SUPPLIER SELECTION USING A HYBRID MODEL FOR 3C INDUSTRY

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Abstract. Supplier selection is a good strategy for firms that can reduce operating costs and improve competitiveness for computer, communication and consumer electronics (3C) industry. The major aim of this research is to build a systematic approach for establishing a supplier selection model, and then prioritize improvement criteria in order to best supply chain management. The study proposed a hybrid approach by using the interpretive structural modeling (ISM) method to deal with the interrelationship among criteria, and the analytic network process (ANP) method is employed to recognize the criteria of supplier selection and evaluate with respect to environmental competency for the case of Taiwan's 3C industry. The study shows that the proposed model could be an effective and efficient decision-making tool that can be easily extended to other contexts. Especially, it has provided decision-makers and researchers with better understanding of the differences in supplier selection activity needs and specific management interventions by examining these criteria.

Keywords: supplier selection, interpretive structural modeling, analytic network process, hybrid model, 3C industry, Taiwan.

JEL Classification: C02, C44, C86, L10, M11, O11.

Introduction

Supplier selection decisions affect various functional areas from procurement of raw materials and components to production and delivery of the end products. Selecting appropriate suppliers will significantly reduce the costs of purchasing materials and improve competitive conditions. For this reason, supplier selection problem has been gaining attention in both academic literature and industrial practice.

Supplier selection has been treated as a multi-criteria decision making (MCDM) problem and a wide range of mathematical methods have been undertaken to provide the problems (Agarwal *et al.* 2011; Boer *et al.* 2001; Ho *et al.* 2010; Ku *et al.* 2010; Liou *et al.* 2011). Nevertheless, some have striven to apply the MCDM method to different supplier selection issues, but have assumed the criteria to be independent. It is usually using the analytic hierarchical process (AHP) to construct a model of the supplier selection problems, some main problems should be highlighted as follows. Firstly, in the real world, different criteria are seldom independent and always have a degree of interactive relationships, sometimes with dependence and feedback effects (Tsai, Chou 2009; Tzeng *et al.* 2007). Secondly, given growing environmental concerns during the past decade, a consensus is emerging that environmental pollution issues accompanying industrial development should be addressed together with supplier selection. Despite the growing importance of environmental issues for supplier in the supplier selection (Lamming, Hampson 1996; Rao 2002; Srivastava 2007), it is usually excluded from earlier studies.

In view of the significance of incorporating the environmental issues into supplier selection as well as the limitation of previous studies, the motivation of the study aim to build a systematic approach for establishing a supplier selection model, and then prioritize improvement criteria in order to best supply chain management. To achieve this goal, we use the interpretive structural modeling (ISM) method to deal with the interrelationship among criteria, and the analytic network process (ANP) method (which releases the restriction of the hierarchical structure) is employed to recognize the criteria of supplier selection and evaluate with respect to environmental competency in supplier selection. Therefore, two methods are incorporated in this study. First, we construct the relation map obtained from ISM which can help the user visualize the complex relationships among the criteria. Second, based on the results of the relation map we consider the interdependence and feedback effect between criteria by applying the ANP. Data from a Taiwan's computer, communication and consumer electronics (3C) industry is used to demonstrate this model. This generic model can be easily extended to other industries, to provide some useful information to decision makers or managers for their referential purposes.

The remainder of this paper is organized as follows. In the following section, the related researches of supplier selection criteria are reviewed. The section 2 presents the methods of this study, the ISM and ANP. The section 3 illustrates an empirical case study taking the Taiwanese 3C industry as an example used to validate our model. Discussion and findings are provided in the fourth section. The paper ends with some important managerial implications and suggestions for further research.

1. The evaluating criteria for supplier selection

Choosing criteria is a fundamental section in a decision-making model, especially in supplier selection. A number of research works published in the last decades have addressed a variety of criteria that are important in supplier selection. The analysis of such criteria for the selection, measuring the performances of potential suppliers and

the introduction of a new categories of selection criteria following the market evolutions have been the focus of many researchers and practitioners.

According to the previous studies, various organizations select their suppliers through different criteria across different periods of time and environments. Unlike, the other researchers, we list some of these criteria by types of firms in Table 1.

Table 1. Applications of selected criteria/ sub-criteria for vendor evaluation

Type of firms	Criteria/ sub-criteria	References
Baby food manufacturer	Price, quality, delivery.	Weber (1996)
Bicycle manufacturer	Quality, delivery, price, facility, technical capability, financial position, past performance attitude, flexibility, service.	Muralidharan *et al.* (2002)
Bottling machinery industry	Product price, shipment quality, delivery compliance.	Petroni and Braglia (2000)
Equipment manufacturer	Acquisition costs, product quality, delivery reliability.	Karpak *et al.* (2001)
Public road and rail transportation	Make-up, processing time, prototyping time, design revision time, quality system, co-design, technological level.	Dulmin and Mininno (2002)
Telecommunications company	Cost (capital expenditure, operating expenditure), quality (technical, operational, vendor).	Tam and Tummala (2001)
Wafer-testing	Delivery management capability, quality management capability, integrated service capability, price.	Lin *et al.* (2010)
Airline industry	Compatility, risk, quality, cost.	Liou *et al.* (2011)
Automotive industry	Delivery, quality, price, transportation cost, technology, production system flexibility.	Golmohammadi and Mellat-Parast (2012)
Watch manufacturer	Relationship closeness, quality of product, delivery capabilities, warranty level, experience time.	Liao and Kao (2011)
Irrigation equipment industry	Strategic operational performance, Organizational factor, environmental factor.	Dou *et al.* (2013)

In summary, the existing literature is very rich with the criteria of supplier selection, we conclude there are no universal or exact criteria for supplier selection; thus, supplier selection mean different things for different industries. It seems to suggest that the concept of supplier selection is context-dependent, and its evaluation should reflect the industry environment being investigated. The proposed methodology for supplier selection and how to extract the evaluating criteria in the Taiwan's 3C industry are briefly described in the subsequent sections.

2. Methodology

In this section, we introduce the concepts of the ISM and ANP methods, respectively.

2.1. Interpretive structural modeling

Interpretive structural modeling (ISM), proposed by Warfield (1974a), is based on discrete mathematics, graph theory, social sciences, group decision- making, and computer assistance (Warfield 1974a; 1974b; 1976). The procedures of the binary matrix manipulation of ISM are illustrated as follows:

(1) List criteria (sub-criteria) considered for the problem, and define each criterion (sub-criterion) as e_i, $i = 1,2,3,..., n$.

(2) Formation of incidence matrix. From the criteria (sub-criteria) identified in step 1, establish adjacency (relation) matrix which shows the relationship among the criteria (sub-criteria). Let e_i be the ith criterion, and π_{ij} be the interrelationship between i^{th} and j^{th} criteria. The adjacency matrix is then developed based on a pair-wise comparison of variables. Moreover, the adjacency matrix is formed by asking questions such as, "Will element e_i affect element e_j?". If the answer is yes, then $\pi_{ij} = 1$. If the answer is no, then $\pi_{ij} = 0$. The adjacency matrix is an n x n matrix $A = [\pi_{ij}]$ can be described as follows:

$$A = \begin{array}{c} \\ e_1 \\ e_2 \\ \vdots \\ e_n \end{array} \begin{array}{c} e_1 \quad e_2 \quad \dots \quad e_n \\ \left[\begin{array}{cccc} 0 & \pi_{12} & \cdots & \pi_{1n} \\ \pi_{21} & 0 & \cdots & \pi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{n1} & \pi_{n2} & \cdots & 0 \end{array} \right]. \end{array} \qquad (1)$$

(3) Deduction of reachability matrix. The reachability matrix $R = [r_{ij}]$ is the limit of the Boolean n-multiple product of $A + I$, where I is a Boolean unity matrix, and "+" is addition in Boolean sense. The reachability matrix R represents all linkages between system variables. The entry $r_{ij} = 1$ indicates that variable e_j is under the direct or indirect influence of variable e_i, or it is said that variable e_j is reachable by variable e_i if $r_{ij} = 1$.

(4) Construction of system levels. The "entry level" of a system is a set of variables that cannot be reached by any variables in other sets. All system levels could be identified one by one using a recursive algorithm that excludes the current "entry level" from consideration in the next round after it is identified. The final reachability matrix R^* provides a basic guideline when establishing the system structure.

The main benefits of the ISM methodology is that it transforms unclear and poorly articulated models of systems into visible and well-defined models (Sage 1977). Therefore, we can simply plot the network structure based on the adjacency matrix and reachability matrix to construct the relationships of all the criteria and sub-criteria.

2.2. ANP

The ANP is a generalization of the Analytic Hierarchy Process (AHP) (Saaty 1996). The AHP, also developed by Saaty (1980), is one of the most widely used MCDM methods. However, the AHP method has some fallible premises with the assumption

that the criteria are independent (Satty 1996). The ANP extends the AHP to problems with dependence and feedback. It allows for more complex interrelationships among decision elements by replacing a hierarchy in the AHP with a network (Saaty 2009).

ANP uses a "supermatrix" to obtain the composite weight to deal with the relationship of feedback and interdependence among the criteria. If no interdependent relationship exists among the criteria, then the pairwise comparison value would be 0. If an interdependent and feedback relationship exists among the criteria, then such value would no longer be 0, and an unweighted supermatrix W would be obtained. If the matrix does not conform to the principle of column stochastic, the decision-maker can provide the weights to adjust it into a supermatrix that conforms to the principle of column stochastic. It will then become a weighted supermatrix W. Then, the limited weighted supermatrix W^* is obtained based on Eq. (2), and the gradual convergence of the interdependence relationship results in the obtaining the accurate relative weights among the criteria:

$$W^* = \lim_{k \to \infty} W^k. \tag{2}$$

Moreover, the ANP is the mathematical theory that can deal with all kinds of dependences systematically. Recently, there has been a huge increase in the use of the ANP in a variety of decision making problems (S. Chen, R. Chen 1998; Tjader *et al.* 2013; Hsu *et al.* 2013). In the supplier selection problem, some criteria may have some interdependencies and cannot be captured by the AHP method. Therefore, we use the ANP method instead of the popular AHP approach to the supplier selection model for Taiwan's 3C industry.

2.3. Proposed approach

For supplier selection problem, some criteria may have dependent or feedback relationships. It may distort the actual results if we assume the independence among the criteria. Hence, this study proposed a hybrid model, integrating ISM and ANP to solve supplier selection problem considering environment factors, as follows.

Step 1: Problem description. The first step is to define the service evaluation problem. Moreover, an expert team is formed that not only replies to the questionnaires to construct the evaluation and selection model but also provides professional knowledge based on experience in the service industry.

Step 2: Establishing supplier selection criteria. In the step, the criteria and sub-criteria suitable to evaluate the supplier selection are selected.

Step 3: Using ISM to analyze the interrelationships among the criteria and sub-criteria. In this step, the interrelationships among the criteria in the evaluation model are constructed by applying the ISM method so that a structural network relationship map and the reachability matrix can be constructed accordingly.

Step 4: Utilizing ANP to calculate the relative weight for each criterion and sub-criterion. The ANP is then utilized to derive the weightings based on these interrelationships and the network relationship map from the ISM step. The final step is to determine the limiting the weighted supermatrix for the weight and calculating the weights of all criteria and sub- criteria.

3. Empirical analysis

In this section, an empirical case of the supplier selection for Taiwan's 3C industry is used to illustrate the feasibility of the proposed approach.

3.1. Problem descriptions

The 3C industry in Taiwan, mainly OEM/ODM, is closely related to oversea big electronic companies, holds a significant position in the design, manufacturing and assembly in the global supply chain. The 3C firms need to outsource most of their component to subcontractors and therefore the supplier evaluation and selection is crucial. Therefore, we take a case from Taiwan's 3C industry to demonstrate the proposed approach.

The model is developed and then validated using data from the expert team, which contained 20 experts with extensive experience consulting in this study. Among the 20 experts, 10 were from the computer manufacturer, 5 were from the communication manufacturer, and the remaining 5 were from the consumer-electronics manufacturer. The average industry experience of the experts was about six years. Although this study did not have a large number of experts, they also provided their professional knowledge and experience in 3C and supplier management, along with an industrial perspective. Moreover, they also replied to the questionnaires for constructing this evaluation and selection model.

3.2. Establishing supplier selection criteria

The supplier selection criteria were developed on the basis of a literature review and a series of discussions with expert team. This discussion with the expert team helped us to classify the various criteria of decision-making into five criteria are most suitable. The five criteria include: (1) *Flexible capability* (F); (2) *Quality capability* (Q); (3) *Technological capability* (T); (4) *Environmental management capability* (E); and (5) *Service capability* (S). These criteria were then divided into various sub-criteria, as indicated in Table 2. Because these relevant criteria are summarized on the basis of associated work and consulted by expert team, it can have relatively high content validity and face validity.

3.3. Using ISM to analyze the interrelationships among criteria and sub-criteria

Since the supplier selection is complex, it is not appropriate to assume the elements within selection process are independent. Therefore, we sought to find the important criteria for the various criteria and measure the relationships among these criteria. Experts were asked to score the relationships among criteria and among sub-criteria following the ISM procedures described in methodology. The geometric mean of experts' opinions on the relationship between a pair of criteria (sub-criteria) was calculated. The original interrelationships data amongst all the criteria are listed in Table 3.

Setting the threshold value = 0.50 which represents that more than 50% of the experts determine the interrelationship is existent. If the value of the element inside the matrix is >0.50, the value is counted as 1. If the value of the element is <0.50, the value is counted as 0. Then the interrelationships matrix (**A**) could be gained, and the matrix (R) could be gained, by using Eq. (1), as shown in Tables 4 and 5.

Table 2. The criteria and sub-criteria for supplier selection

Criteria	Sub-criteria	References
Flexible capability (F)	Product flexibility (F1)	Gosling *et al.* (2010); Ndubisi *et al.* (2005)
	Process flexibility (F2)	Gosling *et al.* (2010)
	Delivery flexibility (F3)	Gosling *et al.* (2010)
	Capacity flexibility (F4)	Gosling *et al.* (2010); Ndubisi *et al.* (2005)
Quality capability (Q)	Product quality (Q1)	Chen, Lin and Huang (2006)
	Manufacturing process control ability (Q2)	Evans and Johnson (2005)
	Archive of quality records (Q3)	Evans and Johnson (2005)
Technological capability (T)	Entrepreneurial innovation capability (T1)	Wagner (2009), Schiele (2006)
	Technical support / expertise (T2)	Tam and Tummala (2001)
	Production capability (T3)	Weber, Current and Benton (1991)
Environmental management capability (E)	Environmental protection policy (E1)	Handfield *et al.* (2002); Humphreys *et al.* (2003)
	Research and develop environment friendly materials (E2)	Humphreys *et al.* (2003)
	Product recycle/reuse/recovery (E3)	Handfield *et al.* (2002), Humphreys *et al.* (2003)
Service capability (S)	Conflict / problem solving capability (S1)	Chen, Lin and Huang (2006), Lin and Chang (2008)
	After-sales service (S2)	Tam and Tummala (2001)
	Relationship closeness (S3)	Chen, Lin and Huang (2006), Lin and Chang (2008)

Table 3. Original interrelation matrix

Criteria	F	Q	T	E	S
Flexible capability (F)	0.00	0.55	0.88	0.40	0.95
Quality capability (Q)	0.88	0.00	1.00	0.45	0.85
Technological capability (T)	0.58	0.63	0.00	0.33	0.50
Environmental management capability (E)	0.15	0.45	0.48	0.00	0.40
Service capability (S)	0.87	0.63	0.70	0.10	0.00

Finally, the reachability matrix can be obtained by using Eq. (2). The star (*) indicates the derivative relationship, which did not emerge in the original relation matrix. The correlations of each criterion are shown as Table 6 and Figure 1.

Table 4. Interrelation matrix (A)

Criteria	F	Q	T	E	S
Flexible capability (F)	0.00	1.00	1.00	0.00	1.00
Quality capability (Q)	1.00	0.00	1.00	0.00	1.00
Technological capability (T)	1.00	1.00	0.00	0.00	1.00
Environmental management capability (E)	0.00	0.00	0.00	0.00	0.00
Service capability (S)	1.00	1.00	1.00	0.00	0.00

Table 5. Matrix (R) of all criteria

Criteria	F	Q	T	E	S
Flexible capability (F)	1.00	1.00	1.00	0.00	1.00
Quality capability (Q)	1.00	1.00	1.00	0.00	1.00
Technological capability (T)	1.00	1.00	1.00	0.00	1.00
Environmental management capability (E)	0.00	0.00	0.00	1.00	0.00
Service capability (S)	1.00	1.00	1.00	0.00	1.00

Table 6. Reachability matrix (R^*) of all criteria

Criteria	F	Q	T	E	S
Flexible capability (F)	1.00	1.00	1.00	0.00	1.00
Quality capability (Q)	1.00*	1.00	1.00	0.00	1.00
Technological capability (T)	1.00	1.00	1.00	0.00	1.00
Environmental management capability (E)	0.00	0.00	0.00	1.00	0.00
Service capability (S)	1.00*	1.00	1.00*	0.00	1.00

Based on R^*, the interrelationship among the five criteria can be depicted as in Figure 1. According to the experts' opinions through ISM analysis, *Quality capability* (Q), *Flexible capability* (F), *Technological capability* (T) and *Service capability* (S) were mutually interrelated. This can be seen from the double-sided arrows among the four criteria in Fig. 1. For example, while *Quality capability* (Q) had an effect on Flexible capability (F), *Technological capability* (T) and *Service capability* (S), the criterion was also affected by these three criteria. Such kind of interrelationships also applied to the other three criteria *Flexible capability* (F), *Technological capability* (T) and *Service capability* (S). Also note that *Environmental management capability* (E) was independent from other criteria. Such an outcome might seem to be surprising, but it was generated
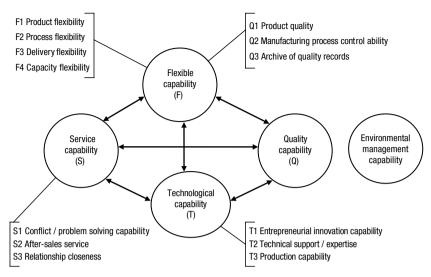
Fig. 1. ANP networked evaluation structure for supplier selection

from the experts' opinions through ISM. The result was double-confirmed after the network was formed. A possible reason behind could be that the interrelationship among *Environmental management capability* and other criteria were not very significant, and thus could be neglected in the criteria level.

3.4. Utilizing ANP to calculate the relative weight for each criterion and sub-criterion

After the previous stage which uses ISM to analyze the interrelationships among the criteria and setting up networked level evaluation structure is done, in the stage, ANP professional questionnaire is developed based on the previous stage. In this research, the opinions of experts were collected and then entered into ANP software of Super Decision to obtain the relative weights of each sub-criterion of each evaluation criteria. Based on the relationship of the four main criteria (see Fig. 1), aiming the sub-criteria belongs to each criteria designing ANP questionnaire, as well as using geometric mean from the experts' opinions to construct a pairwise comparison matrix. An unweighted supermatrix, a weighted supermatrix, and eventually a converged limiting supermatrix (see Table 7) are obtained by introducing pairwise comparison values of sub-criteria in the matrix into ANP software of Super Decision. Then the relative weights of four criteria and sub-criteria are collected (see Table 8).

As illustrated in Table 8, all the consistency ratio (CR) values are less than 0.1, indicating consistency (Saaty 1980). It also could be seen from Table 8 that *Quality capability* (Q) (0.3799) is the one valued the most in the 3C industry, followed closely by *Technological capability* (T) (0.26551), *Flexible capability* (F) (0.23215) and *Service capability* (S) (0.1214) come after in the sequence of four criteria. Moreover, we make a ranking for each sub-criterion in each criterion which indicates the degree of importance from the questionnaire collection. These priorities of the sub-criteria also are listed in Table 8.

Table 7. Limiting supermatrix

	Flexible capability (F)				Quality capability (Q)			Technological capability (T)			Service capability (S)		
	F1	F2	F3	F4	Q1	Q2	Q3	T1	T2	T3	S1	S2	S3
F1	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940	0.02940
F2	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800	0.10800
F3	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092	0.06092
F4	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383	0.03383
Q1	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159	0.21159
Q2	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485	0.11485
Q3	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344	0.05344
T1	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622	0.14622
T2	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400	0.04400
T3	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629	0.07629
S1	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886	0.06886
S2	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975	0.02975
S3	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285	0.02285

Table 8. Relative weights of criteria / sub-criteria

Criteria / sub-criteria	Relative weight (ranking)
Flexible capability (F) (CR = 0.01)	0.23215 (3)
Product flexibility (F1)	0.12663 (4)
Process flexibility (F2)	0.46522 (1)
Delivery flexibility (F3)	0.26241 (2)
Capacity flexibility (F4)	0.14574 (3)
Quality capability (Q) (CR = 0.07)	0.37988 (1)
Product quality (Q1)	0.55700 (1)
Manufacturing process control ability (Q2)	0.30232 (2)
Archive of quality records (Q3)	0.14068 (3)
Technological capability (T) (CR = 0.03)	0.26651 (2)
Entrepreneurial innovation capability (T1)	0.54865 (1)
Technical support / expertise (T2)	0.16511 (3)
Production capability (T3)	0.28624 (2)
Service capability (S) (CR = 0.02)	0.1214 (4)
Conflict / problem solving capability (S1)	0.56692 (1)
After-sales service (S2)	0.24494 (2)
Relationship closeness (S3)	0.18814 (3)

In the *Flexible capability* category, the *Process flexibility* (F2) (0.46522) was rated as the most important criterion; in *Quality capability*, *Product quality* (Q1) (0.55700) was rated as the most important; in *Technological capability*, *Entrepreneurial innovation capability* (T1) (0.54865) was rated as the most important; and in *Service capability, Conflict / problem solving capability* (S1) (0.56692) was rated as the most important. After calculated all the weightings in the evaluation model through the ANP method, the completed Taiwan's 3C industry supplier selection model can be fully established.

4. Discussion and findings

This study not only uses ANP to find out the relative importance between criteria, but also aims at discussing evaluation structure which is the mutual influence between one criteria and the other. Through using ISM approach to give a better understanding of a system structure and draws up a useful guideline in generating a graphical representation of the structure. Herewith the essential analysis results and discussions of ISM, and ANP are elaborated as below.

Firstly, via the result of ISM analysis, it could be seen that *Quality capability*, *Flexible capability*, *Technological* and *Service capability* were mutually interrelated. This can be seen from the double-sided arrows among the four criteria in Figure 1. The diagraph

obtained through ISM helps the 3C industry managers and suppliers to critically investigate each criteria and its influence thus helps them to improve the strategies for criteria. Moreover, the *Environment management capability* was independent from other criteria.

Secondly, what factors management should stress more in the supplier selection of 3C industry should be understood so that more effort can be put on improving the priorities of these factors and on evaluating suppliers. The priority/weight values of the criteria, it can be observed from Table 8 that *Quality capability* (Q) (0.3799) is the most important criterion for supplier selection, followed by *Technological capability* (T) (0.26551), *Flexible capability* (D) (0.23215) and *Service capability* (S) (0.1214) by ANP. The result shows the quality capability of supplier is the major concern of the Taiwan's 3C industry. It's also an important message to the 3C industry that if they want to win the business, the *Quality capability* of supplier related operations need to be enhanced.

Finally, the priorities of the sub-criteria also are listed in Table 8. In the *Flexible capability* category, the *Process flexibility* (F2) (0.46522) was rated as the most important criterion; in *Quality capability* category, *Product quality* (Q1) (0.55700) was rated as the most important; in *Technical capability* category, *Entrepreneurial innovation capability* (T1) (0.54865) was rated as the most important; and in *Service capability* category, *Conflict / problem solving capability* (S1) (0.56692) was rated as the most important. It should be emphasized again that the proposed hybrid model is capable of handling such interdependencies.

Conclusions

This study has contributed to, in particular, the supplier selection literature by: (i) proposing a research framework that relates determinants to supplier selection for 3C industry, (ii) developing valid and reliable measures for the dimensions based on expert's qualitative opinion, and (iii) developing a supplier selection hierarchical analytical structure to evaluate the factors in supplier selection using ISM and ANP. In practical supplier selection problems, vast amounts of criteria and attributes are typically interactive and interdependent and with elusive qualitative information. This study developed an effective evaluation framework to evaluate the factors in supplier selection for 3C industry. In this paper, we propose a hybrid model combining ISM and ANP, wherein ISM is to construct the complex network relationship, and ANP is to simultaneously consider the relationships of feedback and dependence of criteria in 3C industry for the case Taiwanese. Moreover, the ANP can be used not only as a way to handle the inner dependences within a set of criteria/ attributes, but also as a way of producing more valuable information for decision-making. The case study shows that decision-makers are able to capture a fairly complete picture of supplier selection while assessing the priorities of the criteria developed, validated, and operationalized by the proposed approach.

Although the present model proves valuable, there are still some areas for further development. This study builds a supplier selection model by applying five criteria however, the interrelationship among *Environmental management capability* and other criteria

were not very significant. Moreover, it is suggested that future study could develop a richer, multi-hierarchical structure that incorporates other criteria/ sub-criteria with quantitative and qualitative measurement. Other analytical techniques (e.g., Decision Making Trial and Evaluation Laboratory, fuzzy integral) can be employed to solve the interactive and feedback relationships between the factors and to further explore the relative importance among the factors.

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