Research Journal of

Business Management

ISSN 1819-1932

Academic Journals Inc.

www.academicjournals.com

Research Journal of Business Management 9 (1): 106-123, 2015
ISSN 1819-1932 / DOI: 10.3923/rjbm.2015.106.123

Integrated Factor Analysis and Fuzzy Analytic Network Process (FANP) Model for Supplier Selection Based on Supply Chain Risk Factors

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ABSTRACT

Currently, the supply chain management is an important part of several organizations. The risk in supply chain is a potential variation of outcomes which decreases the efficiency in operations. The supplier selection is one of the most critical functions to the success of a manufacturing firm. The objective of this study was to develop the supplier evaluation in supply chain risk approach based on an integrated factor analysis and Fuzzy Analytic Network Process (FANP) model. The model has applied to an electrical and electronic industry in Thailand. The framework of this study had two main thoughts. The first part was to investigate supply chain risk factors from data collection via questionnaire. The questionnaire was answered by 225 respondents in electrical and electronic companies in Thailand. By means of the statistical technique of factor analysis, it was revealed that supply chain risk factors can be categorized into six factors and thirty sub-factors. The second part was to develop a mathematical model for supplier selection decisions via using FANP by incorporating supply chain risk factors acquired from the first part. A detailed step by step implementation method for determining fuzzy scales and calculating weights factors and sub-factors were discussed and finally issues prioritize risk value for alternative best supplier were also mentioned.

Key words: Upplier selection, fuzzy, analytic network process, factor analysis, supply chain risk factors

INTRODUCTION

Supply chain has become a key element in the global economy. Currently, the supply chain is changing rapidly, resulting in a business environment with uncertainty (Xiao *et al*., 2012; Wu and Olson, 2008). The global competition is intensifying, making supply chain has become more complex (Tummala and Schoenherr, 2011). The supply chain is the global network used to deliver products and services, since the raw materials sourcing process through the information flow process and physical distributions (Cooper and Ellram, 1993). Supply chain consists of management systems, operations, assembly, purchasing, production scheduling, inventory management, processing, storage and transportation. Thus, supply chain management is the integration of activity over the relation of the supply chain to achieve sustainable competitive advantage (Monczka *et al*., 2008; Rossetti and Dooley, 2010). The increased competition resulted in a manufacturing organization to meet the needs of customers (Vinodh *et al.*, 2011). Supply chain is a network of suppliers (Sahin and Robinson, 2002; Wu and Olson, 2008). Therefore, the supplier selection is the beginning of supply chain process. Thus, the appropriate supplier selection is one of the most important issues for any organization (Amindoust *et al.*, 2012). When changes in the competitive environment, supplier selection is not only based on price and quality but various risk factors should be take into consideration as well. The risk is an inherently subjective construct that deals with the possibility of loss (Yates and Stone, 1992). The risk in supply chain related to the supplier selection. Risk suppliers are important parts of the supply chain risk (Xiao *et al.*, 2012). As a result, the companies need to consider the supplier risks because the supplier risk in the supply chain is the probability of disruption and impact on performance of any firm (Zsidisin and Ritchie, 2008). In order to generate the sustainable maximize profit, the company needs to achieve the goal of low cost, high flexible quality and greater customer satisfaction (Setak *et al.*, 2012). The supplier selection process is a key role which helps the business to be success in a global arena.

The purpose of this study, was to develop a supplier selection model based on supply chain risk factors. An electrical and electronic industry in Thailand is selected as a case study to investigate supply chain risk factors and to develop a model for helping decision makers in supplier selection decision. The first part of the study is to identify and explore supply chain risk factors in a supplier selection and the second part is to use the fuzzy analytic network process model to calculate the local weights of the factors and sub-factors, inner dependence weights, global weights and then calculate supply chain risk value of each supplier. The results of the application are discussed and main findings and contributions are drawn and future developments are suggested.

FACTOR ANALYSIS

Factor analysis is a statistical technique commonly used in many areas of science whenever it is intended to extract the relevant information about a data set, usually presented in the form of a table whose rows are the cases and the columns are the variables that characterize these cases (De Sa *et al.*, 2014). The basic idea of factor analysis is based on correlation to group the original variables, to make variable correlation in the same group high and in the different groups less (Niu *et al.*, 2011). The variables in the same group have a high correlation. In contrast, the variables with low correlation are arranged apart into different groups (Jun *et al.*, 2011).

The statistical method of studying the internal interdependent relation of the related matrix of the index variable X_i(i = 1, 2,..., p) into a few factor F_j(i = 1,..., m, m<, p) and the factor F_j(i = 1, 2,..., m) reappear (Gao, 2005), can be expressed as follows:

$$\begin{cases} X_1 = a_{11}F_1 + a_{12}F_2 + \ldots + a_{1n}F_m + \varepsilon_1, \\ X_2 = a_{21}F_1 + a_{22}F_2 + \ldots + a_{2n}F_m + \varepsilon_2, \\ \qquad \cdots\cdots\cdots \\ X_1 = a_{p1}F_1 + a_{p2}F_2 + \ldots + a_{pn}F_m + \varepsilon_p \end{cases} \quad (1)$$

Among which, X = $(X_1, X_2,..., X_p)^T$ is the original index F = $(F_1, F_2,..., F_m)^T$, is the factor of the index X, A = $(a_{ij})_{p\times m}$(m<p) is the factor load matrix and, ε is th special factor.

The basic steps to draw major factors with the factor analysis method are show as follow (Wang, 2004):

- To study out the related correlation coefficient matrix of the original data
- To study out the feature value $\lambda_i(i = 1, 2, ..., p)$ on the basis of the matrix and define its feature vector's matrix A meets F = A'X, F, is the major factor matrix
- To fix the number of the major factors by calculating the information contribution and accumulating contribution rates of the feature root λ_i. The cobtribution rate:

$$d_i = \lambda / \sum_{i=1}^{m} \lambda_i$$

reflects the percentage of how much the i-th major factor's degree of variation occupies in the degree of the total variation. The higher the rate is, the more important the factor. The accumulating contribution rate:

$$\left(\sum_{i=1}^{m} \lambda_i / \sum_{j=1}^{p} \lambda_i \right)$$

is the important basic to selecting the number m of the major factors which should generally be a higher percentage
- The factor can be rotated to make the loads of m major factors on the variable $X_i(i = 1, 2, ..., p)$ have noticeable discrepancy in order to get the clear meaning of the major factor

Fuzzy analytic network process (FANP): Fuzzy ANP technique uses both interdependence of criteria and inner dependence of criteria with pairwise comparison matrix. Chang (1996) extent analysis method is used to evaluate fuzzy pairwise comparisons. It is very useful in situations where there is a high degree of interdependence between various attributes of the alternatives. The membership functions of triangular fuzzy number used to represent pairwise comparison of decision variables from "Very bad" to "Excellent" and the middle preference values between them. The membership functions, $M_i = (m_{i1}, m_{i2}, m_{i3})$, where, i =1,2,..., n and m_{i1}, m_{i2}, m_{i3} are the lower, middle and upper values of the fuzzy number M_i, respectively. According to the concept of extent analysis, each object is taken and extent analysis for each goal g_i is performed, respectively. Therefore, the m extent analysis values for each object are obtained as the following signs:

$$M_{gi}^1, M_{gi}^2, ..., M_{gi}^m, i = 1, 2, ..., n \tag{2}$$

where, $M_{gi}^j (j = 1, 2, ..., m)$ are triangular fuzzy numbers.

The steps of Chang (1996) extent analysis can be given as the following:

The value of fuzzy synthetic extent with respect to the i-th object is defined as:

$$Si = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{3}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$ perform the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{4}$$

And to obtain:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{i}\right]^{-1}$$

perform the fuzzy addition operation of $M_{gi}^{i}\,(j=1, 2, ..., m)$ values such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{5}$$

Then compute the inverse of the vector in Eq. 5 as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{N} l_i}\right) \tag{6}$$

The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = \sup[\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{7}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \tag{8}$$

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i = 1, 2,..., k) can be defined by:

$$V(M \geq M_1, M_2, ..., Mk) = \min V(M \geq M_i),\ i = 1, 2, ..., k \tag{9}$$

Assume that:

$$d(S_i) = \min V(S_i \geq S_k),\ k = 1, 2, ..., n;\ k \neq i \tag{10}$$

Then calculate the weights vector is given by:

$$W' = d(S_i), d(S_2), ..., d(S_n))^T \tag{11}$$

Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))T \tag{12}$$

where, W is a nonfuzzy number, and A_i = (i = 1, 2,..., n) are n elements.

MATERIALS AND METHODS

This study proposes the supplier selection modeling based on supply chain risk factors which consists of two main stages. These stages can be divided into 10 steps for using to evaluate suppliers. The first stage is to identify supply chain risk factors for establishing group of factors and sub-factors from practical point of views. The second stage is to employ fuzzy ANP method for calculating the weights of the factors and sub-factors and calculate supply chain risk value of each supplier for the alternative. The model steps of this study are demonstrated in Fig. 1:

Step 1: Identify supply chain risk factors from related literature reviews which included a variety of supply risk sources such as price, financial, material, performance, capability and so on

Step 2: Integrate expert opinions by interviewing key persons about risk and relevant factors in supplier selection process

Step 3: Conduct a questionnaire survey for exploring supply chain risk factors in practices

Step 4: Group supply risk factors and sub-factors through factor analysis

Step 5: Determine the fuzzy scale for importance weight of factors and sub-factors from a decision maker who takes responsibility in supplier selection process in a company. Choose the appropriate linguistic variables for the relative weights of the factors which are given in Fig. 2 and Table 1, then make a pairwise comparison with respect to each factor from expert opinion by using the linguistic scale

Step 6: Calculate the local weights of the factors and sub-factors

Step 7: Calculate the inner dependence weights of the factors, the inner dependence matrix of each factor with respect to the other factors. This inner dependence matrix is multiplied with the local weights of the factors in order to compute the interdependent weights of the factors

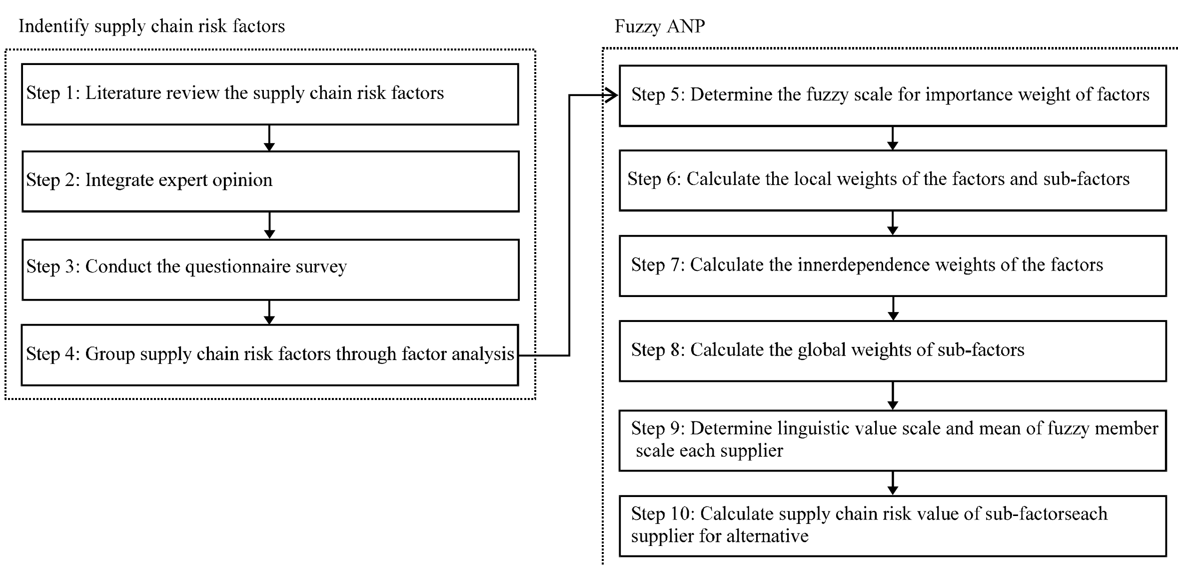

Fig. 1: Step of proposed methodology

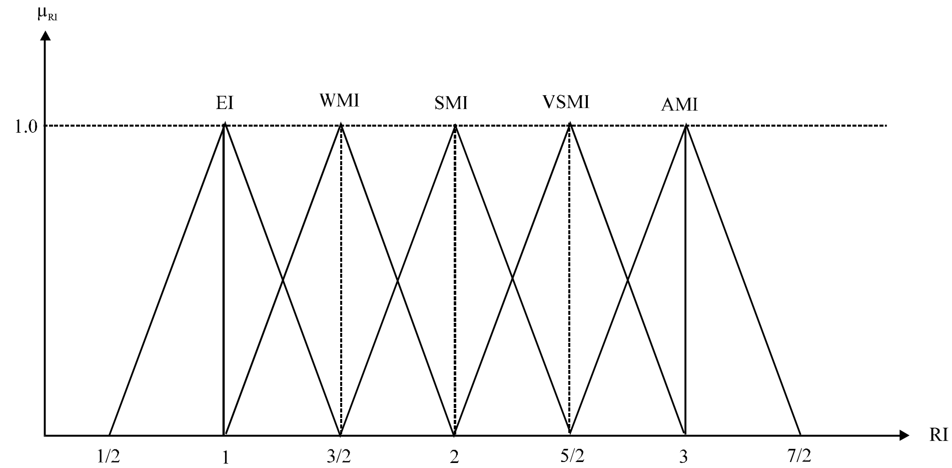

Fig. 2: Linguistic scale for relative importance

Table 1: Linguistic expression for fuzzy scale of relative weights of factors

Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal (if diagonal)	(1, 1, 1)	(1, 1, 1)
Equally important (EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important (WMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important (SMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important (VSMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important (AMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

Table 2: Linguistic values and mean of fuzzy numbers

Linguistic values for sub-factors risk	Mean of fuzzy number
Very high (VH)	1.00
High (H)	0.75
Medium (M)	0.50
Low (L)	0.25
Very low (VL)	0.00

Step 8: Calculate the global weights of sub-factors by multiplying local weight of the sub-factors with the interdependent weights of the factors

Step 9: Determine the membership functions of these linguistic variables by expert opinion as shown in Fig. 3 and the average value related with this variables are shown in Table 2. While using this evaluation scale, the linguistic variables can take different values depending on the structure of the sub-factor. For example, in the evaluation risk of a sub-factor which affects quality product risk is the "Low (L)" linguistic variable takes 0.25 fuzzy average fuzzy average values in the evaluation of a sub-factor which affects quality product risk

Step10: Calculate supply chain risk value of sub-factors each supplier by multiplying global weights of the sub-factors with scale value of sub-factors each supplier, then prioritize risk value in order to select the best supplier

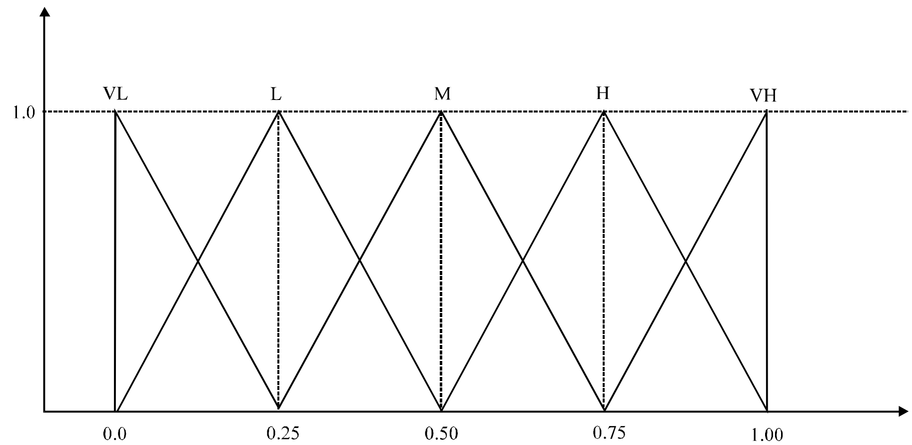

Fig. 3: Membership functions of linguistic values for sub-factors rating

RESULTS

An application of this model is implemented in the electrical and electronic industry in Thailand. There are two stages of this process. The first part (step 1-4) is to explore supply chain risk factors of supplier selection in practices by using interviewing and a questionnaire survey. The second part (step 5-10) is to employ fuzzy ANP model to calculate supply chain risk value of each supplier in an illustrated example. The case study of a large Printed Circuit Board Assembly (PCBA) company in Thailand which has three main suppliers is applied. The proposed model will be explained step by step together with the results as follows:

Step 1: Identify supply chain risk factors from literature review to find as mentioned in Table 3

Step 2: Interview key expert opinions from five electrical and electronic companies in Thailand in different departments working in the company's purchasing team such as purchasing, quality control as well as Research and Development (R and D). Then, develop a questionnaire by integrating the relevant factors from interviewing and literature survey which found significant in supplier selection process

Step 3: The questionnaire was distributed to 225 samples who take responsibility in supplier selection process in electrical and electronic manufacturing companies in Thailand. Respondents were asked to rate question under a five-point Likert scale (i.e., 1 = Very low importance, 2 = Low importance, 3 = Medium importance, 4 = High importance, 5 = Very high importance). Results from the survey indicated that the most of respondents (43.11%) who answered questionnaires are in a manager position. Most of them (64%) are working in large companies and 48% of those companies have their own brand products (Table 4)

Step 4: Group supply risk factors and sub-factors through factor analysis which detailed are shown in Table 5 using SPSS. Factor analysis using principal component method revealed six factors that collectively described managements' perspective on their supplier selection These six factors have been extracted from 30 sub-factors by using the cut-off initial eigen value of 1.00 which account for 16.042, 12.712, 10.280, 10.278, 9.880 and 7.906% of the variance explained after rotating maximum value as displayed in Table 6. Factor 1 (or R1) is entitled "External risk factor" comprising eight variables including policies, politics,

Table 3: Literature review on supply chain risk factors

Risk factors	Shi (2004)	Wu *et al.* (2006)	Kull and Talluri (2008)	Lee (2009)	Matooka *et al.* (2009)	Pujawa and Geraldin (2009)	Olson and Wu (2010)	Tummalaand and Schoenher (2011)	Shemshadi *et al.* (2011)	Xiao *et al.* (2012)
Price	•	•	•	•	•		•	•		
Forecast		•				•	•	•		
Financial	•	•	•	•			•		•	•
Information			•				•	•		
Material		•	•	•		•		•		
Performance				•						•
Organization										•
Capability		•		•		•				
Productivity			•	•			•	•		•
Quality product	•	•	•		•	•	•	•		•
R and D			•					•		•
Technology					•		•		•	•
On-Time		•				•	•	•	•	
Quality of delivery						•				•
Quantity	•				•	•				
Return						•				
Economic	•		•		•		•	•		
Labor disputes								•		
Legal	•	•								
Natural disasters	•	•	•				•	•	•	
Policies	•						•	•		
Politics	•	•								

Table 4: Summary of the demographic characteristics

Category	Frequency	Percentage
Position		
Management	17	7.56
Manager	97	43.11
Assistant manager	71	31.56
Engineer and purchase	40	17.78
Size		
Large	144	64.00
Medium	43	19.10
Small	38	16.90
Tier		
Own brand	108	48.00
1st Tier	80	35.60
2nd Tier	14	6.20
3rd Tier	23	10.20

natural disasters, infrastructure, environment, legal, labor disputes and economic. Factor 2 (or R2) is entitled “Quality control risk factor” comprising five variables including industrial standards, technology, safety, collaborative and R and D. Factor 3 (or R3) is entitled “Delivery risk factor” comprising four variables including on-time, quantity, quality delivery and return. Factor 4 (or R4) is entitled “Material control risk factor” comprising six variables including performance, material, purchase order,

Table 5: Total variance explained

	Initial eigen values			Rotation sums of squared loadings		
Components	Total	Percentage of variance	Cumulative (%)	Total	Percentage of variance	Cumulative (%)
1	11.614	38.714	38.714	4.813	16.042	16.042
2	2.932	9.773	48.487	3.814	12.712	28.754
3	1.727	5.758	54.245	3.084	10.280	39.034
4	1.455	4.851	59.096	3.083	10.278	49.312
5	1.310	4.368	63.464	2.964	9.880	59.192
6	1.090	3.635	67.098	2.372	7.906	67.098
7	.961	3.202	70.301			
...	...	...	...			
30	0.118	0.394	100			

Table 6: Rotated component matrix

Factors	F1	F2	F3	F4	F5	F6
Policies	0.855	0.149		0.104		
Politics	0.820	0.145				
Natural disasters	0.790		0.233	0.156		
Infrastructures	0.665	0.292	0.178	0.116	0.105	
Environments	0.639		0.180		0.314	0.155
Legal	0.632	0.356			0.146	
Labor disputes	0.625	0.280	0.252	0.162		0.209
Economic	0.616	0.429	0.121	0.204	0.118	0.213
Industrial standards	0.175	0.755	0.115	0.304	0.155	
Technology	0.198	0.723	0.207	0.186	0.137	
Safety	0.200	0.722		0.272	0.199	0.175
Collaborative	0.278	0.657				0.192
R and D	0.305	0.654	0.239		0.285	
On-time	0.164	0.179	0.775	0.125	0.162	
Quantity			0.632	0.490	0.142	0.255
Quality delivery	0.122	0.325	0.614	0.165	0.298	
Return	0.157		0.590	0.263	0.107	0.310
Performance	0.274	0.311	0.539		0.189	0.296
Material	0.324	0.136	0.534		0.392	0.135
Purchase order	0.119	0.101	0.119	0.781	0.347	0.142
Inventory	0.165	0.238	0.168	0.744	0.237	0.191
Information	0.196	0.142	0.152	0.716	0.329	0.208
Organization	0.243	0.350	0.317	0.610		
Productivity			0.242	0.245	0.809	
Quality product	0.113	0.275	0.149	0.240	0.763	0.115
Capability		0.400	0.181	0.238	0.627	0.140
Production process	0.189	0.225	0.246	0.254	0.567	0.149
Price		0.149		0.185		0.815
Financial	0.161	0.200	0.198		0.233	0.756
Forecast			0.247	0.251	0.102	0.707

inventory, information and organization. Factor 5 (or R5) is entitled "Production risk factor" comprising four variables including productivity, quality product, capability and production process. And, Factor 6 (or R6) is entitled "Cost and financial risk factor" comprising three variables including price, financial and forecast as shown in Fig. 4. Extracting factors are shown in Table 7

Table 7: Extracting factors

Factor/sub-factor	Detailed description
Factor 1: External risk (R1)	
Policies (R11)	Uncertainty in government policies will impact to the business. Changes in political situation might also affect policies and regulations of the government on a long term, changes in law, increase labor costs, exchange rates changes and infrastructure disruptions
Politics (R12)	Risks associated with political unrest or a political crisis that is affecting the business
Natural disasters (R13)	Risk of suppliers is located in the area of natural disasters such as earthquakes, floods, etc
Infrastructure (R14)	Risk of the physical structure of the logistics infrastructure that is unreliable, such as traffic congestion, transportation is inconvenient, transportation costs are high
Environment (R15)	Risk of from the uncertainty of the supply chain environment. Changes which affect the environment both inside and outside the organization, such as environmental impacts caused by the product, trade barrier regulation, including the various terms of the customer in the field of green procurement
Legal (R16)	Risk associated with non-compliance with various regulations of legal requirements, such as non-compliance with laws or environmental standards, illegal labor, security controls in operation or welfare
Labor disputes (R17)	Risk of labor, such as labor strikes, payment, loss at skilled personnel, the reduction of staff or sabotage from employees
Economic (R18)	Risk related with economic issues such as exchange rate, stability of the currency, financial problems may disrupt the supply, expansion of the economy has increased, impact exchange rate to import raw materials, oil prices changes
Factor 2: Quality control risk (R2)	
Industrial standards (R21)	Risk of material does not meet the standard and practice in procedures is not standard such as Thai Industrial Standards Institute (TISI), Underwriters Laboratories Inc. (UL), Restriction of Hazardous Substances (RoHS), European Conformity (CE)
Technology (R22)	Risk of technology related issues lead to uncertainty in the supply chains, such as supplier without technologically competitive, updates in information technology and the compatibility of the operating system. System is not modern and reliable, as no system is linked to both internal and external efficiency or without computers to assist in the operation and decision making
Safety (R23)	Risk associated with the safety in the working environment which is cause injury or damage to property. Including the ability to affect performance, such as events that could cause damage, chance of harm or error occurs, environment with the ability of the body and mind
Collaborative (R24)	Risk of cooperate in activities to improve quality and efficiency, Communication and relationships with suppliers Management style and corporate culture varies with suppliers or collaboration research and development
R and D (R25)	Risk of the design and development of new products or quickly redesign the product to satisfy customer's requirements for design change, such as, there are no technological and research and development (R&D) support. The loss of time from new product development will affect to launch products into the market, engineer no experienced, product quality or product lacks credibility
Factor 3: Delivery risk (R3)	
On time (R31)	Risk of delivery to the customer on time, such as issues of capacity and congestion of the port, Process customs clearances at the ports, higher cost of transportation, transportation breakdowns and so on
Quantity (R32)	Risk of product damage during transport, such as the leakage of the product, the packaging does not meet the specifications, damage during transportation
Quality delivery (R33)	Risk of fluctuations in the quantity of goods that do not meet the order, missing assembly parts due to a defect in quality management and the uncertainty of suppliers
Return (R34)	Risk from delay in returning raw materials/products to the manufacturer or the delay in the process of coming back from customers because the customer refused
Factor 4: Material control risk (R4)	
Performance (R41)	Risk of suppliers in the implementation of major policies to meet customer demand as the most powerful ability in production such as ability to production, quality control or delivery

Table 7: Continue

Factor/sub-factor	Detailed description
Material (R42)	Risk of material shortages. The current global demand for resources increases. Impact of the lack of material to produce products such as the satisfaction of the cost of raw materials, quality of raw materials or raw materials came late in production due to shortages or safety stock
Purchase order (R43)	Risk from the purchasing standard process and the delayed process or any material or information flow within each supply chain step, such as purchase order (PO) or purchase requisition (PR) not completed, incorrectly data from the supplier, error forecasting
Inventory (R44)	Risk of low efficiency inventory management affects to holding inventory cost and also affect to the depreciation, loss space, pending orders, inventories excessive capital investment efficiency, and costs from managing unnecessary
Information (R45)	Risk of management information has potentially critical incident consequences and will effect to other critical area of risk. Supplier's information systems are out of dated or unreliable (Kull and Talluri, 2008). Risk also refers to data which are not credible and lost or disclosed to competitors
Organization (R46)	Risk of organizational structure will affect operations within the organization. That is affect handicaps to achieve objectives such as operational process, quality control, compliance with rules or orders, unclear development or management responsibilities
Factor 5: Production risk (R5)	
Productivity (R51)	Risk of the highest capability in production when the order increases production process not flexibility to be able to change quickly for support orders
Quality product (R52)	Risk from quality of raw materials or production process. The production inputs do not meet quality specifications originate from individual supplier failures. Lower quality control standards. No quality control systems and continuous improvement process. Parts rejected by the customer or a defective check incoming quality control and production lines. The defect has not been detected in the quality control process, To analyze the correctly product quality and quality management to produce efficiently or staff lack of quality training
Capability (R53)	Risk of the supplier capability such as the ability to make quality products, the ability to reduce costs, technological capabilities, and manufacturing capability to develop and manufacture new products
Production process (R54)	Risk of inefficient production process, such as quality control, production speed, production cost or customer responsiveness on time
Factor 6: Cost and financial risk (R6)	
Price (R61)	The price of raw material is significant to risk variation in price impacts on the competitiveness. The possibility of having an unstable increasing trend product price in compared with other suppliers in the future is key issue of the company, such as unexpected problems allocating raw materials, yield problem, Specification changes
Financial (R62)	Risk of financial stability or credit risk such as stock prices, cash flow, profit and loss statements. Financial stability is the necessary requisite for long-term partnership between supplier and the manufacturer. In addition, companies need working capital for the business to achieve liquidity events that are not expected
Forecast (R63)	Risk error from forecast uncertainty in the planning, preparation and delivery of raw materials or caused rapid changes in production planning, material recorded incorrectly

Step 5: This decision is converted to the hierarchical structure to transform the factors, sub-factors and alternative as the schematic structure shown in Fig. 5. The ultimate goal is to choose the best supplier which will be placed in the first level. Main factors (external risk, quality control risk, delivery risk, material control risk, production risk, cost and financial risk) and their sub-factors are located in the second and the third level, respectively. Then a decision maker is asked to determine the fuzzy scale for importance weight of factors and sub-factors. Choose the appropriate linguistic variables for the relative weights of the factors which is given in Fig. 3 and Table 3. Then the decision

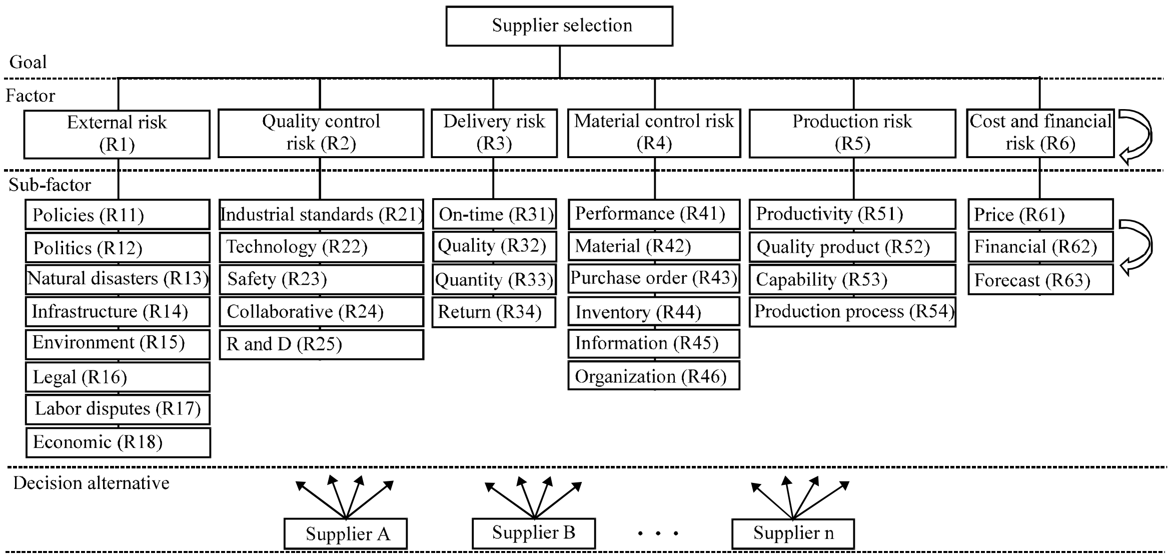

Fig. 4: Model for supplier selection

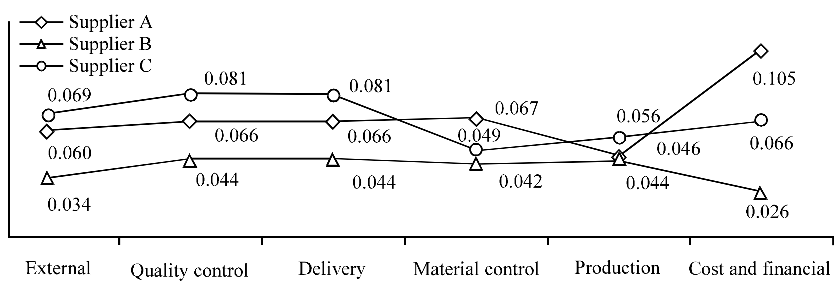

Fig. 5: Supply chain risk weight of factors result by suppliers

maker continues to make a pairwise comparison with respect to each factor using the linguistic scale. For example "What do you think of scale importance between quality control risk factors when it is compared with delivery risk factors?" If the answer is "Quality control risk is Weakly More Important (WMI) than delivery risk", so the linguistic scale is (1, 3/2, 2) as details appeared in Table 3

Step 6: Calculate the fuzzy evaluation matrix and the local weights as shown in Table 8-14

Step 7: Calculate the inner dependence weights of the factors are calculated and the dependencies among the factors are considered of main factors are shown in Table 15

Step 8: Calculate the interdependent weights of factors by multiplying inner dependence matrix in Table 16 with the local weights of the factors provided in Table 8:

$$\begin{bmatrix} 1.0000 & 0.1759 & 0.1516 & 0.1610 & 0.1605 & 0.1359 \\ 0.2226 & 1.0000 & 0.2359 & 0.2527 & 0.2449 & 0.2558 \\ 0.1733 & 0.1876 & 1.0000 & 0.1760 & 0.1920 & 0.1782 \\ 0.1997 & 0.2118 & 0.2117 & 1.0000 & 0.2129 & 0.2162 \\ 0.2137 & 0.2371 & 0.2119 & 0.2774 & 1.0000 & 0.2139 \\ 0.1908 & 0.1876 & 0.1888 & 0.1830 & 0.1896 & 1.0000 \end{bmatrix} \times \begin{bmatrix} 0.1334 \\ 0.1984 \\ 0.1535 \\ 0.1737 \\ 0.1829 \\ 0.1580 \end{bmatrix} = \begin{bmatrix} 0.1352 \\ 0.1967 \\ 0.1539 \\ 0.1740 \\ 0.1822 \\ 0.1581 \end{bmatrix}$$

Table 8: Local weights and pair-wise comparison matrix of "Main factors"

Risk factors	R1	R2	R3	R4	R5	R6	Weights
External (R1)	1, 1, 1	2/5, 1/2, 2/3	1/2, 1, 3/2	1/2, 2/3, 1	1/2, 2/3, 1	2/3, 1, 2	0.1334
Quality control (R2)	3/2, 2, 5/2	1, 1, 1	1, 3/2, 2	1/2, 1, 3/2	1, 3/2, 2	1/2, 1, 3/2	0.1984
Delivery (R3)	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	2/3, 1, 2	1/2, 2/3, 1	2/3, 1, 2	0.1535
Material control (R4)	1, 3/2, 2	2/3, 1, 2	1/2, 1, 3/2	1, 1, 1	2/3, 1, 2	1/2, 1, 3/2	0.1737
Production (R5)	1, 3/2, 2	1/2, 2/3, 1	1, 3/2, 2	1/2, 1, 3/2	1, 1, 1	1, 3/2, 2	0.1829
Cost and financial (R6)	1/2, 1, 3/2	2/3, 1, 2	1/2, 1, 3/2	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	0.1580

Table 9: Local weights and pair-wise comparison matrix of "External risk" sub-factors

Sub-factors	R11	R12	R13	R14	R15
Policies (R11)	1, 1, 1	1, 3/2, 2	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 3/2, 2
Politics (R12)	1/2, 2/3, 1	1, 1, 1	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1
Natural disasters (R13)	3/2, 2, 5/2	3/2, 2, 5/2	1, 1, 1	2/3, 1, 2	1, 3/2, 2
Infrastructure (R14)	1, 3/2, 2	3/2, 2, 5/2	1/2, 1, 3/2	1, 1, 1	1, 3/2, 2
Environment (R15)	1/2, 2/3, 1	1, 3/2, 2	1/2, 2/3, 1	1/2, 2/3, 1	1, 1, 1
Legal (R16)	3/2, 2, 5/2	3/2, 2, 5/2	1, 3/2, 2	1/2, 1, 3/2	1, 3/2, 2
Labor disputes (R17)	1, 3/2, 2	3/2, 2, 5/2	1/2, 1, 3/2	1/2, 1, 3/2	1, 3/2, 2
Economic (R18)	2/3, 1, 2	1, 3/2, 2	2/3, 1, 2	1/2, 2/3, 1	1/2, 1, 3/2

Sub-factors	R16	R17	R18	Weight
Policies (R11)	2/5, 1/2, 2/3	1/2, 2/3, 1	1/2, 1, 3/2	0.1056
Politics (R12)	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	0.0552
Natural disasters (R13)	1/2, 2/3, 1	2/3, 1, 2	1/2, 1, 3/2	0.1496
Infrastructure (R14)	2/3, 1, 2	2/3, 1, 2	1, 3/2, 2	0.1534
Environment (R15)	1/2, 2/3, 1	1/2, 2/3, 1	2/3, 1, 2	0.1027
Legal (R16)	1, 1, 1	1, 3/2, 2	1, 3/2, 2	0.1687
Labor disputes (R17)	1/2, 2/3, 1	1, 1, 1	2/3, 1, 2	0.1429
Economic (R18)	1/2, 2/3, 1	1/2, 1, 3/2	1, 1, 1	0.1219

Table 10: Local weights and pair-wise comparison matrix of "Quality control risk" sub-factors

Sub-factors	R21	R22	R23	R24	R25	Weight
Industrial standards (R21)	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	1, 3/2, 2	0.1359
Technology (R22)	1/2, 2/3, 1	1, 1, 1	3/2, 2, 5/2	1, 3/2, 2	1, 3/2, 2	0.2558
Safety (R23)	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1, 1, 1	1/2, 2/3, 1	1/2, 2/3, 1	0.1782
Collaborative (R24)	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 3/2, 2	1, 1, 1	1/2, 2/3, 1	0.2162
R and D (R25)	1/2, 2/3, 1	1/2, 2/3, 1	1, 3/2, 2	1, 3/2, 2	1, 1, 1	0.2139

Table 11: Local weights and pair-wise comparison matrix of "Delivery risk" sub-factors

Sub-factors	R31	R32	R33	R34	Weight
On-time (R31)	1, 1, 1	1, 3/2, 2	1/2, 1, 3/2	1, 3/2, 2	0.2968
Quality (R32)	1/2, 2/3, 1	1, 1, 1	2/3, 1, 2	1, 3/2, 2	0.2566
Quantity (R33)	2/3, 1, 2	1/2, 1, 3/2	1, 1, 1	3/2, 2, 5/2	0.2968
Return (R34)	1/2, 2/3, 1	1/2, 2/3, 1	2/5, 1/2, 2/3	1, 1, 1	0.1497

Table 12: Local weights and pair-wise comparison matrix of "Material control" risk sub-factors

Sub-factors	R41	R42	R43	R44	R45	R46	Weight
Performance (R41)	1, 1, 1	2/3, 1, 2	1/2, 1, 3/2	2/3, 1, 2	1, 3/2, 2	2/3, 1, 2	0.1744
Material (R42)	1/2, 1, 3/2	1, 1, 1	1, 3/2, 2	1/2, 1, 3/2	1, 3/2, 2	2/3, 1, 2	0.1816
Purchase order (R43)	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	1/2, 2/3, 1	1/2, 1, 3/2	2/3, 1, 2	0.1536
Inventory (R44)	1/2, 1, 3/2	2/3, 1, 2	1, 3/2, 2	1, 1, 1	1, 3/2, 2	2/3, 1, 2	0.1816
Information (R45)	1/2, 2/3, 1	1/2, 2/3, 1	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	1/2, 2/3, 1	0.1359
Organization (R46)	1/2, 1, 3/2	1/2, 1, 3/2	1/2, 1, 3/2	1/2, 1, 3/2	1, 3/2, 2	1, 1, 1	0.1729

Table 13: Local weights and pair-wise comparison matrix of "Production risk" sub-factors

Sub-factors	R51	R52	R53	R54	Weight
Productivity (R51)	1, 1, 1	1/2, 2/3, 1	1/2, 1, 3/2	2/3, 1, 2	0.2300
Quality product (R52)	1, 3/2, 2	1, 1, 1	1, 3/2, 2	1/2, 1, 3/2	0.2901
Capability (R53)	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	1/2, 2/3, 1	0.2106
Production process (R54)	1/2, 1, 3/2	2/3, 1, 2	1, 3/2, 2	1, 1, 1	0.2693

Table 14: Local weights and pair-wise comparison matrix of "Price and financial risk" sub-factors

Sub-factors	R61	R62	R63	Weight
Price (R61)	1, 1, 1	1, 3/2, 2	1/2, 1, 3/2	0.3690
Financial (R62)	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	0.3356
Forecast (R63)	2/3, 1, 2	1/2, 2/3, 1	1, 1, 1	0.2954

Table 15: Computed global weights of sub-factors

Factors	Interdependent weights	Sub-factors	Local weights	Global weights
External risk (R1)	0.1352	Policies (R11)	0.1056	0.0075
		Politics (R12)	0.0552	0.0202
		Natural disasters (R13)	0.1496	0.0207
		Infrastructure (R14)	0.1534	0.0139
		Environment (R15)	0.1027	0.0228
		Legal (R16)	0.1687	0.0193
		Labor disputes (R17)	0.1429	0.0165
		Economic (R18)	0.1219	0.0267
Quality control risk (R2)	0.1967	Industrial standards (R21)	0.1359	0.0503
		Technology (R22)	0.2558	0.0351
		Safety (R23)	0.1782	0.0425
		Collaborative (R24)	0.2162	0.0421
		R and D (R25)	0.2139	0.0457
Delivery risk (R3)	0.1539	On time (R31)	0.2968	0.0395
		Quantity (R32)	0.2566	0.0457
		Quality delivery (R33)	0.2968	0.0230
		Return (R34)	0.1497	0.0303
Material control risk (R4)	0.1740	Performance (R41)	0.1744	0.0316
		Material (R42)	0.1816	0.0267
		Purchase order (R43)	0.1536	0.0316
		Inventory (R44)	0.1816	0.0236
		Information (R45)	0.1359	0.0301
		Organization (R46)	0.1729	0.0419
Production risk (R5)	0.1822	Productivity (R51)	0.2300	0.0529
		Quality Product (R52)	0.2901	0.0384
		Capability (R53)	0.2106	0.0491
		Production process (R54)	0.2693	0.0583
Cost and financial risk (R6)	0.1581	Price (R61)	0.3690	0.0531
		Financial (R62)	0.3356	0.0467
		Forecast (R63)	0.2954	0.0075

Then, calculate the global weights of sub-factors by multiplying local weight of the sub-factors with the interdependent weight of factors. Computed values are shown in Table 16

Step 9: The membership functions of these linguistic variables as shown in Fig. 4 for eachsupplier are determined by the same decision maker and the average value related with this variables are shown in Table 2. Therefore, the scale value each supplier are shown in Table 17

Table 16: Inner dependence weights of the factors

Factors	R1	R2	R3	R4	R5	R6
External risk (R1)	1.0000	0.1759	0.1516	0.1610	0.1605	0.1359
Quality control risk (R2)	0.2226	1.0000	0.2359	0.2527	0.2449	0.2558
Delivery risk (R3)	0.1733	0.1876	1.0000	0.1760	0.1920	0.1782
Material control risk (R4)	0.1997	0.2118	0.2117	1.0000	0.2129	0.2162
Production risk (R5)	0.2137	0.2371	0.2119	0.2274	1.0000	0.2139
Cost and financial risk (R6)	0.1908	0.1876	0.1888	0.1830	0.1896	1.0000

Table 17: Supplier selection based on supply risk factor

		Supplier A			Supplier B			Supplier C		
Sub factor	Global weights	Linguistic evaluation	Scale value	Risk value	Linguistic evaluation	Scale value	Risk value	Linguistic evaluation	Scale value	Risk value
R11	0.0075	M	0.50	0.007	M	0.50	0.007	M	0.50	0.007
R12	0.0202	M	0.50	0.004	M	0.50	0.004	M	0.50	0.004
R13	0.0207	VH	1.00	0.020	L	0.25	0.005	M	0.50	0.010
R14	0.0139	H	0.75	0.016	L	0.25	0.005	M	0.50	0.010
R15	0.0228	L	0.25	0.003	L	0.25	0.003	H	0.75	0.010
R16	0.0193	G	0.25	0.006	L	0.25	0.006	L	0.25	0.006
R17	0.0165	VL	0.00	0.000	VL	0.00	0.000	M	0.50	0.010
R18	0.0267	L	0.25	0.004	L	0.25	0.004	H	0.75	0.012
R21	0.0503	VL	0.00	0.000	VG	0.00	0.000	L	0.25	0.007
R22	0.0351	M	0.50	0.025	L	0.25	0.013	M	0.50	0.025
R23	0.0425	L	0.25	0.009	VL	0.00	0.000	M	0.50	0.018
R24	0.0421	L	0.25	0.011	M	0.50	0.021	L	0.25	0.011
R25	0.0457	M	0.50	0.021	L	0.25	0.011	M	0.50	0.021
R31	0.0395	VL	0.00	0.000	M	0.50	0.023	L	0.25	0.011
R32	0.0457	L	0.25	0.010	L	0.25	0.010	L	0.25	0.010
R33	0.0230	VL	0.00	0.000	L	0.25	0.011	L	0.25	0.011
R34	0.0303	L	0.25	0.006	M	0.50	0.012	M	0.50	0.012
R41	0.0316	M	0.50	0.015	VL	0.00	0.000	L	0.25	0.008
R42	0.0267	L	0.25	0.008	VL	0.00	0.000	VL	0.00	0.000
R43	0.0316	L	0.25	0.007	L	0.25	0.007	L	0.25	0.007
R44	0.0236	B	0.75	0.024	M	0.50	0.016	M	0.50	0.016
R45	0.0301	L	0.25	0.006	M	0.50	0.012	M	0.50	0.012
R46	0.0419	L	0.25	0.008	L	0.25	0.008	L	0.25	0.008
R51	0.0529	L	0.25	0.010	M	0.50	0.021	M	0.50	0.021
R52	0.0384	L	0.25	0.013	L	0.25	0.013	L	0.25	0.013
R53	0.0491	L	0.25	0.010	L	0.25	0.010	L	0.25	0.010
R54	0.0583	L	0.25	0.012	VL	0.00	0.000	L	0.25	0.012
R61	0.0531	H	0.75	0.044	L	0.25	0.015	M	0.50	0.029
R62	0.0467	M	0.50	0.027	VL	0.00	0.000	L	0.25	0.013
R63	0.0075	H	0.75	0.035	L	0.25	0.012	M	0.50	0.023
Total risk value				0.359			0.246			0.366

Step 10: Calculate supply chain risk value of sub-factors each supplier by multiplying the globalweights of the sub-factors with scale value of sub-factors each supplier. The risk value results of each supplier are shown in Table 17. The table displays that a total risk value of supplier A = 0.359, Supplier B = 0.246 and Supplier C = 0.366, respectively. Graphicall presentation of results of each supplier are demonstrated in Fig. 5

From the graphical representation, it can be seen that supplier C has the highest risk on external criteria, quality control and delivery, whereas supplier B has the highest risk on material control. The production risk of every supplier is not different. Supplier A has the highest risk on cost and financial issues, followed by supplier C and supplier B, respectively. As such, in overall it can be concluded that supplier B is the best supplier for this company which has the lowest priority from the other alternatives.

DISCUSSION

A decision making of the best supplier selection can increase the efficiency of supply chain operations. Factor analysis and fuzzy ANP are used in the integrated way to supplement the supplier selection process. This study explores supply chain risk factors for supplier selection applied to an actual case study. The results reveal that there are six factors which electrical and electronic companies in Thailand are taken into consideration i.e. risks from external, quality control, delivery, material control, production, cost and financial which include thirty sub-factors. quality control has the highest ranking, followed by production and material control, respectively. This proved that this study has validity in practical scenario as quality is always considered as the first priority to evaluation supplier (Dickson, 1966; Ho *et al*., 2007; Deshmukh and Sunnapwar, 2013). If qualities of raw material or product do not meet the standards or industrial regulations, it will lead to ineffective supply chain and decrease the value of products. Consequently, products cannot be exported or launched to the market in time. Furthermore, production risk was also ranked as the second importance for the electrical and electronic case company. It is pretty much true as production process also will have directly affected to the efficiency of any company. When production process is not flexible or inefficient, it will decrease the performance of the organization. For the risk of material control like material shortages, inventory management low efficiency will affect to inventory holding cost, error on forecasting resulting in incapability to meet customer' due date. When considering of the important weights of sub-factors risk, it found that production process, price and productivity are the top three highest ranked. These three sub-factors are also linked to the importance of main factors since they have directed effect to the quality of product, ability to compete on price and flexibility to be able to change quickly to support customers. According to this study, supplier B has found to be the best supplier because overall score was the lowest among all suppliers.

CONCLUSION

The study employed the fuzzy ANP approach to determine the fuzzy scale for importance weights of factors can application of the proposed method will offer relevant companies for more precise and accuracy analysis and help them to be more flexible in making a decision to evaluate the suppliers. The model can include both subjective and objective criteria which gain more realistic in making a decision. Moreover, it is easy to modify the concepts with other firms who need to find suitable tool in selecting the right alternative. However, there are some imitations in this research.

The study applies fuzzy ANP model with a small number of expert, therefore, future study should include a group of expert opinion for determining fuzzy number in making pairwise comparison. in addition, further research can be extended by combining the FANP model to Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method to rank supplier.

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