Sustainable Supplier Selection with ANP and Fuzzy ANP: A Salt Production Company Example

Chi-Yang Tsai †
Department of Industrial Engineering and Management
Yuan Ze University, Taoyuan, Taiwan
Tel: (+886) 3-463-8800, Email: iecytsai@saturn.yzu.edu.tw

Stephany Molina
Department of Industrial Engineering and Management
Yuan Ze University, Taoyuan, Taiwan
Tel: (+886) 3-463-8800, Email: s1025457@mail.yzu.edu.tw

Abstract. Sustainability is a center topic nowadays, not only for companies which are developing new social responsibilities activities or process in the making of their products but also the ones that have the acknowledgement of a social or environmental misconduct at any stage of the supply chain. There are several cases, in which global brands suffered reputational damage through theirs suppliers' social or environmental misconduct. These cases reveal that the supplier's business behavior influences a company performance and as a consequence, the consideration of sustainability in the supplier selection process becomes fundamental. In this study, we consider the problem of selecting a supplier that can help the company meet the standards for sustainability. A set of criteria and sub-criteria is established. The techniques of Analytical Network Process (ANP) and Fuzzy Analytical Network Process (FANP) are then applied. A salt production company example is presented, in which the company needs to select a sustainable supplier of Nylon used in the salt production as a material to construct the appropriate environment to evaporate the water of the salt. The results obtained by the two techniques to the same selection problem were analyzed and compared.

Keywords: Sustainability, Supplier Selection, Analytic Network Process, Fuzzy Analytic Network Process.

1. INTRODUCTION

Supply chain management represent one of the most significant issues for companies nowadays, thus is an extensive area to talk about. Among various related subjects, supplier selection is one involved that has gained mounting attention in literature and business practices. The changing global environment raises important questions regarding sourcing activities undertaken by companies. Innovative ideas should be taken in consideration to reduce cost, waste, lead time and to optimize process avoiding to affect quality of the final product or service. The main consideration of the present thesis is sustainability included in supplier selection. The idea of including sustainability as a criteria should be consider as a challenge, especially because traditionally, supplier selection is based on the criterion of price. In fact, the definitive judgment is often made without the needed information. Moreover sometimes sustainability could incur on new implementations in the process of companies. Any challenge can become an opportunity, innovate products and environmental features are key sources of competitive advantage. Nowadays, it is more common to hear about sustainable entrepreneurship, hybrid organizations (Boyd et al., 2009), green alliances and companies that have embraced corporate social responsibility. These types of organizations have achieved sustainability when adopting the well-known triple bottom line: profit, people and planet.

The UN World Commission on Environment and Development United Nations (1987) and the United Nations (2005) World Summit refer to sustainable development as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.(Caniëls et al., 2013). Sustainable development and sustainability is frequently interpreted as a synthesis of economic, environmental and social development, the triple-bottom-line approach.

Even though environmental considerations in supplier selection decisions have existed, a more systematic inclusion of other sustainability factors is needed. The previous dual concerns of economic and environmental aspects in supplier

selection need to be expanded into a triad that involves social factors, i.e. human rights abuses, child labor, and irresponsible investment. Globally, companies are increasingly acknowledging the importance of social issues like human rights, labor and corruption. Consequently, consideration of both environmental and social factors needs to be at the forefront of companies' supplier selection agenda (Bai and Sarkis, 2009).

This research aims at demonstrating how companies can take sustainability into account when they are selecting suppliers. Even if there are several researches about supplier selection, there are few taking sustainability into account in this subject. This research emphasizes on a comprehensive and reliable methodology to select suppliers, including sustainability as part of the main criteria when selecting suppliers. Two methods are applied, Analytical Network Process (ANP) and Fuzzy-ANP (FANP). The objectives are two-fold: (1) to develop a sustainable supplier selection system and (2) to compare performance of ANP and Fuzzy-ANP methods. We would like to construct a system to select suppliers that meet the requirement of sustainability of the company. The criteria and sub-criteria needed to be considered are to be determined, referring to the triple-bottom line approach: economic, environmental and social culture. ANP and Fuzzy-ANP methods are applied and their performance will be evaluated and compared.

Supplier selection methods are divided into two clusters, single model and combined model. In single model methods, only one technique is applied. Commonly used techniques include mathematical methods such as Analytic Hierarchy Process (AHP), Linear Programming (LP), and Data Envelopment Analysis (DEA). Artificial intelligence techniques, such as neural networks, case base reasoning, and fuzzy set theory, can also be applied (Deshmukh and Vasudevan, 2014). There are some studies about green supply chain, were the terms "green" and "sustainability" are both refereeing to ecological sustainability, the planet aspect of the triple bottom line concept (Caniëls et al., 2013).

ANP, introduced by Saaty, is a generalization of the AHP (Saaty, 1996). ANP is the first mathematical theory that makes it possible to deal with all kinds of dependences and feedbacks by replacing hierarchies with networks. ANP it is convenient in situations where there is a high degree of interdependence between various attributes of the alternatives. The main objective is to determinate the overall influence of all the elements (Kahraman and Ö ztays, 2014).

The fuzzy set was introduced by Zadeh in 1965. In fuzzy set, instead of a certain number values, linguistic expressions can be defined easily. The linguistic expressions allows precise modeling of imprecise statements such as "equally important", "very important" or "strongly important". Generally, the fuzzy sets are defined by the membership functions. The membership function assigns to each object a grade of membership ranging between 0 and 1. The degree to which an element belongs to a set is defined by the value between 0 and 1 (Kahraman and Ö ztays, 2014).

The rest of the paper is organized as follows. The next section introduces the construction of sustainable supplier selection systems by ANP and FANP, respectively. A real case is presented to illustrate the use of the systems in section 3. The last section concludes the paper.

2. SYSTEM CONSTRUCTION

When selecting suppliers for the company, there are too many factors needed to be considered, making the right decision while having to deal with various peoples' opinions becomes complex. To solve this problem a multi-criteria decision making method is needed which have to provide as result the best option of supplier taking into consideration the traditional factors to select supplier as well as sustainability. The multi-criteria decision making method applied in this research is the Analytic Network Process (ANP). This method is comparatively easy to apply and it has the capacity of allows interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). However, the conventional ANP still cannot reflect the human style of thinking. Fuzziness is always existent in people opinions. A different technique included in the method like fuzzy numbers, would provide better results. Therefore, fuzzy-ANP approach is selected. The procedure of this research is illustrated in Figure 1.

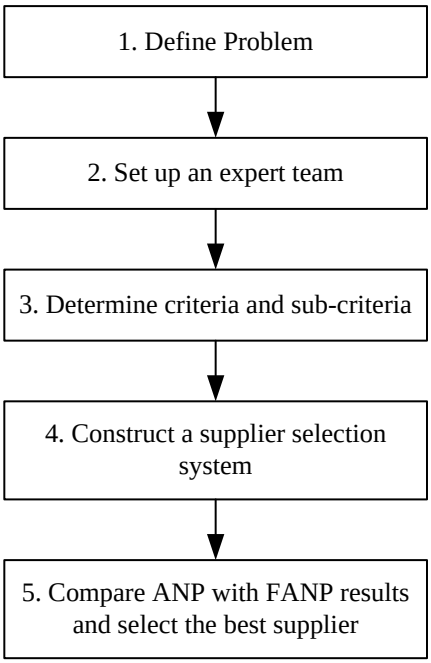

Figure 1: Research procedure.

We first for a list of criteria that should be considered in supplier selection through review of relate literature. After reviewing 16 related research papers who propose criteria and sub-criteria that should be considered in supplier selection, 3 criteria and 29 sub-criteria are obtained, as listed in Table 1. Next, we found 15 experts with working experience in the related area from LinkedIn, a business-oriented social networking service, mainly used for professional networking. We asked them for their opinions on whether these sub-criteria are relevant to supplier selection. The resulting approval % is also shown in Table 1.

Table 1: Criteria and sub-criteria.

Criteria	**Sub criteria**	**Approval %**
Economic	Cost/Price	100.00%
	Quality	93.33%
	Technology capability	73.33%
	Production facilities and capacity	100.00%
	Financial capability	86.67%
	Organization and management	60.00%
	Delivery	93.33%
	Service	100.00%
	Flexibility	100.00%
Environmental	Environmental cost	60.00%
	Green design	46.67%
	Environmental management system	46.67%
	Environmental competencies	33.33%
	Green R&D	20.00%
	Pollution control	80.00%
	Green Product	66.67%
	Resource consumption	60.00%
	ECO-design requirements for energy using product	46.67%
	Ozone depleting chemicals	26.67%
	Waste electrical and electronic equipment	26.67%
	Recycling	60.00%
	Green supply chain management innovation	46.67%
	Packaging	80.00%
	Labelling/certification	80.00%
	Storage	86.67%
Social Culture and Strategy	The interest and rights of employees	73.33%
	Work safety and labor health	80.00%
	Respect for the policy	93.33%
	Relationship	86.67%

The first sub-criteria, Cost/Price, has the approval of all the 15 experts. All but one expert consider the sub-criteria, Quality, relevant, resulting in an approval % of 93.33%. 8 sub-criteria receive approval of less than half of the participants in the survey, indicating low relevance. We screen out these sub-criteria and keep the remaining 21 sub-criteria. Table 2 summarizes the final result.

Table 2: Final list of criteria and sub-criteria.

Criteria	**Sub criteria**
Economic	Cost/Price
	Quality
	Technology capability
	Production facilities and capacity
	Financial capability
	Organization and management
	Delivery
	Service
	Flexibility
Environmental	Environmental cost
	Pollution control
	Green Product
	Resource consumption
	Recycling
	Packaging
	Labelling/certification
	Storage
Social Culture and Strategy	The interest and rights of employees
	Work safety and labor health
	Respect for the policy
	Relationship

To determine the level of relevance of these criteria and sub-criteria, we again turned to LinkedIn experts for their thoughts on the relationship of interdependence among the 3 selected criteria and 21 sub-criteria. This time, an expert team containing 11 members is set up. Their nationalities and positions are listed in Table 3. All of them have more than 10 years of experience in supply chain area and wide knowledge of sustainability.

The experts tend to specify their preferences in the form of natural language expressions. The fuzzy linguistic variable, whose value represents the range from natural to artificial language, is a variable that reflects different aspects of human language. The variable describing human expressions in the study are divided as equal, moderate favors, strong favors, very strong favors and extreme favors. The linguistic scales are explained as in Table 4. For the purpose of the ANP method, a 1 to 9 scale is presented for the relative importance of pairwise comparison. When making pairwise comparisons, the

questions are formulated in terms of dominance or influence. A sample of pairwise comparison questionnaire is provided in Table 5.

Table 3: Members of expert team.

No.	Country	Position
1	Canada	Senior manager, Global supply chain department, Paradigm Electronics.
2	USA	Manager and leader of integrated supply chain, MSIE, CSCP.
3	Switzerland	Supply chain business review leader, IKES Supply Chain.
4	Saudi Arabia	Experienced supply management professional, Al Majdouie Group.
5	Italy	Assistant professor, Department of Chemical and Environmental Engineering (DICCA), University of Genoa.
6	Israel	Founder and CEO, Granot Strategic Consulting.
7	Honduras	Supply chain manager, Millicom, Honduras.
8	USA	Director of finance, Global retail strategy, UPS.
9	USA	Logistics and supply chain, Charlotte area, North Carolina.
10	Germany	E-procurement manager, CWS-boco.
11	Italy	Industrial logistic director, CNH Industrial.

Table 4: Linguistic scale explanation.

Score	Definition	Explanation
1	Equal	Two activities contribute equally to the objective
3	Moderate	Experience and judgment slightly favor one activity over another
5	Strong	Experience and judgment strongly favor one activity over another
7	Very Strong	An activity is favored very strongly over another
9	Extreme	The evidence favoring one activity over another is of the highest possible order of affirmation

The filled questionnaires are collected from the 11 experts and the result is summarized. We first analyze the outcome of the survey by applying ANP and obtain a set of weights of each criterion and sub-criterion. The analysis is done by using Super Decisions, a software developed by Dr. Saaty, with the purpose of provide assistance in the decision-making process.

With ANP, the experts' opinions are taken as an exact number that could not necessarily give a precise value of the experts' linguistic preference. To evaluate the decision maker preferences with FANP, pairwise comparison matrices are structured by using triangular fuzzy number (TFN). Table 6 shows the TFN linguistic scale used in this research. For example, the "moderate favors" value of the linguistic scale take place in the relevant cell against the triangular fuzzy numbers (1, 3, 5).

Table 5: Sample of pairwise comparison questionnaire.

		9	7	5	3	1	3	5	7	9		
No.	Sub-criteria	Extreme favors	Very strong favors	Strong favors	Moderate favors	Equal	Moderate favors	Strong favors	Very strong favors	Extreme favors	Sub-criteria	No.
S2	Quality										Delivery	S7
S2	Quality										Service	S8
S2	Quality										Flexibility	S9

After all the experts' pairwise comparisons are collected from the survey, the fuzzy values of expert's opinions are calculated. We then proceed to construct the pairwise comparison matrix. A set of weights of criteria and sub-criteria is the obtained based on FANP. It is important to emphasize that the data used in both techniques is the same.

In these models we want to evaluate if the final results will give us the same alternative in both ANP and FANP. Meanwhile we construct the case study, we can make comparison of the weights obtain in both methods for the criteria and sub-criteria.

Table 7 shows the final weights of the criteria for both methods ANP and FANP. It is apparent that there are some differences among methods. FANP has considered 45.53% for the economic criteria while ANP has considered 48.74% for the same criteria, it should be emphasized that both methods agreed on the most relevant criteria for this example which is the Economic aspect of the model. Nonetheless it is normal to

observe some variances in weights due to the differences to input the data in both methods, ANP used just a specific scale where the number of preference is selected, while FANP use fuzzy numbers to demonstrate a preference.

Table 6: Triangular fuzzy number linguistic scale.

Linguistic scale for importance	**TFN scale**		
(1) Equal	1	1	3
(2) Moderate	1	3	5
(5) Strong	3	5	7
(7) Very Strong	5	7	9
(9) Extreme	7	9	9

The two methods agreed on the most relevant criteria for this example which is the Economic aspect of the model. Nonetheless it is normal to observe some variances in weights due to the differences to input the data in both methods, ANP used just a specific scale where the number of preference is selected, while FANP use fuzzy numbers to demonstrate a preference.

Table 7: Criteria weights.

Criteria	**ANP**	**FANP**
Economic	0.486471	0.455346
Environmental	0.208706	0.208921
Social Culture	0.208706	0.086760

Table 8 shows the weights of the sub-criteria for both methods. Again, we have observed some variances between the results of two methods. We highlight those with the large differences between sub-criteria (0.01 approximately the difference of priority between sub-criteria found).

3. CASE

The constructed supplier selection system is applied to a case company to demonstrate its use. The case is presented in this section.

PRONASALCO S. de R. L. is a company of salt production in the south of Honduras. It was established by Jose Molina in 1980 as a family business. At the beginning the company was dedicated only to the salt extraction, which was sold without processing in it. In 1990 the company decided to reach more customers, achieved a better productivity level, improved incomes and the benefits for their employees. During that year the company became not only a salt producer but also a packing and distribution company, reaching the wholesale buyers and final consumers, thereby obtaining higher revenues and also turned into a source of employment for workers in the community.

Table 8: Sub-criteria weights.

Sub-criteria	**ANP**	**FANP**
Cost/Price	0.081756	0.08676
Delivery	**0.042220**	**0.034647**
Financial capability	0.042800	0.040444
Flexibility	0.061173	0.062395
Organization management	0.071992	0.074662
Production facilities and capacity	0.077697	0.07175
Quality	**0.096694**	**0.080211**
Service	**0.064624**	**0.053366**
Technology capability	**0.027841**	**0.030245**
Environmental cost	**0.019033**	**0.026894**
Green product	0.014127	0.017686
Labeling/Certification	**0.040411**	**0.038291**
Packaging	**0.031398**	**0.026662**
Pollution control	0.022495	0.025339
Recycling	0.010297	0.01028
Resource consumption	0.015406	0.017052
Storage	**0.069412**	**0.057079**
Relationship	**0.00345**	**0.004349**
Respect for the policy	**0.024209**	**0.030311**
The interest and rights of employees	0.027113	0.026859
Work safety and labor health	0.041365	0.044199

In the manufacturing process, nylon is needed as an indispensable material for the key process step. PRONASALCO S. de R. L. uses and changes the nylon each production season. This material is essential on each production season and determine 20% of the total production cost. Due to the characteristics of the process, the required nylon can only be obtained from 3 suppliers in Honduras. They are Interplast S.A. (supplier 1), Plasticos Pineda S. de R. L. (supplier 2) and Plasticos Varguansdis S. de R. L (supplier 3).

The quality and sales terms of nylon depends on each supplier, which makes supplier selection an important decision for the case company.

PRONSALCO S. de R. L. does not have a supplier selection system, and does not have an advantage over its competitors. As the present research attempts to include sustainability into the supplier selection system, a sustainable supplier selection system was proposed to the CEO and Operations manager of PRONASALCO S. de R. L. to select the best supplier of Nylon.

To choose the most suitable nylon supplier for the case company, another expert team is set up. Each member in the team is the owner of a salt production company, as shown in Table 9. These experts are asked to evaluate the three nylon suppliers based on the criteria and sub-criteria selected in the previous section. The accounting and financial areas had collected historic information of suppliers from 2013-2015 likewise the operations area did. This information was collected with the purpose of bring quantitative values for objective judgments. Information required includes technical information of the material from each supplier, historical data from the sales area, historical data from production area, historical data from quality control, and accounting information.

Table 9: Salt production experts.

Company	Experience (Years)
Perla y Calamar	50
Sal yodada Radiante	50
Palomo	30
Sal yodada Henecan	24
Corinto y Ostra	30
El velero	20
La Gaviota	26
La Macarela	45
Sal Yodada Flamingo	25
Plato Azul	50

Combined with the weights of the criteria and sub-criteria, the synthesized priorities (normalized values) of the three suppliers are then calculated. The results are shown in Table 10.

Table 10: Synthesized priorities.

	ANP	FANP
Supplier 1	0.333770	0.343637
Supplier 2	0.347390	0.345627
Supplier 3	0.318841	0.310735

Both methods provide the same ranking of the three suppliers. Supplier 2 is the most suitable supplier for the case company, followed by supplier 2.

4. CONCLUSION

After developing this system we can endorse the relevance of using methods of decision analysis based on quantitative models and decision makers' experiences. Supplier selection could be hard if the necessary data is not provided or if the company does not count with a respectable supplier selection system. After analyzing the data obtained from the questionnaires, calculated the parameter local weights, acquired the local weights for the alternatives and constructed the ANP model. We made a comparison between the two techniques. The developed system can be applicable to any company, and as shown in the results either FANP or ANP are techniques with similar answers when defining a solution, selection of technique will rely on the company requirements and objectives.

Even though the model seems to be very accurate and completed, there are always going to be some improvements to make in order to achieve a better working system with an output of more accurate solutions. These are some observations we were able to identify through the realization of this system but are part of future research. The criteria and sub-criteria established can be used for other supplier selection models utilizing a different technique. For a sustainable supplier selection system, a review among relevant criteria and sub-criteria by different experts would be necessary, it is important to remind that criteria and sub-criteria were selected by experts to develop an original supplier selection system, those criteria and sub-criteria can be revaluated to model improvements.

REFERENCES

Boyd, B., Henning, N., Reyna, E., Wang, D., and Welch, M. (2009) *Hybrid organizations: New business models for environmental leadership*, Greenleaf Publishing.

Caniëls, M. C. J., Gehrsitz, M. H., and Semeijn, J. (2013) Participation of suppliers in greening supply chains: An empirical analysis of German automotive suppliers. *Journal of Purchasing and Supply Management*, **19**, 134-143.

Bai C, and Sarkis J. (2009) Supplier selection and sustainability: A Grey Rough Set evaluation, *Working Paper, Clark University, George Perkins Marsh Institute*.

Deshmukh, A. J., and Vasudevan, H. (2014) Emerging supplier selection criteria in the context of traditional vs. green supply chain management. *International Journal of Managing Value and Supply Chains*, **5**, 19-33.

Kahraman C, and Öztaysi B. (2014) *Supply Chain Management under Fuzziness*, Springer-Verlag Berlin Heidelberg.

Saaty, T. L. (1996) *Decision Making with Dependence and Feedback: The Analytic Network Process*. University of Pittsburgh. RWS Publications.