-factor Environmental cost that is used as an input for fuzzy system on the next level of the hierarchy. The output from the Environmental Cost Fuzzy System can be seen in Appendix D.

6.3 Environmental system output fuzzy system

The final stage of the fuzzy hierarchy for the Environmental Factor is the Output Fuzzy System which summates the outputs from all the sub-factors. The results from each of the sub-factors are shown in the Appendixes with Green Image in Appendix E, Design for Environment in Appendix F, Environmental Management Systems in Appendix G and Environmental Competencies in Appendix H. The inputs to the Output Fuzzy System are also scaled membership function, the scaling depending on the priority level given to each individual sub-factor. The results obtained from the Output Fuzzy System provide a rating for each supplier which indicated how suitable it would be for a particular Buying Organisation. The system or user can then select a number of the top companies identified for further analysis.

For Buying Organisation 1 and 2 the suppliers identified for selection are presented in figure 10 and table 4. The supplier with the lowest output value is considered to be the most suitable supplier for selection for the particular Buying Organisation. As illustrated in the graph for Buying Organisation 1 the most suitable supplier is Supplier 19 followed by Supplier 49 and then Supplier 46. The top three companies for Buying Organisation 2 are Supplier 49 followed by Supplier 16 and then Supplier 43. The change in order identified for each Buying Organisation is directly related to the changes in priorities that have been set on the system. This can be seen with Supplier 19 which has risen to top position for Buying Organisation 1 the change in priorities has caused Supplier 19 to move up 11 positions in the sub-factor ‘Environmental Cost’ and caused Supplier 49 which is the best supplier without priorities to move down 4 positions in the same sub-factor. In sub-factor ‘Green Image’ the changes in priorities causes Supplier 19 to move up 6 positions while Supplier 49 maintains its position. Similar movement is present in the other sub-factors with Supplier 19 moving up 6 positions in ‘Design for Environment’ and Supplier 49 only moving up 3 positions, while Supplier 19 maintaining its 1st position in ‘Environmental Management Systems’ but increasing the winning margin considerably, Supplier 49 moves up 2 positions. In ‘Environmental Competencies’ Supplier 19 moves up 4 positions while Supplier 49 moves down 3 positions. Similar relationships are present throughout the results and can be seen in Appendix I. The graphical representation of the results illustrates how close each supplier is in respect to each other in their suitability for selection.

[Insert figure 10 about here]

[Insert table 4 about here]

The results presented illustrate the levels of influence that can be obtained through the use of a Fuzzy Hierarchical System with scalable fuzzy membership functions. The results show how natural priorities are implemented to influence the results to varying degrees without completely controlling the final result.

7. Conclusions

Environmental management is becoming increasingly important for organisations to consider. Companies are investing a considerable amount in both financial and employee resources. Managers and investors need to know whether the financial commitment is achieving results, whilst community and environmental groups are demanding improved environmental impacts. From reducing pollution to meeting environmental regulations, organisations need environmental performance measures. Integrating environmental management techniques along the supply chain is an appropriate method of enhancing the environmental performance of an industry.

A system has been presented in this paper that assists in the evaluation of suppliers in the supplier selection process. A user centred approach has been achieved that adequately reflects the position of any buying organisation and the priorities in the supplier selection process. The major benefit of this system is that in a computational inexpensive manner the proposed system is capable of implementing a range of user priorities that influence to varying degrees the system output. The priorities of environmental data within the system have been deduced using expert knowledge. The expert prioritises environmental data, based on its importance from the buying organisation's perspective. The hierarchical fuzzy system with scalable fuzzy membership function employed, imparts user priorities onto the system that can gently or strongly influence the supplier selection process. This provides a computational inexpensive manner of applying the prioritised influences involved in the human decision making process. The system attempts to emulate the environmental influences and priorities adhered to by a companies own experts, but on a larger scale and in a more timely and cost effective manner. The results presented in this paper illustrate the varying degrees of influence that have been exerted on the system and how the system has successfully emulated the supplier selection process. The results demonstrate an accurate reflection of suitable supplier selection for individual Buying Organisations. From the results obtained, it can be concluded that the approach is promising, for implementing the supplier selection process.

Future developments:

- ***Learning scaling factors*** - The constant scaling employed in this paper is effective but a future development would attempt to encompass more understanding of the user priority meaning. This understanding would negotiate the beliefs of the user in the context of the priority settings, negotiating the value of the priority settings in a uniform or non uniform manner. It is proposed that several methods of computational intelligence will be investigated including Fuzzy Logic, Neural Networks and Evolutionary Computing or a hybrid combination of these computational techniques.

Complex challenges still exist to identify pollution prevention opportunities and to measure pollution prevention progress. Factors complicating the analysis include comparisons among product lines, with industry peers, with firms in the same geographic vicinity and with previous years' information and performance. An increased emphasis on sustainability, pollution per production unit, efficiency and environmental expenditure exists. However, another challenge yet to be examined is whether these measures, or how they are used, reflect the social, political, regulatory and scientific values and opinions of our local and global societies. Companies have increased the depth and breadth of environmental performance measures and disclosure. However, such data cannot easily be compared even within the same industry. The introduction of the ISO 14000 series of standards may eventually lead to useful measures and databases of environmental performance, with ISO14031 on Environmental Performance Evaluation providing draft guidance on Environmental Performance Indicators.

Appendix A

[Insert figure 11 about here]

Appendix B

[Insert figure 12 about here]

[Insert figure 13 about here]

Appendix C

[Insert figure 14 about here]

[Insert figure 15 about here]

Appendix D

[Insert figure 16 about here]

[Insert figure 17 about here]

Appendix E

[Insert figure 18 about here]

[Insert figure 19 about here]

Appendix F

[Insert figure 20 about here]

[Insert figure 21 about here]

Appendix G

[Insert figure 22 about here]

[Insert figure 23 about here]

Appendix H

[Insert figure 24 about here]

[Insert figure 25 about here]

Appendix I

[Insert figure 26 about here]

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Environmental Factor	Sub-sections
Supplier as company	Environmental system, management, other concerns (laws, research)
Suppliers process	Articles for our needs, articles for other companies
Product	Recycling, other concerns (packaging, production spill)
Transportation	Return loads, choice of transportation, the suppliers geographical location, optimising loads

Table 1 Environment criteria and sub-sections of (Enarsson's 1998) Ishikawa framework

Researcher	Key Criteria identified	Focus of study	Limitations
Sarkis et al (1996)	1. Design for environment 2. Life cycle analysis 3. Total quality environmental management 4. Green supply chain 5. ISO 14000 EMS requirements	Evaluate the environmental performance of a company's existing operation system	Quantitative factors such as the emission level of pollutants are not considered. Not applied to the supplier selection process.
Noci (1995)	1. Change in physical performance, e.g. air emissions, energy consumption 2. Change in economical performance, e.g. incremental revenues, environmental taxation	Evaluate performance of recycling-based programmes	Criteria are not applied to supplier selection process. Qualitative criteria such as environmental management system and supplier's 'green' image are not considered.
Azzone and Noci (1996)	1. 'External' environmental effectiveness 2. Environmental efficiency 3. 'green' image 4. Environmental flexibility	Evaluation is applied to the product development process	Not all environmental categories are considered, e.g. EMS, design for environment. Not applied to the supplier selection process.
Noci (1997)	1. Green competencies 2. Environmental efficiency 3. Supplier 'green' image 4. Net life cycle cost	Evaluate suppliers' environmental performance	Not all environmental categories are considered, e.g. EMS, design for environment. Details of the selection process are not provided.
Enarrson (1998)	1. Supplier as company 2. Supplier process 3. Product 4. Transportation	Evaluate suppliers' environmental performance	Quantitative environmental criteria such as energy consumption, waste emission levels are not considered. Procedures for selecting suppliers are not provided.

Table 2 Summary of studies related to developing environmental assessment frameworks and categories

Pollutants				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 4	0.556	Supplier 10	0.504
2nd	Supplier 18	0.567	Supplier 4	0.520
3rd	Supplier 10	0.575	Supplier 37	0.525
4th	Supplier 22	0.600	Supplier 18	0.540
5th	Supplier 37	0.618	Supplier 22	0.600
6th	Supplier 33	0.632	Supplier 33	0.659
7th	Supplier 41	0.705	Supplier 41	0.700
8th	Supplier 17	0.790	Supplier 48	0.746
9th	Supplier 8	0.835	Supplier 8	0.758
10th	Supplier 9	0.867	Supplier 44	0.794
11th	Supplier 32	0.876	Supplier 9	0.806
12th	Supplier 48	0.883	Supplier 27	0.853
13th	Supplier 44	0.920	Supplier 46	0.866
14th	Supplier 27	0.952	Supplier 47	0.887
15th	Supplier 46	0.965	Supplier 17	0.897
16th	Supplier 23	0.968	Supplier 38	0.910
17th	Supplier 26	0.974	Supplier 25	1.001
18th	Supplier 31	0.977	Supplier 12	1.029
19th	Supplier 45	0.989	Supplier 23	1.030
20th	Supplier 6	1.003	Supplier 2	1.037
21st	Supplier 42	1.014	Supplier 21	1.040
22nd	Supplier 19	1.025	Supplier 31	1.046
23rd	Supplier 13	1.027	Supplier 5	1.048
24th	Supplier 38	1.055	Supplier 26	1.060
25th	Supplier 47	1.068	Supplier 6	1.069

Table 3 Top Half of Companies in the Pollutant Fuzzy System

Environmental Issues				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 19	1.520	Supplier 49	1.666
2nd	Supplier 49	1.646	Supplier 16	1.695
3rd	Supplier 46	1.670	Supplier 43	1.738
4th	Supplier 43	1.678	Supplier 19	1.781
5th	Supplier 16	1.779	Supplier 46	1.837
6th	Supplier 34	1.782	Supplier 11	1.860
7th	Supplier 35	1.871	Supplier 35	1.901
8th	Supplier 23	1.888	Supplier 41	1.902
9th	Supplier 13	1.892	Supplier 44	1.904
10th	Supplier 44	1.917	Supplier 34	1.904
11th	Supplier 15	1.930	Supplier 2	1.949
12th	Supplier 11	1.933	Supplier 23	1.951
13th	Supplier 28	1.939	Supplier 24	1.957
14th	Supplier 2	1.941	Supplier 47	1.965
15th	Supplier 4	1.947	Supplier 29	1.974
16th	Supplier 29	1.947	Supplier 4	1.992
17th	Supplier 17	1.958	Supplier 28	1.996
18th	Supplier 47	1.964	Supplier 15	1.999
19th	Supplier 27	1.967	Supplier 13	2.000
20th	Supplier 14	1.984	Supplier 7	2.007
21st	Supplier 41	2.000	Supplier 27	2.007
22nd	Supplier 24	2.008	Supplier 5	2.010
23rd	Supplier 31	2.041	Supplier 17	2.017
24th	Supplier 32	2.042	Supplier 12	2.019
25th	Supplier 1	2.045	Supplier 1	2.028

Table 4 Top 25 Suppliers System Output

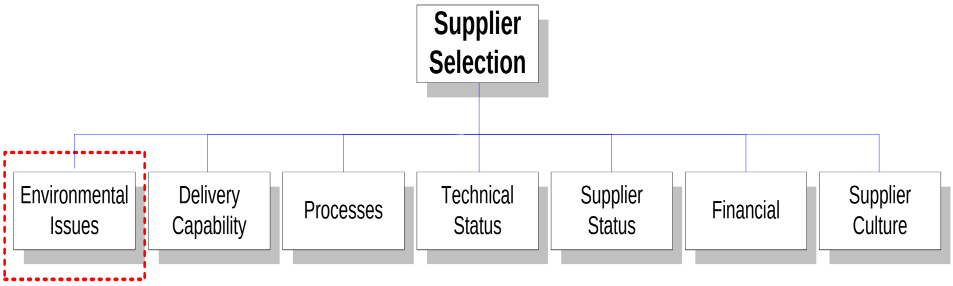

Figure 1 – Supplier Selection Criteria

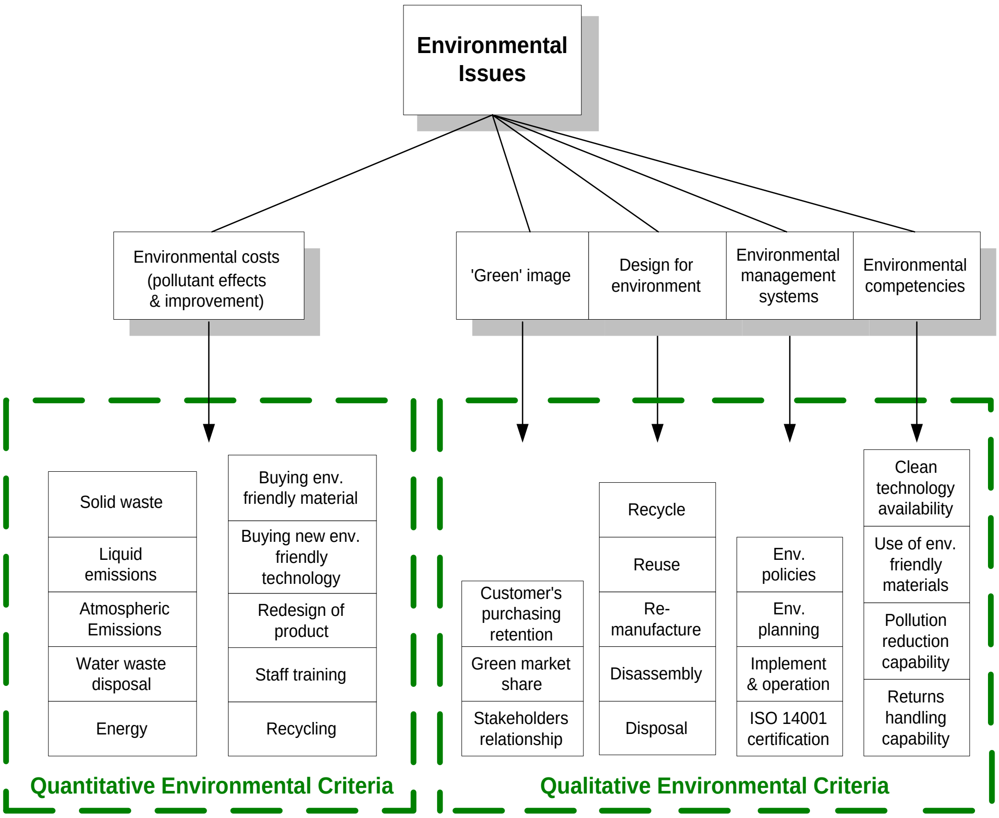

Figure 2 - Environmental framework for incorporating environmental criteria into the supplier selection process

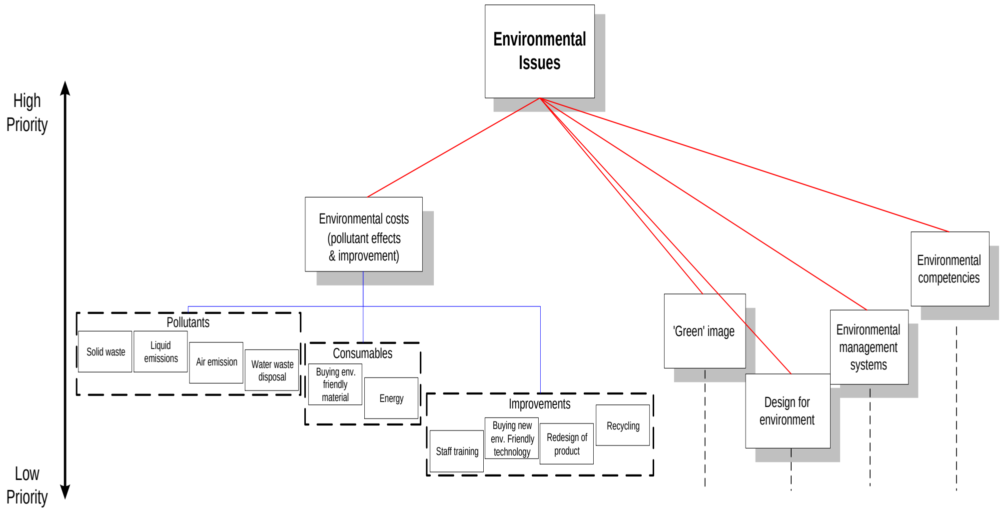

Figure 3 – Environmental Criteria and Sub-Criteria

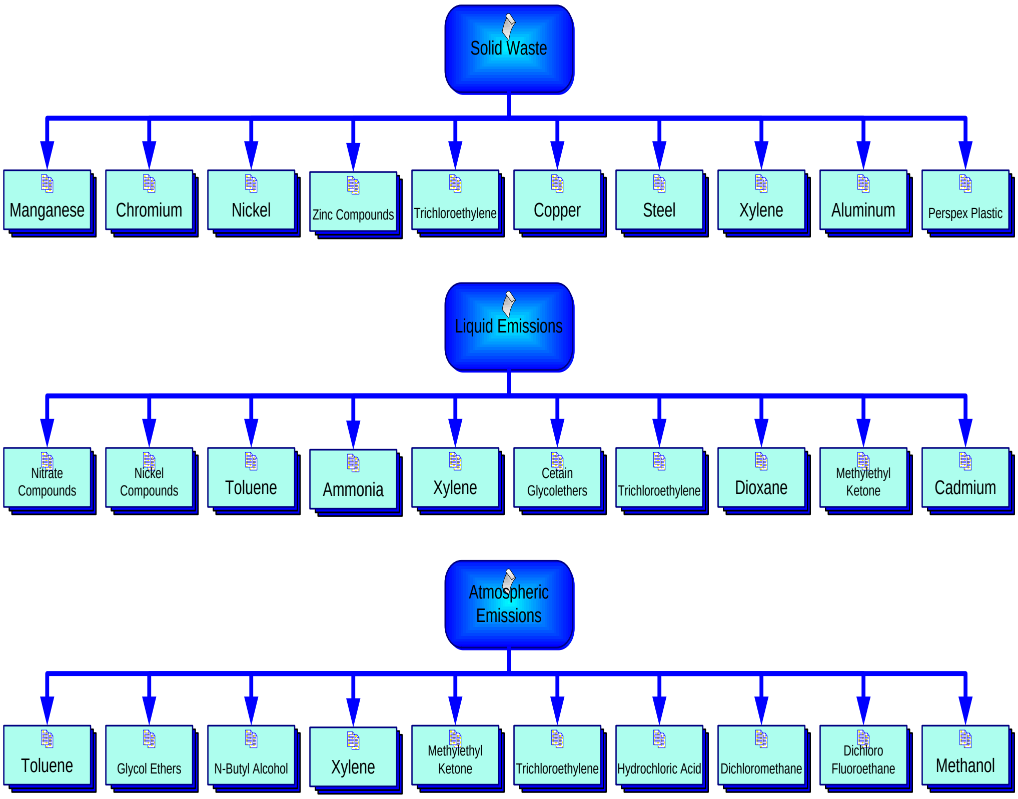

Figure 4 – Sub-Criteria Inputs

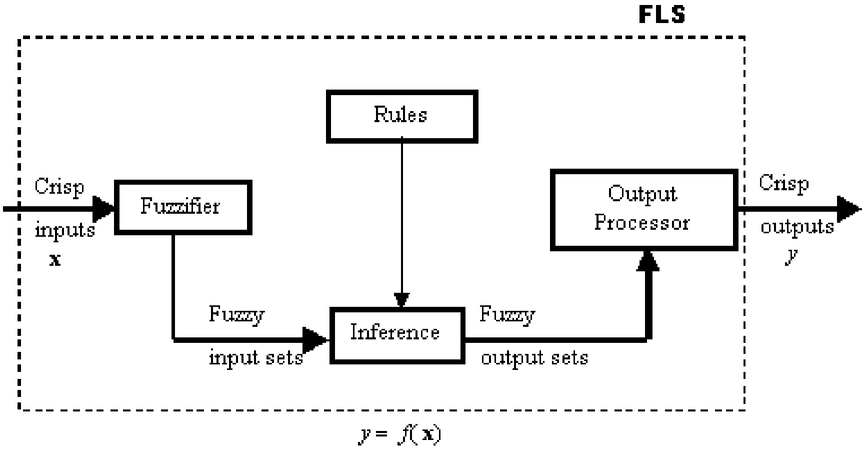

Figure 5 – Fuzzy Logic System (FLS)

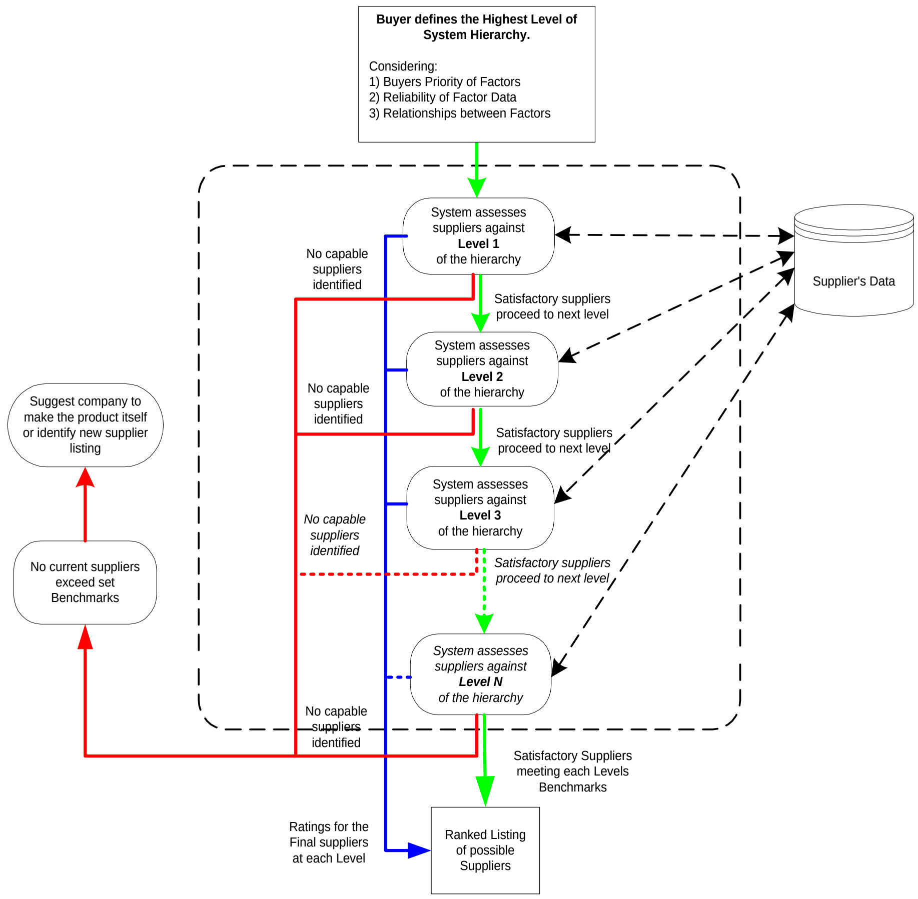

Figure 6 – System Overview

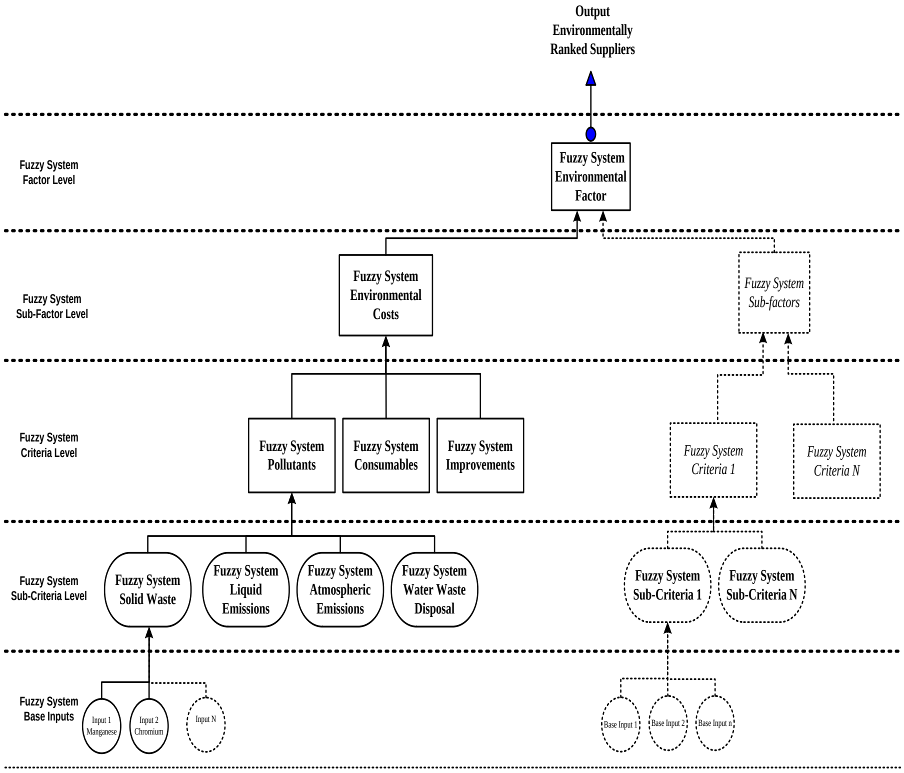

Figure 7 – Fuzzy Systems

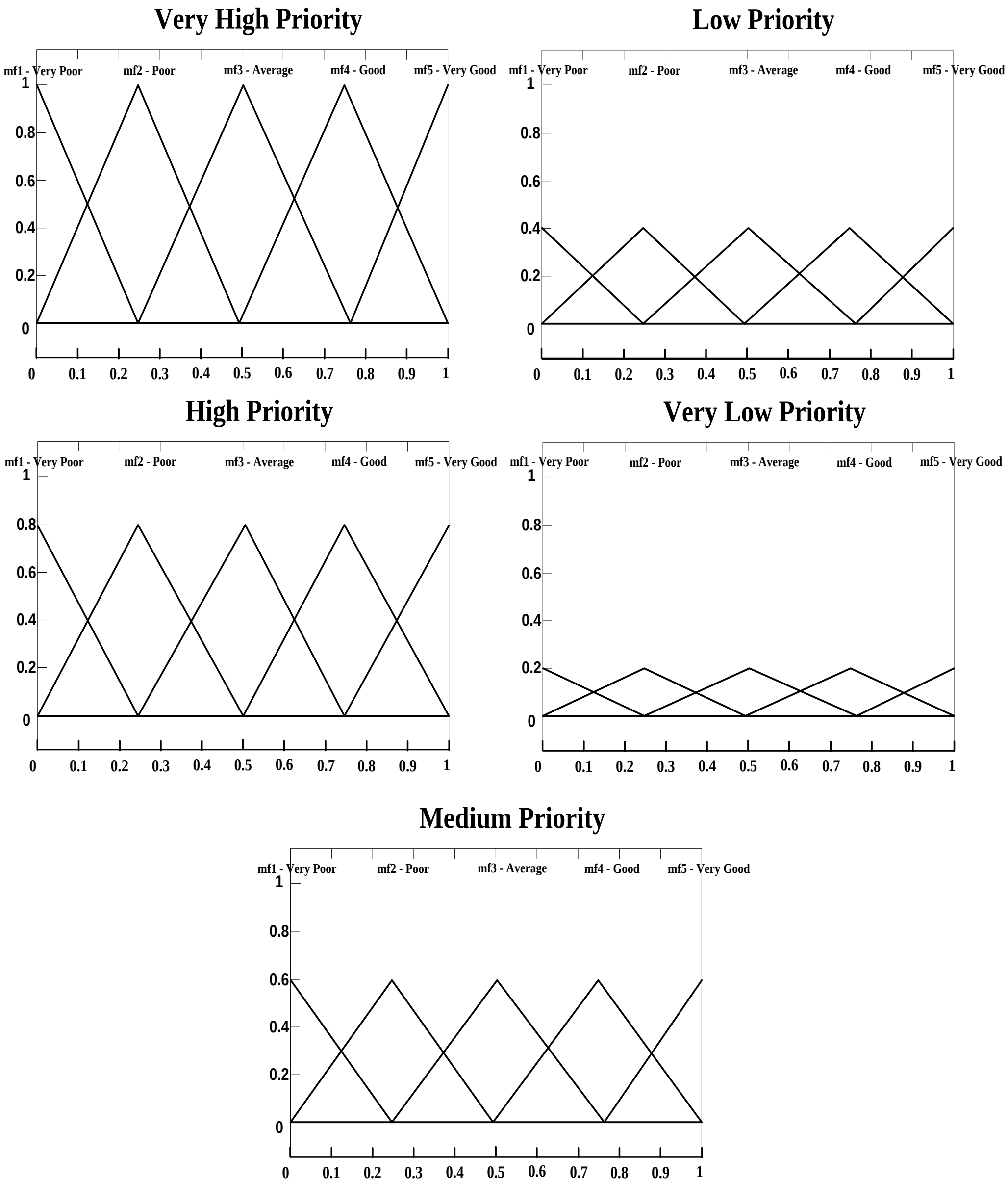

Figure 8 - Fuzzy Membership Functions - Priority Scaling

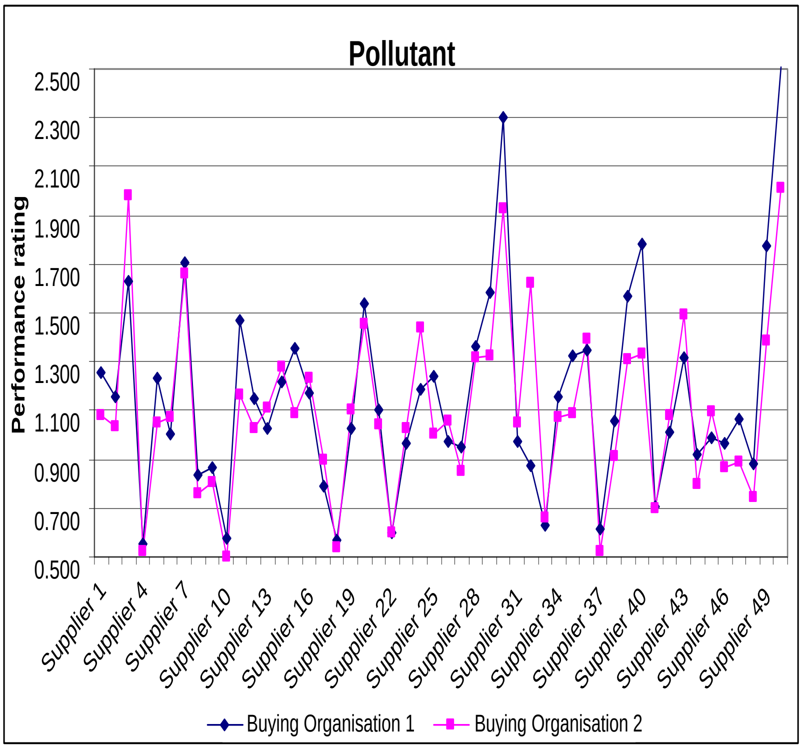

Figure 9 Pollutant Output for Buying Organisation 1 & 2

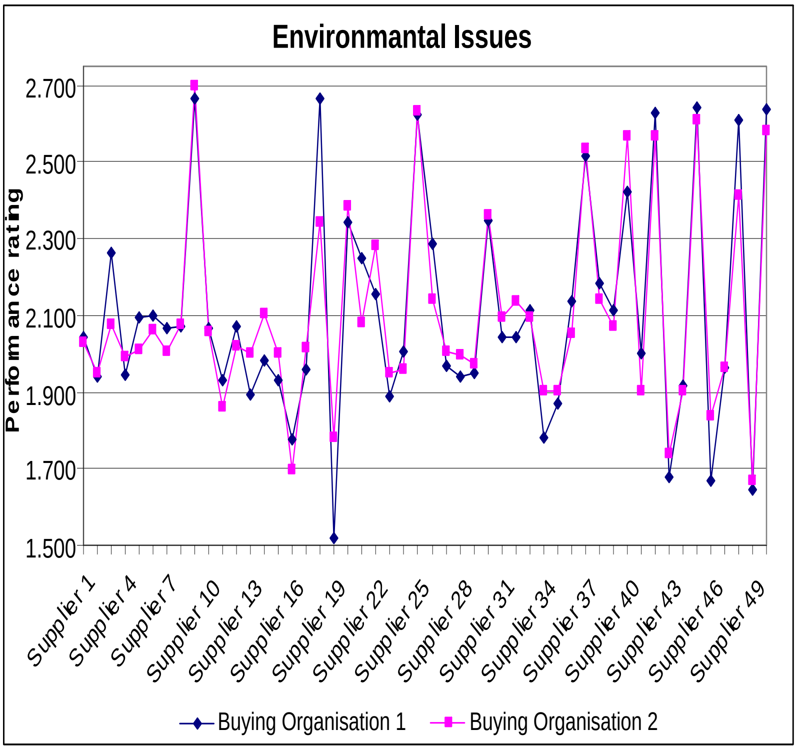

Figure 10 Comparing Supplier Output Ratings for Buying Organisation 1 and 2

Pollutants				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 4	0.556	Supplier 10	0.504
2nd	Supplier 18	0.567	Supplier 4	0.520
3rd	Supplier 10	0.575	Supplier 37	0.525
4th	Supplier 22	0.600	Supplier 18	0.540
5th	Supplier 37	0.618	Supplier 22	0.600
6th	Supplier 33	0.632	Supplier 33	0.659
7th	Supplier 41	0.705	Supplier 41	0.700
8th	Supplier 17	0.790	Supplier 48	0.746
9th	Supplier 8	0.835	Supplier 8	0.758
10th	Supplier 9	0.867	Supplier 44	0.794
11th	Supplier 32	0.876	Supplier 9	0.806
12th	Supplier 48	0.883	Supplier 27	0.853
13th	Supplier 44	0.920	Supplier 46	0.866
14th	Supplier 27	0.952	Supplier 47	0.887
15th	Supplier 46	0.965	Supplier 17	0.897
16th	Supplier 23	0.968	Supplier 38	0.910
17th	Supplier 26	0.974	Supplier 25	1.001
18th	Supplier 31	0.977	Supplier 12	1.029
19th	Supplier 45	0.989	Supplier 23	1.030
20th	Supplier 6	1.003	Supplier 2	1.037
21st	Supplier 42	1.014	Supplier 21	1.040
22nd	Supplier 19	1.025	Supplier 31	1.046
23rd	Supplier 13	1.027	Supplier 5	1.048
24th	Supplier 38	1.055	Supplier 26	1.060
25th	Supplier 47	1.068	Supplier 6	1.069
26th	Supplier 21	1.106	Supplier 34	1.070
27th	Supplier 12	1.147	Supplier 42	1.079
28th	Supplier 34	1.155	Supplier 1	1.082
29th	Supplier 2	1.156	Supplier 35	1.084
30th	Supplier 16	1.173	Supplier 15	1.089
31st	Supplier 24	1.184	Supplier 45	1.098
32nd	Supplier 14	1.216	Supplier 19	1.106
33rd	Supplier 5	1.231	Supplier 13	1.108
34th	Supplier 25	1.243	Supplier 11	1.163
35th	Supplier 1	1.255	Supplier 16	1.231
36th	Supplier 43	1.315	Supplier 14	1.276
37th	Supplier 35	1.328	Supplier 39	1.308
38th	Supplier 36	1.345	Supplier 28	1.318
39th	Supplier 15	1.357	Supplier 29	1.327
40th	Supplier 28	1.366	Supplier 40	1.331
41st	Supplier 11	1.469	Supplier 49	1.384
42nd	Supplier 20	1.538	Supplier 36	1.390
43rd	Supplier 39	1.567	Supplier 24	1.442
44th	Supplier 29	1.582	Supplier 20	1.453
45th	Supplier 3	1.627	Supplier 43	1.491
46th	Supplier 7	1.705	Supplier 32	1.623
47th	Supplier 49	1.777	Supplier 7	1.659
48th	Supplier 40	1.780	Supplier 30	1.926
49th	Supplier 30	2.302	Supplier 3	1.983
50th	Supplier 50	2.509	Supplier 50	2.013

Figure 11 Ranking scores from the ‘Pollutants’ fuzzy system

Consumables				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 33	0.648	Supplier 33	0.702
2nd	Supplier 8	1.038	Supplier 50	1.021
3rd	Supplier 50	1.086	Supplier 47	1.074
4th	Supplier 47	1.119	Supplier 8	1.080
5th	Supplier 45	1.228	Supplier 45	1.187
6th	Supplier 17	1.291	Supplier 17	1.345
7th	Supplier 14	1.353	Supplier 14	1.403
8th	Supplier 22	1.388	Supplier 22	1.451
9th	Supplier 4	1.532	Supplier 29	1.501
10th	Supplier 29	1.540	Supplier 42	1.566
11th	Supplier 34	1.569	Supplier 4	1.590
12th	Supplier 42	1.616	Supplier 34	1.609
13th	Supplier 31	1.630	Supplier 21	1.650
14th	Supplier 41	1.634	Supplier 31	1.676
15th	Supplier 5	1.693	Supplier 41	1.713
16th	Supplier 21	1.715	Supplier 12	1.719
17th	Supplier 35	1.736	Supplier 5	1.757
18th	Supplier 12	1.747	Supplier 38	1.758
19th	Supplier 38	1.786	Supplier 35	1.758
20th	Supplier 27	1.793	Supplier 46	1.799
21st	Supplier 15	1.818	Supplier 27	1.817
22nd	Supplier 46	1.870	Supplier 15	1.866
23rd	Supplier 2	2.025	Supplier 2	2.083
24th	Supplier 43	2.117	Supplier 30	2.116
25th	Supplier 36	2.168	Supplier 43	2.142
26th	Supplier 24	2.174	Supplier 36	2.144
27th	Supplier 30	2.201	Supplier 24	2.241
28th	Supplier 19	2.220	Supplier 19	2.272
29th	Supplier 25	2.296	Supplier 25	2.358
30th	Supplier 20	2.403	Supplier 1	2.382
31st	Supplier 1	2.477	Supplier 40	2.447
32nd	Supplier 40	2.513	Supplier 20	2.459
33rd	Supplier 39	2.530	Supplier 39	2.497
34th	Supplier 28	2.689	Supplier 28	2.645
35th	Supplier 48	2.704	Supplier 3	2.758
36th	Supplier 7	2.767	Supplier 48	2.776
37th	Supplier 16	2.785	Supplier 7	2.795
38th	Supplier 3	2.817	Supplier 16	2.795
39th	Supplier 13	2.897	Supplier 13	2.901
40th	Supplier 49	2.936	Supplier 11	2.929
41st	Supplier 11	3.011	Supplier 49	2.950
42nd	Supplier 23	3.016	Supplier 23	3.048
43rd	Supplier 10	3.079	Supplier 9	3.094
44th	Supplier 9	3.116	Supplier 10	3.115
45th	Supplier 37	3.291	Supplier 37	3.340
46th	Supplier 26	3.493	Supplier 26	3.549
47th	Supplier 6	3.708	Supplier 6	3.735
48th	Supplier 32	3.708	Supplier 32	3.735
49th	Supplier 18	3.735	Supplier 18	3.763
50th	Supplier 44	3.816	Supplier 44	3.789

Figure 12 Ranking scores from the ‘Consumables’ fuzzy system

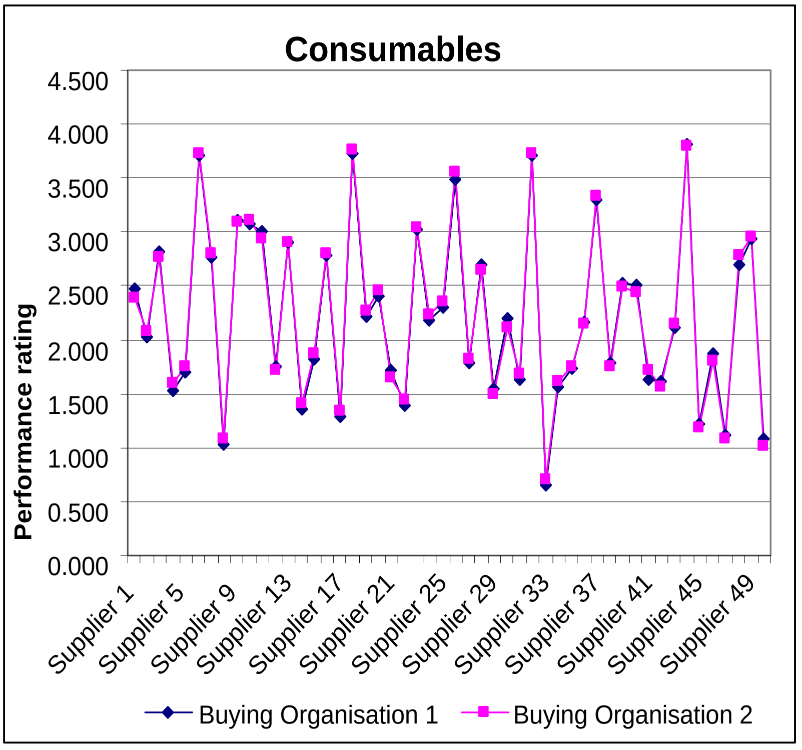

Figure 13 Results from the ‘Consumables’ fuzzy system

Improvements				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 17	0.809	Supplier 17	0.971
2nd	Supplier 47	1.155	Supplier 47	1.158
3rd	Supplier 12	1.215	Supplier 12	1.182
4th	Supplier 45	1.279	Supplier 21	1.342
5th	Supplier 21	1.299	Supplier 30	1.346
6th	Supplier 30	1.332	Supplier 49	1.358
7th	Supplier 49	1.477	Supplier 45	1.473
8th	Supplier 36	1.591	Supplier 36	1.609
9th	Supplier 37	1.681	Supplier 35	1.680
10th	Supplier 2	1.735	Supplier 37	1.740
11th	Supplier 4	1.747	Supplier 15	1.790
12th	Supplier 44	1.753	Supplier 2	1.843
13th	Supplier 43	1.767	Supplier 22	1.855
14th	Supplier 15	1.777	Supplier 38	1.876
15th	Supplier 35	1.784	Supplier 43	1.889
16th	Supplier 32	1.792	Supplier 20	1.894
17th	Supplier 25	1.855	Supplier 27	1.910
18th	Supplier 38	1.892	Supplier 44	1.945
19th	Supplier 27	1.920	Supplier 32	1.954
20th	Supplier 19	1.948	Supplier 25	1.956
21st	Supplier 41	1.953	Supplier 19	2.010
22nd	Supplier 29	1.968	Supplier 23	2.013
23rd	Supplier 3	1.996	Supplier 6	2.015
24th	Supplier 34	2.006	Supplier 8	2.015
25th	Supplier 22	2.027	Supplier 41	2.022
26th	Supplier 28	2.035	Supplier 3	2.035
27th	Supplier 8	2.086	Supplier 29	2.037
28th	Supplier 14	2.092	Supplier 4	2.038
29th	Supplier 31	2.110	Supplier 14	2.101
30th	Supplier 5	2.129	Supplier 5	2.127
31st	Supplier 20	2.153	Supplier 24	2.150
32nd	Supplier 1	2.198	Supplier 31	2.162
33rd	Supplier 6	2.222	Supplier 28	2.195
34th	Supplier 9	2.231	Supplier 1	2.206
35th	Supplier 23	2.278	Supplier 34	2.284
36th	Supplier 7	2.292	Supplier 7	2.354
37th	Supplier 24	2.292	Supplier 46	2.412
38th	Supplier 42	2.458	Supplier 9	2.426
39th	Supplier 11	2.494	Supplier 11	2.477
40th	Supplier 46	2.502	Supplier 40	2.530
41st	Supplier 26	2.581	Supplier 39	2.533
42nd	Supplier 39	2.583	Supplier 26	2.541
43rd	Supplier 13	2.593	Supplier 16	2.605
44th	Supplier 40	2.602	Supplier 42	2.646
45th	Supplier 50	2.654	Supplier 48	2.752
46th	Supplier 10	2.798	Supplier 50	2.756
47th	Supplier 33	2.798	Supplier 13	2.787
48th	Supplier 16	2.894	Supplier 33	2.804
49th	Supplier 48	2.920	Supplier 10	2.931
50th	Supplier 18	3.719	Supplier 18	3.693

Figure 14 Ranking scores from the ‘Improvements’ fuzzy system

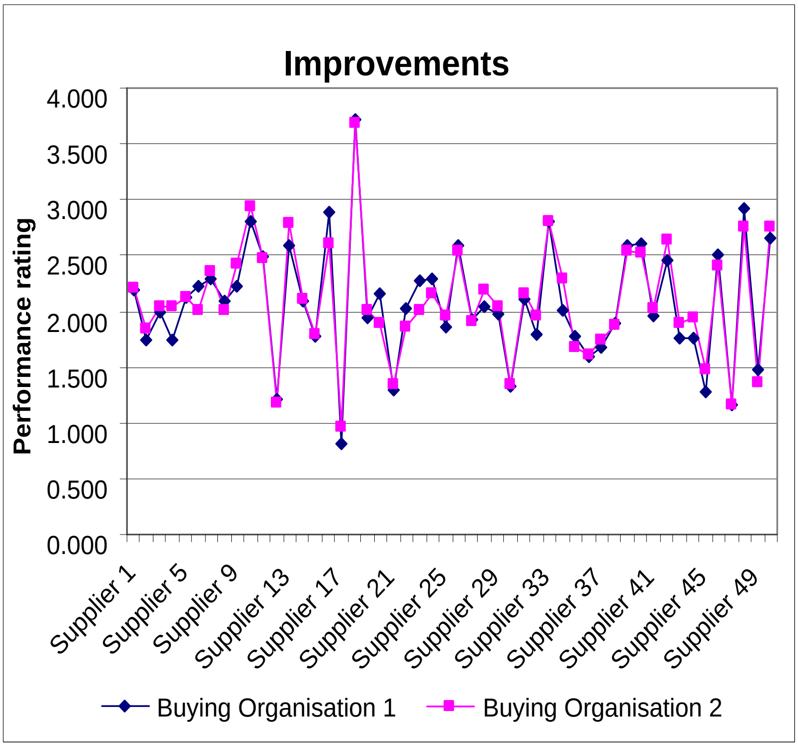

Figure 15 Results from the ‘Improvements’ fuzzy system

Environmental Costs				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 17	1.156	Supplier 17	1.259
2nd	Supplier 4	1.273	Supplier 47	1.262
3rd	Supplier 22	1.344	Supplier 22	1.394
4th	Supplier 47	1.397	Supplier 8	1.406
5th	Supplier 8	1.403	Supplier 4	1.412
6th	Supplier 45	1.420	Supplier 45	1.490
7th	Supplier 33	1.439	Supplier 12	1.513
8th	Supplier 41	1.469	Supplier 21	1.547
9th	Supplier 21	1.614	Supplier 41	1.577
10th	Supplier 27	1.624	Supplier 33	1.581
11th	Supplier 12	1.640	Supplier 38	1.600
12th	Supplier 38	1.670	Supplier 27	1.610
13th	Supplier 31	1.688	Supplier 35	1.675
14th	Supplier 34	1.744	Supplier 2	1.696
15th	Supplier 14	1.756	Supplier 15	1.711
16th	Supplier 19	1.777	Supplier 5	1.781
17th	Supplier 2	1.796	Supplier 14	1.789
18th	Supplier 35	1.841	Supplier 31	1.792
19th	Supplier 5	1.853	Supplier 29	1.812
20th	Supplier 42	1.863	Supplier 34	1.858
21st	Supplier 15	1.870	Supplier 36	1.876
22nd	Supplier 46	1.899	Supplier 46	1.880
23rd	Supplier 36	1.905	Supplier 50	1.881
24th	Supplier 10	1.906	Supplier 25	1.921
25th	Supplier 29	1.910	Supplier 30	1.936
26th	Supplier 43	1.923	Supplier 10	1.972
27th	Supplier 25	1.997	Supplier 19	1.974
28th	Supplier 37	2.029	Supplier 42	1.986
29th	Supplier 50	2.040	Supplier 43	1.997
30th	Supplier 24	2.080	Supplier 37	2.037
31st	Supplier 30	2.123	Supplier 49	2.071
32nd	Supplier 9	2.134	Supplier 48	2.094
33rd	Supplier 48	2.144	Supplier 20	2.113
34th	Supplier 23	2.169	Supplier 1	2.150
35th	Supplier 49	2.170	Supplier 24	2.191
36th	Supplier 13	2.216	Supplier 9	2.201
37th	Supplier 1	2.253	Supplier 23	2.216
38th	Supplier 28	2.261	Supplier 28	2.341
39th	Supplier 20	2.304	Supplier 3	2.358
40th	Supplier 3	2.322	Supplier 44	2.371
41st	Supplier 32	2.335	Supplier 39	2.373
42nd	Supplier 44	2.394	Supplier 40	2.375
43rd	Supplier 18	2.415	Supplier 11	2.414
44th	Supplier 39	2.421	Supplier 16	2.426
45th	Supplier 16	2.428	Supplier 7	2.443
46th	Supplier 7	2.429	Supplier 13	2.497
47th	Supplier 40	2.475	Supplier 18	2.561
48th	Supplier 26	2.491	Supplier 6	2.690
49th	Supplier 11	2.496	Supplier 26	2.691
50th	Supplier 6	2.534	Supplier 32	2.733

Figure 16 Ranking scores from the ‘Environmental cost’ fuzzy system

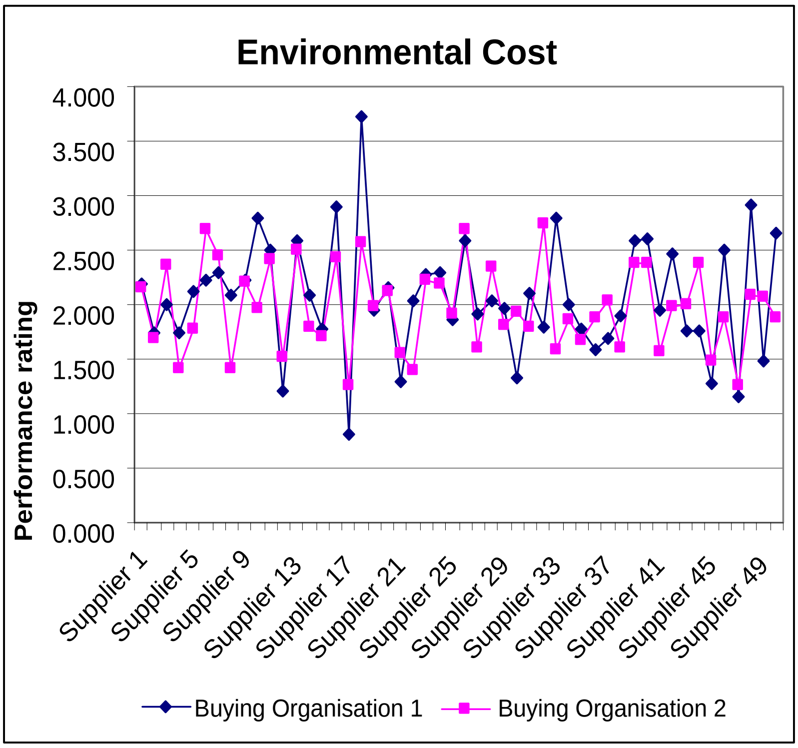

Figure 17 Results from the ‘Environmental cost’ fuzzy system

Green Image				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 49	0.256	Supplier 49	0.318
2nd	Supplier 16	0.664	Supplier 16	0.616
3rd	Supplier 5	1.047	Supplier 31	1.203
4th	Supplier 31	1.137	Supplier 12	1.226
5th	Supplier 12	1.217	Supplier 41	1.226
6th	Supplier 41	1.217	Supplier 5	1.279
7th	Supplier 7	1.405	Supplier 7	1.279
8th	Supplier 2	1.467	Supplier 43	1.468
9th	Supplier 39	1.475	Supplier 39	1.475
10th	Supplier 3	1.481	Supplier 10	1.525
11th	Supplier 43	1.500	Supplier 3	1.607
12th	Supplier 21	1.533	Supplier 21	1.742
13th	Supplier 29	1.533	Supplier 29	1.742
14th	Supplier 10	1.566	Supplier 33	1.742
15th	Supplier 33	1.800	Supplier 2	1.748
16th	Supplier 35	1.801	Supplier 24	1.863
17th	Supplier 1	1.842	Supplier 1	1.890
18th	Supplier 8	1.842	Supplier 8	1.890
19th	Supplier 38	1.867	Supplier 18	1.890
20th	Supplier 18	1.934	Supplier 35	1.939
21st	Supplier 24	1.985	Supplier 11	1.947
22nd	Supplier 19	2.024	Supplier 38	1.947
23rd	Supplier 11	2.055	Supplier 36	1.985
24th	Supplier 4	2.083	Supplier 44	1.985
25th	Supplier 34	2.155	Supplier 4	2.156
26th	Supplier 47	2.178	Supplier 26	2.156
27th	Supplier 26	2.241	Supplier 47	2.195
28th	Supplier 36	2.247	Supplier 19	2.216
29th	Supplier 44	2.247	Supplier 34	2.232
30th	Supplier 27	2.406	Supplier 27	2.255
31st	Supplier 17	2.472	Supplier 42	2.333
32nd	Supplier 15	2.500	Supplier 17	2.436
33rd	Supplier 9	2.565	Supplier 15	2.500
34th	Supplier 20	2.612	Supplier 9	2.652
35th	Supplier 42	2.636	Supplier 30	2.652
36th	Supplier 23	2.647	Supplier 23	2.719
37th	Supplier 37	2.647	Supplier 37	2.719
38th	Supplier 46	2.647	Supplier 46	2.719
39th	Supplier 30	2.716	Supplier 20	2.759
40th	Supplier 6	2.784	Supplier 6	2.774
41st	Supplier 28	2.795	Supplier 40	2.902
42nd	Supplier 50	2.795	Supplier 13	2.931
43rd	Supplier 40	2.833	Supplier 14	2.931
44th	Supplier 48	2.905	Supplier 28	2.931
45th	Supplier 25	3.036	Supplier 50	2.931
46th	Supplier 32	3.036	Supplier 25	2.971
47th	Supplier 13	3.075	Supplier 32	2.971
48th	Supplier 14	3.075	Supplier 48	2.971
49th	Supplier 22	3.240	Supplier 22	3.252
50th	Supplier 45	3.358	Supplier 45	3.262

Figure 18 Ranking scores from the ‘Green image’ fuzzy system

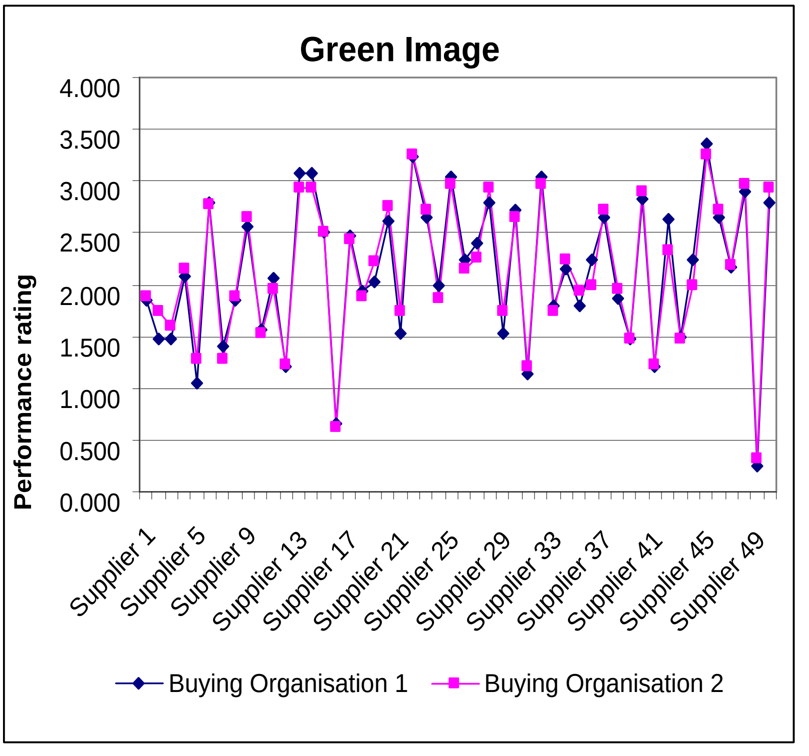

Figure 19 Results from the ‘Green image’ fuzzy system

Design for Environment				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 46	0.786	Supplier 34	0.925
2nd	Supplier 34	0.978	Supplier 11	0.965
3rd	Supplier 11	1.112	Supplier 46	0.981
4th	Supplier 32	1.249	Supplier 32	1.328
5th	Supplier 15	1.357	Supplier 15	1.496
6th	Supplier 21	1.559	Supplier 23	1.529
7th	Supplier 1	1.559	Supplier 24	1.534
8th	Supplier 23	1.628	Supplier 37	1.552
9th	Supplier 28	1.636	Supplier 28	1.575
10th	Supplier 33	1.642	Supplier 17	1.680
11th	Supplier 17	1.646	Supplier 21	1.720
12th	Supplier 37	1.673	Supplier 14	1.787
13th	Supplier 10	1.790	Supplier 1	1.789
14th	Supplier 24	1.802	Supplier 6	1.791
15th	Supplier 40	1.831	Supplier 43	1.861
16th	Supplier 30	1.898	Supplier 27	1.865
17th	Supplier 43	1.906	Supplier 30	1.870
18th	Supplier 6	1.917	Supplier 7	1.875
19th	Supplier 27	1.925	Supplier 36	1.879
20th	Supplier 47	1.973	Supplier 38	1.902
21st	Supplier 36	1.996	Supplier 18	1.977
22nd	Supplier 7	2.013	Supplier 10	1.993
23rd	Supplier 13	2.026	Supplier 47	2.012
24th	Supplier 38	2.040	Supplier 33	2.014
25th	Supplier 12	2.066	Supplier 2	2.107
26th	Supplier 19	2.126	Supplier 12	2.124
27th	Supplier 14	2.184	Supplier 40	2.147
28th	Supplier 2	2.251	Supplier 41	2.179
29th	Supplier 5	2.294	Supplier 35	2.284
30th	Supplier 18	2.296	Supplier 13	2.300
31st	Supplier 35	2.318	Supplier 26	2.341
32nd	Supplier 49	2.332	Supplier 19	2.362
33rd	Supplier 41	2.347	Supplier 5	2.425
34th	Supplier 31	2.468	Supplier 31	2.439
35th	Supplier 4	2.561	Supplier 49	2.552
36th	Supplier 25	2.570	Supplier 4	2.603
37th	Supplier 26	2.599	Supplier 25	2.612
38th	Supplier 22	2.660	Supplier 16	2.655
39th	Supplier 3	2.676	Supplier 3	2.684
40th	Supplier 8	2.714	Supplier 50	2.723
41st	Supplier 29	2.755	Supplier 22	2.749
42nd	Supplier 42	2.827	Supplier 42	2.766
43rd	Supplier 16	2.831	Supplier 8	2.797
44th	Supplier 44	2.833	Supplier 44	2.831
45th	Supplier 50	2.892	Supplier 9	2.904
46th	Supplier 9	2.965	Supplier 29	2.941
47th	Supplier 45	3.112	Supplier 45	2.951
48th	Supplier 39	3.148	Supplier 48	2.991
49th	Supplier 48	3.195	Supplier 39	3.210
50th	Supplier 20	3.582	Supplier 20	3.649

Figure 10 Ranking scores from the ‘Design for environment’ fuzzy system

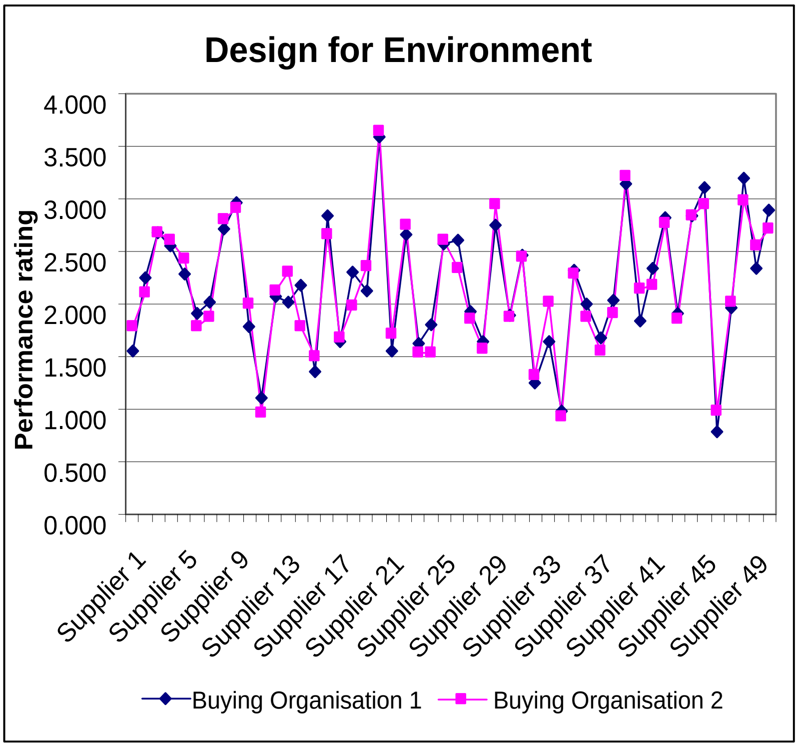

Figure 11 Results from the ‘Design for environment’ fuzzy system

Environmental Magement Systems				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 19	0.818	Supplier 19	0.988
2nd	Supplier 13	0.925	Supplier 13	0.989
3rd	Supplier 20	1.441	Supplier 50	1.392
4th	Supplier 50	1.497	Supplier 45	1.579
5th	Supplier 23	1.506	Supplier 6	1.623
6th	Supplier 28	1.511	Supplier 28	1.625
7th	Supplier 22	1.540	Supplier 39	1.661
8th	Supplier 39	1.591	Supplier 22	1.668
9th	Supplier 6	1.601	Supplier 23	1.683
10th	Supplier 45	1.668	Supplier 20	1.709
11th	Supplier 43	1.747	Supplier 35	1.709
12th	Supplier 5	1.748	Supplier 43	1.801
13th	Supplier 47	1.814	Supplier 5	1.871
14th	Supplier 4	1.826	Supplier 17	1.927
15th	Supplier 26	1.914	Supplier 26	1.934
16th	Supplier 35	1.964	Supplier 47	1.979
17th	Supplier 29	1.976	Supplier 4	1.994
18th	Supplier 17	1.984	Supplier 29	2.016
19th	Supplier 49	1.991	Supplier 16	2.106
20th	Supplier 15	2.111	Supplier 15	2.145
21st	Supplier 34	2.137	Supplier 49	2.146
22nd	Supplier 16	2.162	Supplier 38	2.245
23rd	Supplier 24	2.202	Supplier 46	2.276
24th	Supplier 46	2.218	Supplier 24	2.329
25th	Supplier 33	2.232	Supplier 34	2.417
26th	Supplier 14	2.234	Supplier 8	2.438
27th	Supplier 2	2.263	Supplier 31	2.444
28th	Supplier 31	2.289	Supplier 33	2.448
29th	Supplier 27	2.322	Supplier 14	2.452
30th	Supplier 38	2.329	Supplier 27	2.470
31st	Supplier 9	2.465	Supplier 21	2.480
32nd	Supplier 8	2.537	Supplier 42	2.482
33rd	Supplier 1	2.557	Supplier 2	2.495
34th	Supplier 3	2.563	Supplier 41	2.502
35th	Supplier 21	2.585	Supplier 3	2.514
36th	Supplier 44	2.677	Supplier 1	2.559
37th	Supplier 41	2.689	Supplier 44	2.655
38th	Supplier 42	2.697	Supplier 9	2.658
39th	Supplier 7	2.739	Supplier 7	2.686
40th	Supplier 48	2.776	Supplier 48	2.723
41st	Supplier 10	2.787	Supplier 10	2.810
42nd	Supplier 12	2.820	Supplier 12	2.897
43rd	Supplier 36	2.985	Supplier 30	2.952
44th	Supplier 30	3.013	Supplier 11	2.982
45th	Supplier 11	3.048	Supplier 36	2.982
46th	Supplier 32	3.083	Supplier 32	3.165
47th	Supplier 18	3.355	Supplier 18	3.212
48th	Supplier 25	3.375	Supplier 25	3.385
49th	Supplier 37	3.593	Supplier 37	3.558
50th	Supplier 40	3.640	Supplier 40	3.626

Figure 12 Ranking scores from the ‘Environmental management systems’ fuzzy system

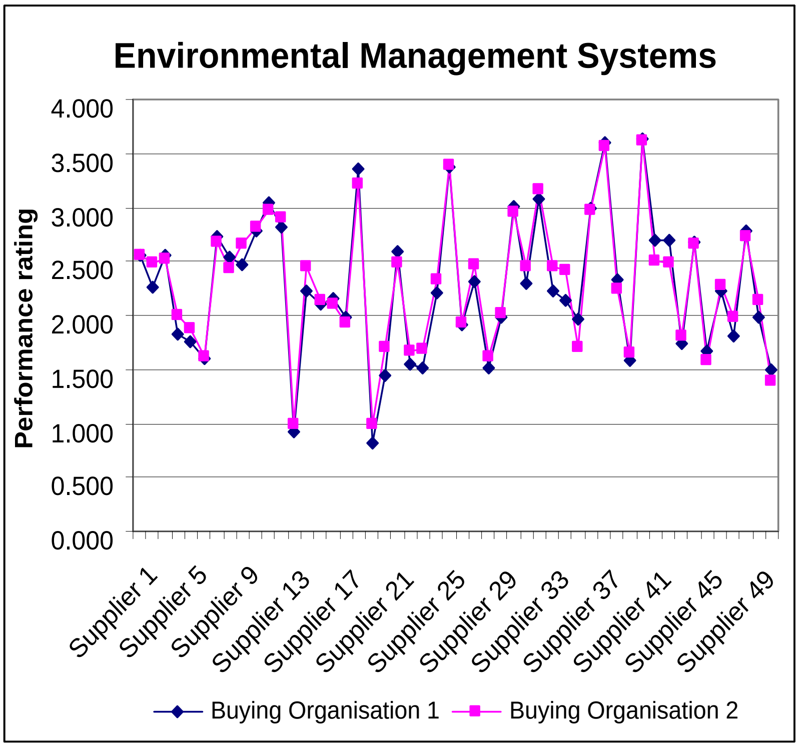

Figure 13 Results from the ‘Environmental management systems’ fuzzy system

Environmental Competencies				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 44	0.562	Supplier 44	0.621
2nd	Supplier 16	1.243	Supplier 29	1.381
3rd	Supplier 23	1.401	Supplier 16	1.387
4th	Supplier 29	1.449	Supplier 35	1.643
5th	Supplier 35	1.459	Supplier 20	1.721
6th	Supplier 14	1.651	Supplier 40	1.747
7th	Supplier 40	1.744	Supplier 39	1.754
8th	Supplier 28	1.811	Supplier 41	1.754
9th	Supplier 27	1.818	Supplier 25	1.769
10th	Supplier 19	1.834	Supplier 27	1.802
11th	Supplier 48	1.842	Supplier 23	1.804
12th	Supplier 25	1.870	Supplier 14	1.829
13th	Supplier 11	1.878	Supplier 32	1.853
14th	Supplier 20	1.922	Supplier 19	1.886
15th	Supplier 2	1.926	Supplier 48	1.903
16th	Supplier 22	1.928	Supplier 28	1.932
17th	Supplier 8	1.929	Supplier 4	1.948
18th	Supplier 32	1.939	Supplier 22	1.948
19th	Supplier 39	1.940	Supplier 46	2.099
20th	Supplier 41	1.940	Supplier 36	2.102
21st	Supplier 46	1.967	Supplier 43	2.127
22nd	Supplier 43	1.994	Supplier 49	2.129
23rd	Supplier 36	2.025	Supplier 2	2.132
24th	Supplier 4	2.051	Supplier 11	2.177
25th	Supplier 49	2.060	Supplier 3	2.197
26th	Supplier 37	2.287	Supplier 8	2.230
27th	Supplier 15	2.351	Supplier 15	2.329
28th	Supplier 7	2.388	Supplier 37	2.330
29th	Supplier 17	2.429	Supplier 1	2.337
30th	Supplier 13	2.455	Supplier 31	2.337
31st	Supplier 3	2.481	Supplier 42	2.468
32nd	Supplier 34	2.497	Supplier 24	2.469
33rd	Supplier 47	2.518	Supplier 13	2.472
34th	Supplier 9	2.529	Supplier 17	2.513
35th	Supplier 10	2.529	Supplier 34	2.519
36th	Supplier 1	2.557	Supplier 6	2.532
37th	Supplier 31	2.557	Supplier 9	2.535
38th	Supplier 30	2.573	Supplier 10	2.535
39th	Supplier 42	2.577	Supplier 47	2.562
40th	Supplier 45	2.596	Supplier 30	2.620
41st	Supplier 24	2.646	Supplier 45	2.653
42nd	Supplier 18	2.696	Supplier 7	2.661
43rd	Supplier 12	2.807	Supplier 5	2.686
44th	Supplier 6	2.829	Supplier 12	2.759
45th	Supplier 26	2.984	Supplier 26	2.800
46th	Supplier 5	2.998	Supplier 18	2.899
47th	Supplier 38	3.088	Supplier 21	2.952
48th	Supplier 33	3.116	Supplier 33	2.956
49th	Supplier 21	3.211	Supplier 38	3.177
50th	Supplier 50	3.607	Supplier 50	3.542

Figure 14 Ranking scores from the ‘Environmental competencies’ fuzzy system

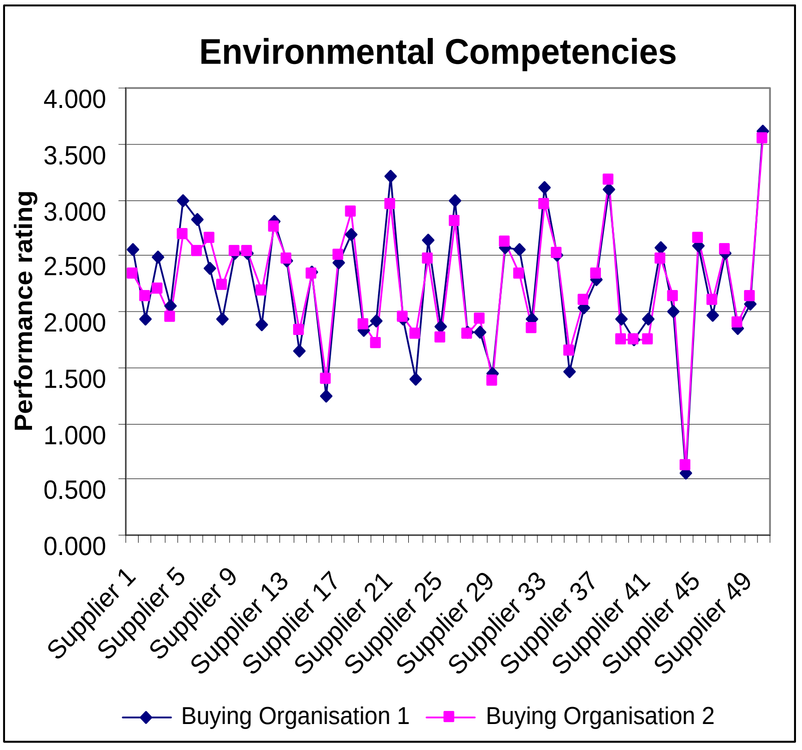

Figure 15 Results from the ‘Environmental competencies’ fuzzy system

Environmental Issues				
Position	Buying Organisation 1		Buying Organisation 2	
1st	Supplier 19	1.520	Supplier 49	1.666
2nd	Supplier 49	1.646	Supplier 16	1.695
3rd	Supplier 46	1.670	Supplier 43	1.738
4th	Supplier 43	1.678	Supplier 19	1.781
5th	Supplier 16	1.779	Supplier 46	1.837
6th	Supplier 34	1.782	Supplier 11	1.860
7th	Supplier 35	1.871	Supplier 35	1.901
8th	Supplier 23	1.888	Supplier 41	1.902
9th	Supplier 13	1.892	Supplier 44	1.904
10th	Supplier 44	1.917	Supplier 34	1.904
11th	Supplier 15	1.930	Supplier 2	1.949
12th	Supplier 11	1.933	Supplier 23	1.951
13th	Supplier 28	1.939	Supplier 24	1.957
14th	Supplier 2	1.941	Supplier 47	1.965
15th	Supplier 4	1.947	Supplier 29	1.974
16th	Supplier 29	1.947	Supplier 4	1.992
17th	Supplier 17	1.958	Supplier 28	1.996
18th	Supplier 47	1.964	Supplier 15	1.999
19th	Supplier 27	1.967	Supplier 13	2.000
20th	Supplier 14	1.984	Supplier 7	2.007
21st	Supplier 41	2.000	Supplier 27	2.007
22nd	Supplier 24	2.008	Supplier 5	2.010
23rd	Supplier 31	2.041	Supplier 17	2.017
24th	Supplier 32	2.042	Supplier 12	2.019
25th	Supplier 1	2.045	Supplier 1	2.028
26th	Supplier 10	2.065	Supplier 36	2.052
27th	Supplier 7	2.069	Supplier 10	2.058
28th	Supplier 8	2.069	Supplier 6	2.063
29th	Supplier 12	2.070	Supplier 39	2.073
30th	Supplier 5	2.095	Supplier 8	2.074
31st	Supplier 6	2.097	Supplier 3	2.075
32nd	Supplier 39	2.112	Supplier 21	2.081
33rd	Supplier 33	2.115	Supplier 31	2.093
34th	Supplier 36	2.135	Supplier 33	2.096
35th	Supplier 22	2.158	Supplier 14	2.103
36th	Supplier 38	2.184	Supplier 32	2.135
37th	Supplier 21	2.247	Supplier 38	2.140
38th	Supplier 3	2.264	Supplier 26	2.142
39th	Supplier 26	2.287	Supplier 22	2.282
40th	Supplier 20	2.344	Supplier 18	2.342
41st	Supplier 30	2.348	Supplier 30	2.362
42nd	Supplier 40	2.425	Supplier 20	2.386
43rd	Supplier 37	2.518	Supplier 48	2.412
44th	Supplier 48	2.609	Supplier 37	2.535
45th	Supplier 25	2.623	Supplier 42	2.567
46th	Supplier 42	2.626	Supplier 40	2.568
47th	Supplier 50	2.636	Supplier 50	2.583
48th	Supplier 45	2.642	Supplier 45	2.611
49th	Supplier 18	2.666	Supplier 25	2.635
50th	Supplier 9	2.666	Supplier 9	2.697

Figure 16 Ranking scores from the ‘Environmental issues’ fuzzy system