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A neural network evaluation model for ERP performance from SCM perspective to enhance enterprise competitive advantage

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Abstract

Due to increasing global competition, many enterprises are aware of the benefits of Enterprise Resource Planning (ERP). While the external environments and alliance partnerships facing an enterprise are becoming more complex, executives should consider appropriate partners to enhance efficiency and performance of supply chain management (SCM) as well as to gain potential competitive advantages. This study constructs a conceptual model to evaluate the performance and competitive advantages associated with ERP from a SCM perspective. The resulting model can be used to assist an enterprise in evaluating the potential partnerships. The survey data was gathered from a transnational textile firm in Taiwan. The training and learning models were based on the strategic thrust theory and used the Back-Propagation Network (BPN) as an evaluation tool.

Keywords: Enterprise Resource Planning (ERP); Supply chain management (SCM); Strategic thrust theory; Back-Propagation Network (BPN)

1. Introduction

The internal information systems of a traditional organization are usually orientated on a functional basis. This set-up does not encourage efficient departmental communication within the firm. Traditional information systems do not satisfy the information requirements of global logistic trends. Recently, there has been an emphasis on integrating a company's internal and external activities to improve a firm's competitive edge. This approach, when applied to the development of integrated information systems, has become a major thrust. Davenport (1998) stated that an integrated information system is a smart tool that can be used by a firm to solve problems associated with widely distributed information sources.

Enterprise Resource Planning (ERP) systems can integrate a firm's internal information from a financial perspective, allowing finance, accounting, purchasing and other departments to acquire information in a timely manner. ERP emphasizes integration of the flow of information relating to the major functions of the firm. The broader and more complex the organization is, the more it requires integrating this information flow. When applying supply chain management (SCM), orders can be forecasted efficiently and correctly, stock costs for supply chain partners can be reduced, and a manufacturing schedule can be set to optimize manufacturing and supply time. Additionally, strategic alliance was developed to facilitate collaboration between firms (Forrest & Martin, 1992). It plays an important role in establishing a firm's competitive advantage (Bowersox, 1990). SCM emphasizes close collaboration between supply chain partners and the building of a strong

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alliance in their joint strategic business focus. Therefore, SCM and a firm's competitive advantage are closely linked.

Integrating SCM to an ERP system can facilitate information flow in the supply chain so that partners of the chain can streamline their operations and share information sources to provide timely and accurate services to their customers. Traditional methods to evaluate ERP performance are limited to the internal departments of the company and do not include supply chain partners. However, under the global competition, many companies strengthen their core competencies via selecting their good business partners (Hong, Park, Jang, & Rho, 2005). Moreover, Choy, Lee, and Lo (2003) suggest that improving supply chain execution is important for achieving a firm's competitive advantage. Shin, Collier, and Wilson (2000) emphasized that a firm's performance can be evaluated by one or more key competitive priorities. Therefore, the five strategic forces of the strategic thrust theory can be independent or linked (Wiseman, 1985), and may relate to SCM performance.

This study uses a case to construct a conceptual model for the performance evaluation of an extended ERP system from an SCM perspective. The Back-Propagation Network (BPN) is used as a tool to access tacit knowledge held by the firm's employees and the ERP consultants. This knowledge can be used to evaluate the extended ERP systems that conform to the SCM performances. The goals of this paper are as follows:

(1) To access the tacit knowledge inherent in the case firm's employees and its ERP consultants/experts through the model learning process.
(2) To construct a BPN model to support a firm in evaluating its extended ERP performance from an SCM perspective and to test the competitive advantages gained by the ERP system.
(3) To produce results that will be useful to a firm when selecting partners.

2. Literature review

2.1. Strategic thrust theory

Porter (1985) used a value chain to analyze the operations of firms in reaching global optimization by coordinating activities. Porter identified five key forces that enable a firm to establish a long-term competitive advantage. His "Five Forces Theory" comprises of the bargaining power of suppliers; the bargaining power of buyers; the potential threat of new entrants; the threat of substitute products or services; and rivalry among existing firms.

Wiseman (1984) proposed a Strategic Thrust Theory to assist firms in planning and implementing a strategic information system to gain competitive advantages. The initial Strategic Thrust Theory included differentiation, cost, and innovation (Wiseman, 1984). Wiseman (1985) further broadened the scope of Porter's model, by considering the firm's competitive advantages as dominant over all one's competitors and that can be sustained over a period of time. The scope then was expanded to five postulates (Rackoff, Wiseman, & Ullrich, 1985; Wiseman, 1985) that constitute the major competitive aspects of a firm. The five postulates include differentiation, cost, innovation, growth, and alliance.

2.2. Extended enterprise resource planning (EERP)

Regarding the definition of ERP, some literature states that an ERP system is a package to integrate a firm's internal information systems (Bylinsky, 1999; Davenport, 1998; Laughlin, 1999). The American Production & Inventory Control Society (APICS) defined an ERP system as a financial and accounting oriented information system. Its major functions are the integration and planning of resources including purchasing, production, distribution, performance and reduction of business costs (APICS, 1998). Meanwhile, Tam, Yen, and Beaumont (2002) added human resources as basic functions of ERP. Furthermore, Davenport (1998) separated ERP into four function scopes: finance, human resources, operations logistics and sales and marketing. These four functional models are further divided into 29 sub-functions.

Although there are many definitions of ERP, the functional models developed by various software companies are similar. Most firms contemplating an ERP system focus on the integration of internal resources, but do not consider the competitive environment of global logistics. In order to maximize a firm's competitive advantage, ERP systems should be extended to cooperatively plan and operate with all partners in the supply chain (Akkermans, Bogerd, Yucesan, & van Wassenhove, 2003). Vickery, Calantone, and Droge (1999) proposed supply chain levels that span the value delivery cycles of the manufacturer, its suppliers and its downstream channel members. Ellram (1991) argued that SCM systems should manage the integration of material planning and control that flows both ways from suppliers to end consumers. The extended ERP system seeks to enhance the competitive performance of a firm by closely integrating the internal functions and effectively linking them with the external operations of suppliers and channel members.

After analyzing the relationship between SCM and ERP from both the global business and technology perspectives, Tam et al. (2002) pointed out that there is a demand for the integration of SCM and ERP. They also compared the differences between ERP and SCM systems, and emphasized that extended ERP systems compel firms to provide a communication and information flow among supply chain agents, thus overcoming natural boundaries. The integration of ERP and SCM systems is a natural and necessary process offered for strategic and managerial consideration (Tarn, Razi, Yen, & Xu, 2002). Such extended ERP system can improve supply chain performance and foster greater collaboration across multiple enterprises.

2.3. Criteria of EERP performance

In a business environment incorporating global logistics, external environmental forces impact the internal operations and decisions of the company. How to effectively compete in this global environment is a crucial issue for all firms (Tam et al., 2002). According to Tam et al., the performance of the ERP system should be measured according to supply chain activities. SCM performance criteria are used to ensure the competitive advantage of supply chain members. Skinner (1969) identified four criteria relating to SCM performance which include quality, cost, time and flexibility. Leong, Snyder, and Ward (1990) added innovation. Gerwin (1993), Ward, McCreery, Ritzman, and Sharma (1998) and Dangayach and Deshmukh (2000) used Leong et al.'s criteria to evaluate SCM performance. Dornier, Ernst, Fender, and Kouvelis (1998) included the constructs of service (delivery speed and reliability) and continuing improvement. Handfield and Nichols (1999) regarded total SCM performance as the result of the efforts of all supply chain members. The evaluation of SCM performance should, therefore, measure the performance of the total integrated supply chain and not the performance of an individual member. Yeh (2001) adopts the criteria constructs suggested by Skinner (1969), Leong et al. (1990), Dornier et al. (1998), and refers to Handfield and Nichols (1999) perspective to develop five criteria of electronic SCM performance for transnational industries in Taiwan. These five criteria include time, cost, quality, flexibility, and service. This paper developed the questionnaire based on the five criteria and Wiseman's (1985) competitive advantages to measure extended ERP performance.

2.4. Neural network

Recently, the neural network has been a popularly researched issue. Cascante, Plaisent, Bernard, and Maguiraga (2002) indicated that an artificial neural network is a useful tool in enhancing a manager's performance by assisting with knowledge, experience and expertise, consequently enhancing the quality of decision-making. Neural networks are used in business and banking applications for decision-making, forecasting and analysis (Kuo & Xue, 1998; Wong, Thomas, & Selvi, 1997). A survey of business applications from 1992 to 1998, Vellido, Lisboa, and Vaughan (1999) find neural networks are matured to offer real practical benefits. Consequently, it can be used to assist in selecting the potential suppliers (partners) (Choy et al., 2003).

The neural network concept is derived from biological science. Its components are similar to and have the basic functions of neurons in an organism. The components are organized just like a cranial nerve and possess some of the same characteristics of a cranial nerve. A neural network has the capability to obtain a new result through learning from past experiences and can correct its behavior by reacting to changes in its environment, thus becoming self-correcting.

Neural networks can be classified as both a learning model and a network structure. A number of network models have been developed with the BPN as the one most favored by neural network researchers (Kane, 1998; Sexton, Dorsey, & Johnson, 1998). The structure of a BPN consists of an input layer, an output layer, as well as a hidden layer which may or may not exist. The numbers of the input and output layer nodes are decided by task requirements. The optimal number of hidden layer nodes is determined by certain testing experiment (Chi & Tang, 2005). Pao (1989) argues that a three-layer machine can form arbitrarily complex decision regions and that increasing the number of hidden layers actually decreases the rate of learning in the random vector-pairing problem. Therefore, the BPN model of this study contains one hidden layer.

3. Research methodology

3.1. The constructing procedures of conceptual model

A conceptual model is constructed to evaluate competitive advantage based on an SCM perspective after the subject firm has implemented an extended ERP system. There are four steps to obtain the results of this study. First, in-depth interviews are conducted individually with three reputable consultants each having at least seven years consulting experience in ERP. This interview established the relationship between the criteria used for the firm's SCM performance and the competitive advantages of the Strategic Thrust Theory. It also adjusts the measurement criteria for applicability to the textile industry. Second, the executives of the case firm are surveyed. The survey considered not only the SCM performance of the firm, but also estimated the value of the competitive gains produced through the cooperation with partners. Third, the survey data is used to analyze the relationship between the criteria of SCM performance and competitive advantages. Finally, by reducing the factors of the SCM performance criteria, the conceptual evaluating model is constructed from the learning and testing models. The competitive advantages of the firm and its cooperative partners are then tested. Fig. 1 shows this conceptual evaluation model, that includes six key points.

(1) The learning model (17:17:5, 17 input nodes, 17 hidden nodes, 5 output nodes) extracts tacit knowledge from an ERP consultant company in Taiwan. This knowledge is used to help establish the competitive strategy used by the learning model.
(2) The tacit knowledge extracted from the transnational textile firm in Taiwan is used to provide the firm's SCM performance and to estimate the values of its competitive advantage. This sample data is used to

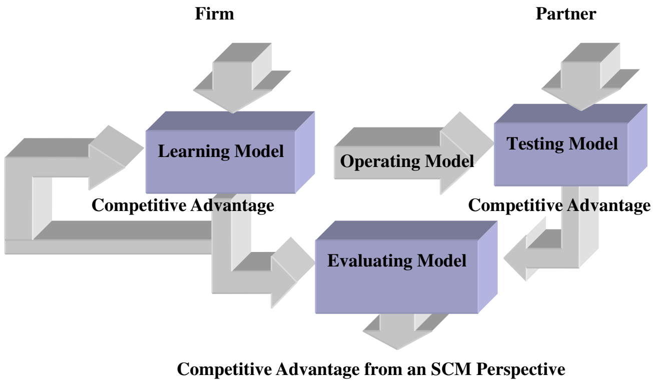

Fig. 1. A conceptual evaluation model of competitive advantage.

train the learning model. Then, the tacit knowledge held by the executives of the firm is integrated into the learning model.

(3) By using an operating model, the training results of the learning model are shifted to a testing model and enable the evaluating model to test the competitive advantages of supply chain members in a "what-if" situation as well as assist in decisions regarding the selection of alliances.
(4) The acquired knowledge is then used to assess the partner's competitive advantage based on the extended ERP performance by the testing model.
(5) The evaluating model uses the competitive advantage values from both the learning model and the testing model to evaluate the combined competitive advantage for its potential partners.
(6) In this selection process, the firm uses these results to make alliance partner choices.

3.2. Sampling

This study chose a transnational textile firm that had adopted an extended ERP system on the advice of three reputable ERP consultants. It was assumed that a firm's performance would relate to the integrated internal and external operations of the organization. Seventy executives belonging to the selected case firm were selected to evaluate the extended ERP performance and the firm's competitive advantage from an SCM perspective. The surveyed sample size is, therefore, 70. Sixty questionnaires were collected, with the assistance of the ERP consultants to come up with an 85.7% efficiency rate. Among the 60 questionnaires, we used 50 questionnaires to train and 10 questionnaires to learn in learning model. And, the evaluation model was trained with 30 of the questionnaires received. A factor analysis was used to reduce the learning model factors. Usually, the sample size is 4 or 5 times that of the measured items for factor analysis in practice. Comrey (1973) proposed that a sample size of less than 100 was not suitable for factor analysis. But Kaiser (1974) adopted the KMO (Kaiser–Meyer–Olkin) value to judge suitability for factor analysis. Kaiser considers that a KMO value less than 0.5 should not be acceptable. The KMO value of this study is 0.799 and therefore, according to Kaiser, is suitable for the use of factor analysis according to Kaiser (Figs. 2–4).

3.3. Questionnaire design

The initial questionnaire is developed that based on the five criteria of SCM performance suggested by Yeh (2001) and Wiseman (1985) competitive advantages. The ERP consultants, with their practical experience, adjusted the initial questionnaire to make it more suitable for the extended ERP system. Before undertaking the training and learning processes, the study used canonical correlation analysis to confirm the relationship between the competitive advantages and the SCM performance criteria to ensure that the questionnaire is indeed suitable for the learning models.

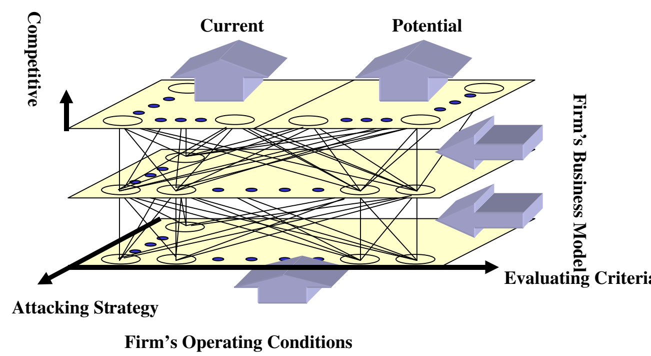

Fig. 2. Learning and testing models of neural network.

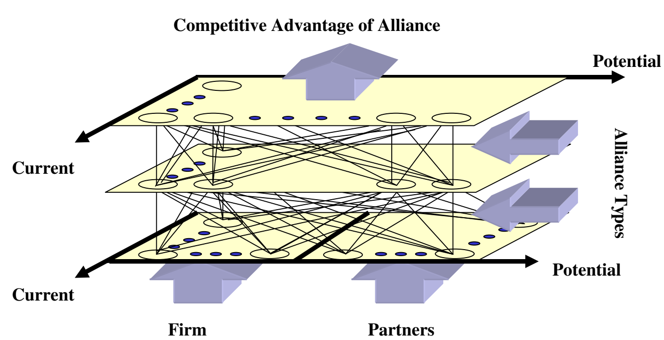

Fig. 3. Evaluation model of neural network.

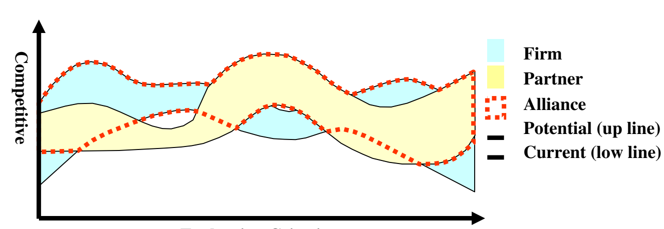

Fig. 4. The conditions before alliance and after alliance.

4. The case firm

The case firm used to produce short staple and copied hair products. Due to the limited demand for these products the firm entered into the business of textile weaving and now produces spun cotton to be woven into cloth for making clothes. Recently, the case firm expanded into international operations and invested in a factory in Mexico making ready-to-wear clothes. It has integrated American market channels and factory sites in Mexico and Asian areas. The case firm has constructed a complete supply chain consisting of factories and markets and has established a textile supply chain prototype.

The customers of this firm include the top five purchasing companies of ready-to-wear clothes in North America. They are J.C.Penney, BK-Mart, BW-Mart, Bsears, and Target. In particular, the case firm is one of the top 60 suppliers of J.C.Penney. This integral manufacturing system produces product-lines of gauze, cloth, dye, and ready-made clothes and operates in North America (Mexico) and Asia. The product innovation department is in Taiwan, manufacturing is in Mexico, and the major marketing channels are in the United States and China. It owns more than 150 retail outlets located in North America and China. It also constructively integrates the SCM's marketing and manufacturing activities to increase resource efficiency within the group enterprise.

By managing the logistics electronically, the case firm and its associated factories are integrated into a coherent supply chain system. This not only encourages efficient collaboration between the case firm and its allied factories, but also substantially shortens operating time, thus supporting the firm's strategy of entering the American market and the global economy.

5. Analysis and results

5.1. Reliability and validity analysis

To measure the reliability of a questionnaire, it is common to use Cronbach's Alpha to measure the consistency of research variables. When Cronbach's α value is greater than 0.7, it is acceptable (Nunnally, 1978). Hair, Anderson, Tatham, and Black (1998) also supported this perspective and proposed that the research variables should be rejected if the Cronbach's α value is less than 0.35. The Cronbach's α value in this study is 0.8522, which implies that this questionnaire has a high reliability. The Cronbach's α value of the individual factors can be seen in Table 1. The Cronbach's α value relating to the service factor is 0.3138. Theoretically, this factor should be rejected. However, considering the recommendations of the ERP consultants, "service" can enhance and strengthen the relationship between a firm and its partners, and is an important factor in improving a firm's SCM performance. Therefore, this study retained the "service" factor as part of the criteria.

This questionnaire was adjusted by three ERP consultants to validate the content. The construct validity of the questionnaire is listed in Table 1. The selected research variables all meet the three conditions proposed by Hair et al. (1998): (1) the eigenvalue of the factor must be greater than 1; (2) after varimax rotating, the absolute value of the factor loading must be greater than 0.5; (3) the difference between each of the factor loadings must be greater than

Table 1
The result of principal component analysis

Factors	Context of measurement items	Factor loading	Eigen-value	Explanatory variance	Cronbach's α
Time	Whether the response of the co-coordinating factory is faster	0.768	15.664	19.035%	0.8513
	Whether the required time to confirm purchasing order is shorter	0.755		(19.035%)	
	Whether the preprocessing time of purchase is shorter	0.706			
	Whether the delivery on time rate of co-coordinating factory is increasing*	0.687			
	Whether the delivery time up rate of co-coordinating factory is increasing*	0.647			
Cost	Whether the document processes for purchase are reduced	0.845	4.224	15.581	0.8595
	Whether the routine work referring to purchase is reduced	0.797		(34.615%)	
	Whether the raw material and component storage for manufacturing are reduced	0.669			
	Whether the storage for manufacturing product is reduced	0.662			
	Whether the storage for manufactured product is reduced	0.627			
	Whether the storage turnover rate is increased	0.542			
Quality	Whether the communication errors for purchasing scale are reduced	0.909	2.974	15.517	0.8923
	Whether the quality of imported material is more consistent	0.852		(50.132%)	
Flexibility	Whether the manufacturing process flexibility of the co-coordinating factory is increasing	0.831	2.774	10.210	0.5448
	Whether the requirement time for co-coordinating factory to adopt the new materials or components is decreasing	0.705		(60.342%)	
Service	Whether the relationship between the central factory and the satellite factory is closer	0.726	2.138	6.461	0.3138
	Whether the in-depth application of IT for the co-coordinating factory is increasing	0.707		(66.803%)	

* Delivery on time rate includes the delivery rate on or before the due date; delivery time up rate means delivery rate on the due date.

Table 2
The test of canonical correlation coefficients

Canonical correlation functions	Eigenvalue	Square of canonical correlation	Approx F	Sig.
1	15.085	0.938	3.05768	0.000
2	3.443	0.775	1.83751	0.001
3	1.961	0.662	1.37800	0.072
4	0.991	0.498	0.99131	0.507
5	0.473	0.321	0.70950	0.798

Alpha = 0.05.

0.3. In other words, the questionnaire used in this study has content validity and construct validity.

5.2. Canonical correlation analysis

This study uses canonical correlation analysis to test the relationships between the criteria of SCM performance and competitive advantages. The results of two canonical correlation functions support the study in the construction of a learning model (see Table 2). The square values of canonical correlation of these functions are 0.938 and 0.775, which indicate a strong relationship between SCM performance and competitive advantage. The canonical correlation analysis results show that there is enough evidence to support the existence of this relationship. It also strengthens the rationalization of this study in viewing the competitive advantages of a firm from an SCM perspective.

5.3. Training, testing and evaluating the model for competitive strategy

This study used a survey to develop the evaluating criteria of SCM performance and the current operating conditions of the attack strategy for competitive advantages. It also derives the weights of the required criteria for a firm to evaluate its cooperative partners and the conditional weight of their alliance. Finally, using the neural network model (17, 17, 5) we developed the business model best suited to coordinate the current conditions and potential advantages for an individual firm. After developing the best business model for the firm, we can then use the conceptual model to test the competitive advantages of the firm's partners. We also use the conditional data of alliance requirements for competitive advantage as the learning data template of the testing model for cooperative advantages, by evaluating the current conditions and the potential for competitive advantage. To go a step further, a complete evaluating model is established after proceeding with learning through the constructed neural network model (10, 10, 5).

Table 3 lists the learning model of case firm. Table 4 lists the evaluating model of case firm and its partners. The results in Tables 3 and 4 show that the model of competitive advantage is able to converge under an error tolerance of 5%. It is implied, therefore, that the evaluating model of competitive advantage has value in practical applications. It can be used to evaluate the competitive advantages of cooperative supply chain members and to understand the current conditions and potential for the competitive advantage of an integrated supply chain.

6. Limitations and contributions

6.1. Limitations

This study collected the training and learning data from a case firm, focusing on its executives. We realize, however, that only a few executives participate in all the business operations and the decision-making strategies in the firm. Furthermore, if the firm's partners do not do business electronically, then the extended ERP cannot promote integral competitive advantages. In this case, the values would be lower for ERP performance. This phenomenon also supports the use of this study in evaluating ERP performance from an SCM perspective.

This study also casts doubts as to the practical value of its application due to the results of the evaluation model. This arises from questions regarding the accuracy of the acquired knowledge from the ERP consultants and the case firm executives. To address this problem, our study selected as interviewers, three reputable consultants who each had at least seven years' ERP consulting experience and executives within a firm that had adopted an extended ERP system as the subjects of interview. In the training process, the

Table 3
Learning model, training parameters and training results

Module	Sample	Network structure			Learning rate	Inertia factor	Error tolerance	Transform function	Iteration number	Error rate
		Output nodes	Hidden nodes	Input nodes						
L1	50	5	17	17	0.7–0.2	0.6–0.2	20%	Sigmoid	836	–
L2	50	5	13	17	0.7–0.2	0.6–0.2	20%	Sigmoid	1310	–
L3	50	5	10	17	0.7–0.2	0.6–0.2	20%	Sigmoid	>100,000	–
L4	50	5	13	17	0.7–0.2	0.6–0.2	15%	Sigmoid	5274	–
L5	50	5	13	17	0.7–0.1	0.6–0.1	10%	Sigmoid	10,126	20%
L6	50	5	13	17	0.6–0.1	0.6–0.1	5%	Sigmoid	13,357	5%

Table 4
Evaluation model, training parameters and training results

Module	Sample	Network structure			Learning rate	Inertia factor	Error tolerance	Transform function	Iteration number	Error rate
		Output nodes	Hidden nodes	Input nodes						
L1	30	5	10	10	0.7–0.2	0.6–0.2	20%	Sigmoid	547	–
L2	30	5	7	10	0.7–0.2	0.6–0.2	20%	Sigmoid	916	–
L3	30	5	5	10	0.7–0.2	0.6–0.2	20%	Sigmoid	1542	–
L4	30	5	3	10	0.7–0.2	0.6–0.1	20%	Sigmoid	>100,000	–
L5	30	5	5	10	0.7–0.1	0.6–0.1	10%	Sigmoid	1825	10%
L6	30	5	5	10	0.6–0.1	0.6–0.1	5%	Sigmoid	2317	5%

model acquired the weights from different departments that enhance the result to suit real practice application.

6.2. Contributions

Most firms implement ERP systems with the assistance of ERP company consultants, but only a few reach their objective. This can be due to various reasons. First, the knowledge contained within the firm and the ERP consultant-company is tacit and lacks integration. Second, the ERP performance is evaluated from the firm-self traditionally. It ignores that performance is affected by its supply chain members. Third, the firm's ERP system cannot be integrated with its partners. These conditions reduce ERP system performance.

The conclusions of this study imply that extracting tacit knowledge from firms and ERP consultants to evaluate SCM performance within an ERP system is possible. Other firms can use the evaluation of these results in reviewing their own ERP systems and alliance partners. Based on the above discussion, the contributions of this study are listed below:

(1) The integration of the tacit knowledge inherent within the firm and the ERP consultants and avoidance of erroneous personal judgments.
(2) A well constructed evaluation model of competitive advantage.
(3) A firm can use this competitive advantage evaluation model to determine its competitive advantages and the competitive advantages of its partners after implementing an extended ERP system based on SCM.
(4) Under limited resources, a firm can use this competitive advantage evaluation model to support decision-making when adjusting the focus of the ERP or the SCM system.
(5) Supplying a firm with the tools to make strategic alliance decisions.

6.3. Future research directions

This model is constructed to be applied on a case by case basis; the data comes from a single transnational textile firm. In follow-up research, the survey can be extended to supply chain members in an upward or downward direction. After the survey has been done, the training and learning parts of the model can be used to increase its practical value. Specifically, future research can include more alliance types. By adjusting for the difference in alliance types, the model will become more flexible. The firm can also evaluate the integral competitive advantages of supply chain members and adjust the cooperative relationships with its partners to ensure satisfaction.

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