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Supplier selection and performance evaluation in just-in-time production environments

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ABSTRACT

The purpose of this paper is to aid just-in-time (JIT) manufacturers in selecting the most appropriate suppliers and in evaluating supplier performance. Many manufacturers employ the JIT philosophy in order to be more competitive in today's global market. The success of JIT on the production floor has led many firms to expand the JIT philosophy to the entire supply chain. The procurement of parts and materials is a very important issue in the successful and effective implementation of JIT; thus, supplier selection and performance evaluation in long-term relationships have became more critical in JIT production environments. The proposed systems can assist manufacturers in handling these issues. In this research, neural network based supplier selection and supplier performance evaluation systems are presented. The proposed approach is not limited to JIT supply. It can assist manufacturers in selecting the most appropriate suppliers and in evaluating supplier performance. The proposed neural network based systems are tested with data taken from an automotive factory, and the results show that the proposed systems can be used effectively.

1. Introduction

Today's companies are faced with fierce competition, which is forcing them to increasingly consider new applications to improve quality and to reduce cost and lead time. For this reason, manufacturers must keep pace with the dynamic requirements of the market and be receptive to change. The aim of many new manufacturing systems, like the just-in-time (JIT) philosophy, is to eliminate waste in the production environment and to continue this process as a continuous cycle, always striving for the best (Lubben, 1988).

The JIT philosophy is an important action in the supply chain management (SCM) system. The JIT purchasing system requires smaller order quantities and tighter delivery times. Hence, manufacturers dealing with the JIT philosophy must collaborate with their suppliers. In order to achieve a successful JIT system, a relationship between the supplier and buyer must be established for close business collaboration as strategic partners.

Matson and Matson (2007) suggested that, for global competitiveness, further support is required for efficient JIT supply chains and that it is critical that JIT suppliers identify and address performance issues as effectively as possible.

Manufacturers practicing JIT require suppliers that punctually supply materials and outsourced parts – in the appropriate quantity and with consistent quality. Because reliable suppliers enable manufacturers to reduce inventory costs and improve product quality, it is understandable that manufacturers are increasingly concerned about supplier selection (Braglia & Petroni, 2000). It is apparent that the selection of appropriate suppliers and effective supplier relationship management are key factors in increasing the competitiveness of firms (Choy, Lee, & Lo, 2003a; Ghodsypour & O'Brien, 2001). In a long-term relationship, after selecting the suppliers, purchasing departments need to periodically evaluate the performance of their suppliers in terms of critical criteria.

Supplier selection and evaluation play an important role in reducing the cost and time to market whilst improving the quality characteristics of the products. They can significantly affect manufacturing costs and production lead time. Although several techniques and models have been employed for selecting and evaluating suppliers, each technique has its own strengths and limitations under different situations. Therefore, there is a strong need to further improve the performance and effectiveness of supplier selection and evaluation approaches in manufacturing environments in order to act effectively in different situations. A detailed literature review with respect to supplier selection and evaluation methods is given in the following section.

In this research, a neural network (NN) technique is used to select suppliers and to evaluate the selected suppliers' performance in order to cope with the limitations of traditional

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techniques. A neural network represents an information-processing technique that is developed to simulate the functions of a human brain.

The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 explains the proposed approach and presents a neural network based supplier selection system and supplier performance evaluation system for JIT manufacturers. Application examples and results are provided in Section 4. Finally, conclusions are presented in Section 5.

2. Literature review

There are several papers regarding the implementation of JIT systems and buyer–supplier relationships under JIT systems in the literature. It can be seen that there is not yet enough research regarding the benefits of neural network approaches in supplier selection and supplier performance evaluation in JIT manufacturing.

Dong, Carter, and Dresner (2001) reported that the implementation of JIT purchasing systems can result, on average, in reduced inventory costs, shorter lead times and improved productivity for buying organizations. Dong et al. (2001) also stated that JIT purchasing strategies are aimed at a synchronized and timely product flow from the supplier to the buyer.

Boer, Labro, and Morlacchi (2001) suggested that with increasing significance of the purchasing function, purchasing decisions become more important. As organizations become more dependent on suppliers, the direct and indirect consequences of poor decision-making become more severe. In addition, several developments further complicate purchasing decision-making. The globalization of trade and the Internet enlarge a purchaser's choice set. Changing customer preferences require a broader and faster supplier selection.

In the supplier selection process, it is not always easy to recognize precise rules, but there is, in general, a coherent way to solve the problem. The choice of supplier is then a problem usually solved by subjective criteria, based on personal experiences and beliefs, on the available information and, sometimes, on techniques and algorithms supporting the decision process (Albino & Garavelli, 1998). The key to enhancing the quality of decision-making in the supplier selection function is to take advantage of the powerful computer-related concepts, tools and techniques that have become available in the last years (Wei, Zhang, & Li, 1997).

Chao, Scheuing, and Ruch (1993) concluded that quality and on-time delivery are the most important attributes of purchasing performance. Ghodsypour and O'Brien (1998) agreed that cost, quality and service are the three main categories to consider when determining supplier selection parameters. Briggs (1994) stated that joint development, culture, forward engineering, trust, supply chain management, quality and communication are the key requirements of a supplier partnership, apart from optimum cost. Petroni and Braglia (2000) evaluated the relative performance of suppliers that have multiple outputs and inputs, based on capabilities relating to management, production facilities, technology, price, quality and delivery compliance. Wei et al. (1997) determined that factors such as a supplier's supply history, product price, technology ability and transport cost have effects on the selection of suppliers.

2.1. Supplier selection methods in the literature

The literature presents several methods for selecting a supplier. Categorical methods are qualitative models. Based on the buyer's experience and historical data, suppliers are evaluated by a set of criteria. The evaluations actually consist of categorizing the supplier's performance based on a set of criteria as either 'positive', 'neutral' or 'negative' (Boer et al., 2001). After a supplier has been rated on all criteria, the buyer gives an overall rating, such that the suppliers are sorted into three categories.

Data envelopment analysis (DEA) is concerned with the efficiency of a decision alternative. The DEA method aids the buyer in classifying the suppliers into two categories: efficient suppliers and inefficient suppliers. Liu, Ding, and Lall (2000) used DEA in the supplier selection process. They evaluated the overall performances of suppliers by using DEA. Saen (2007) used IDEA (Imprecise Data Envelopment Analysis) to select the best suppliers in the presence of both cardinal and ordinal data.

Cluster analysis (CA) represents a class of statistical techniques that can be applied to data that exhibit "natural" groupings (Boer et al., 2001).

Case-based reasoning systems (CBR) combine a cognitive model describing how people use and reason from past experience with a technology for finding and presenting experience (Choy et al., 2003a). Choy, Lee, and Lo (2002b) enhanced a CBR-based supplier selection tool by combining the supplier management network (SMN) and supplier selection workflow (SSW). Choy, Lee, Lau, and Choy (2005) used CBR to select suppliers in the new product development process.

In linear weighting methods, criteria are weighted and the criterion that has the largest weight is given the highest importance. Ghodsypour and O'Brien (1998) integrated AHP and linear programming to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities. Lee, Sungdo, and Kim (2001) used only AHP for supplier selection. They determined the supplier selection criteria based on the purchasing strategy and criteria weights by using AHP. Liu and Hai (2005) used DEA for determining the supplier selection criteria. Then, they interviewed 60 administrators to determine the criterion priorities and they used AHP for selecting suppliers.

Ting and Cho (2008) presented a two-step decision-making procedure – AHP for selecting a set of a firm's candidate suppliers, followed a multi-objective linear programming (MOLP) model for optimal allocations of order quantities to the candidate suppliers.

Boer, Wegen, and Telgen (1998) used the ELECTRE 1 technique to evaluate five supplier candidates. Xia and Wu (2007) used an integrated approach of AHP improved by rough sets theory and multi-objective mixed integer programming, which was proposed to simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing and multiple products, with multiple criteria and with the supplier's capacity constraints. Wang, Huang, and Dismukes (2004) used an integrated AHP and preemptive goal programming (PGP)-based multi-criteria decision-making methodology to take into account both qualitative and quantitative factors in supplier selection. Liu and Hai (2005) compared the voting analytic hierarchy process (VAHP) and AHP for supplier selection process. Chan and Kumar (2007) identified some of the important and critical decision criteria including risk factors for the development of an efficient system for global supplier selection. They used fuzzy extended analytic hierarchy process (FEAHP)-based methodology to select suppliers.

Total cost of ownership (TCO) based models include all costs related to the supplier selection process that are incurred during a purchased item's life-cycle. Degraeve and Roodhooft (1999) evaluated the suppliers based on quality, price and delivery performance by using TCO. They emphasized that the uncertainty of demand, delivery, quality and price must be reflected in the decision problem. Ramanathan (2007) proposed an integrated DEA-TCO-AHP model for the supplier selection problem.

According to Boer et al. (2001), mathematical programming models (MP) allow the decision-maker to formulate the decision problem in terms of a mathematical objective function that subsequently needs to be maximized and minimized by varying the values of the variables in the objective function. MP models are more objective than rating models because they force the decision-maker to explicitly state the objective function; however, MP models often only consider the more quantitative criteria. Karpak, Kasuganti, and Kumcu (1999) enhanced a supplier selection tool by minimizing costs and maximizing the quality reliability. Ghodsypour and O'Brien (1998) integrated the AHP and LP models. Their model presented a systematic approach, considering both qualitative and quantitative criteria. They also expanded sensitivity algorithms for different scenarios. Ghodsypour and O'Brien (2001) used mixed integer programming, including the total cost of logistics. Degraeve and Roodhooft (2000) computed the purchasing cost for different purchasing strategies by using MP. Barla (2003) reduced the number of suppliers from 58 to 10 by using a multi-criteria selection method. Hong, Park, Jang, and Rho (2005) applied the supplier selection process into two steps. They used cluster analysis for pre-qualification of suppliers; then, by using MP, they selected the most appropriate supplier. Yang, Yang, and Abdel-Malek (2007) studied a supplier selection problem in which a buyer, while facing random demand, is to determine ordering quantities from a set of suppliers with different yields and prices. They provided a mathematical formulation for the buyer's profit maximization problem and proposed a solution method based on a combination of the active set method and the Newton search procedure. Kheljani, Ghodsypour, and O'Brien (2007) considered the issue of coordination between one buyer and multiple potential suppliers in the supplier selection process. On the other hand, in the objective function of the model, the total cost of the supply chain is minimized rather than only the buyer's cost. The total cost of the supply chain includes the buyer's cost and the suppliers' costs. The model was solved by applying mixed-integer nonlinear programming. Liao and Rittscher (2007) developed a multi-objective programming model, integrating supplier selection procure lot sizing and carrier selection decisions for a single purchasing item over multiple planning periods while demand quantities are known but varying.

Artificial intelligence (AI)-based systems are based on computer-aided systems and can be trained by purchasing experience or historical data. AI-based supplier selection applications include neural networks (NNs) and expert systems (ES). One of the important advantages of the NN method is that it does not require a formulation of the decision-making process. In this way, NNs can better cope with complexity and uncertainty than traditional methods because these systems are designed to be more similar to human judgement functioning. The user of the system must provide the NN with the properties of the current case. Thus, NN contact with the user is based on what it has learned from historical data. Albino and Garavelli (1998) enhanced a neural network based decision support system for subcontractor rating in construction firms. The system includes a back-propagation algorithm. The constructed network is trained by examples, so the system does not require the decision-maker's rules. Vokurka, Choobineh, and Vadi (1996) and Wei et al. (1997) built up an expert system supporting the supplier selection process. Chen, Lin, and Huang (2006) used linguistic values to assess the ratings and weights for supplier selection factors. These linguistic ratings were expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy multiple criteria decision-making (MCDM) model based on fuzzy-sets theory was proposed to deal with supplier selection problems in the supply chain system.

Wang and Che (2007) demonstrated an integrated assessment model for manufacturers to solve the complex product configuration change problem efficiently and effectively. The model is focused on finding the fundamental supplier combination that will best minimize the cost–quality score, if and when proposed by the customer and/or engineer. They combined fuzzy theory, T transformation technology and genetic algorithms. Wang (2008) built up a decision-making procedure, providing the supplier selection appraisal. The research proposed to find an acceptable near-optimal solution within a short time by a solution-finding model based on genetic algorithms (GA). Liao and Rittscher (2007) studied the supplier selection problem under stochastic demand conditions. Stochastic supplier selection is determined through simultaneous consideration of the total cost, the quality rejection rate, the late delivery rate and the flexibility rate, involving constraints of demand satisfaction and capacity. They used GAs to solve the problem.

2.2. Supplier performance evaluation methods in the literature

Periodic evaluation of supplier quality is carried out to ensure the meeting of relevant quality standards for all incoming items (Jain, Tiwari, & Chan, 2004). In the absence of market-based control mechanisms, the supply exchange could be subject to opportunistic temptations. An accurate rating system can restore competitive pressure within the pool of suppliers by monitoring and comparing the supplier's improvement over time (Toni & Nassimbeni, 2000).

Several different methods for evaluating supplier performance have appeared in the literature, such as the categorical method, the weighted point method, the cost ratio method and the weighted point method using a performance matrix and AHP. Although each of these methods offers advantages under specific conditions, none provide a general methodology for combining multiple criteria or attributes into a single measure of supplier performance (Li, Fun, & Hung, 1997).

Timmerman (1986) ranked different supplier characteristics as "good", "satisfactory", "neutral" and "unsatisfactory" by using the most simple rating model, the 'categorical method'. Humphreys, Mak, and McIvor (1998) emphasized the problems with this approach; for example, the attributes are given equal weightings, which is clearly not the case in practice. In addition, the process is mainly intuitive and does not have the same precision as that provided by a more quantitative approach.

The usage of the AHP technique in supplier performance evaluation has been seen frequently in the literature. In the AHP method, the relative positions of suppliers with respect to given criteria are determined using pair-wise comparison. The main disadvantage of this approach is that the performance measures used for the various criteria must apply standardized units (Humphreys et al., 1998).

In the cost ratio method, standardized cost analysis is first applied and cost ratios for supplier performance evaluation criteria are used to calculate a net adjusted cost for each vendor. This method is not widely used in the industry and requires a comprehensive cost-accounting system. Li et al. (1997) and Humphreys et al. (1998) used dimensional analysis methods in their research. Dimensional analysis methods combine several criteria of different dimensions and relative importance into a single dimensionless entity. Dimensional analysis methods are less subjective.

Schmitz and Platts (2004) studied four major vehicle manufacturers using questionnaires. By applying questionnaires, they ranked their suppliers according to their logistics performance. Talluri and Narasimhan (2004) used the questionnaire technique to evaluate supplier performance. They used questionnaires to evaluate suppliers according to quality, price, delivery and price discount performance. They used DEA to assess the results. One of the most important advantages of this method is that it does not require criteria weightings.

Ohdar and Ray (2004) and Jain et al. (2004) used a fuzzy-based GA to evaluate supplier performance. Sarkar and Mohapatra (2006) proposed a systematic framework for reducing the supply base to a predefined level and considered a number of supplier-related factors in the evaluation process. They used a fuzzy set approach to overcome the difficulty of measurement imprecision associated with qualitative factors. Demirtas and Ustun (2009) integrated Archimedean goal programming (AGP) and the analytic network process (ANP). The integrated approach proposed to evaluate the suppliers and to determine their periodic shipment allocations, given a number of tangible and intangible criteria.

Araz, Ozfirat, and Ozkarahan (2007) developed an outsourcer evaluation and management system for a textile company by the use of fuzzy goal programming (FGP). In the first phase of the methodology, evaluation criteria for the outsourcers and the objectives of the company are determined. In the second phase, the developed FGP model selects the most appropriate outsourcers to be strategic partners with the company and simultaneously allocates the quantities to be ordered from them.

Ordoobadi (2009) described a decision model that applies fuzzy arithmetic operators to manipulate and quantify a decision-maker's subjective assessments.

It can be seen that there is a significant research interest in introducing more effective supplier selection and evaluation approaches in the manufacturing industry in order to achieve better applications. The main objective of this paper is to introduce a neural-network-based non-traditional approach to cope with the limitations of traditional techniques and to support efficient SCM applications in the manufacturing industry for JIT production environments.

3. Proposed approach

In this research, a neural network based approach is used for supplier selection and performance evaluation in JIT production environments. This paper deals with two problems that are widely accepted as important issues to improve the performance of supplier selection and evaluation approaches, which are (1) the complexity of the multi-attribute decision-making process and (2) uncertainties regarding problem definition and data. A neural network based approach can deal with the complexity and conflicts existing in selecting and evaluating supplier cases through its two major characteristics, learning and recall; in addition, it does not require a formulation of the decision-making process. Learning is the process of adjusting a network model to produce the desired output. Recall is the process of providing an output for a given input in accordance within the trained model.

The processes of supplier selection and evaluation are multiple criteria decision-making problems that are affected by several conflicting factors under varying situations. They are multi-attribute decision-making processes that require a consideration of a variety of attributes regarding the target domain and specific issues. As seen in the literature review, there is a strong interest in coping with the weaknesses of traditional techniques in supplier selection and evaluation (Çelebi & Bayraktar, 2008; Choy, Lee, & Lo, 2002a; Guo, Yuan, & Tian, 2009; Ha & Krishnan, 2008; Keskin, İlhan, & Özkan, 2009; Sanayei, Mousavi, & Yazdankhah, 2009; Wang & Yang, 2009; Wu, 2009; Zarandi, Pourakbar, & Turksen, 2008). Although some improvements regarding the multi-objective decision-making process have been achieved, the complexity of problems with conflicting objectives under different conditions regarding the target domain presents shortcomings. This can be overcome by efficiently incorporating intelligent techniques into a selection and evaluation process. Artificial intelligence (AI) methods can better cope with complexity, conflicts and uncertainty under different situations than traditional methods because they are designed to be more like human judgment functioning. Neural network and hybrid techniques present the most promising approaches for overcoming the complexity and conflicts that exist in selecting and evaluating a supplier (Çelebi & Bayraktar, 2008; Choy et al., 2002a; Guo et al., 2009; Ha & Krishnan, 2008; Keskin et al., 2009; Wu, 2009; Zarandi et al., 2008). Although neural networks have been applied to a wide range of manufacturing problems, their use in SCM is quite recent and there are only a few related applications. The objective of this paper is to contribute to the recent research by incorporating a NN based approach in selecting and evaluating of suppliers in an effective way in the area of SCM in JIT production environments.

NN is a powerful data-modelling tool that can capture and represent complex input/output relationships. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system that could perform "intelligent" tasks similar to those performed by the human brain.

The true power and advantage of neural networks lie in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly from the data being modelled. Traditional linear models are simply inadequate when it comes to modelling data that contain non-linear characteristics. NNs "learn" from examples, and if trained carefully, NNs may exhibit some capability for generalization beyond the training data, that is, they can produce approximately correct results for new cases that are not used for training. NNs have been widely used in many classification and optimization situations (Bose & Liang, 1996; Choy, Lee, & Lo, 2003b). The properties that make NNs desirable are evidenced below:

1. NNs process as a parallel system processor. Neurons acts simultaneously. This means that if one of the neurons goes out of service, the network performance is not affected.
2. NNs have the ability to generalize. In the training phase, training data are presented to the network. After training, the NN responds to new data that was not presented in the past.
3. Neurons, which form NNs, have non-linear characteristics. This makes NNs non-linear.

The back-propagation algorithm (BA) is used in this research as a learning algorithm. The algorithm gives a procedure for adjusting the initially randomized set of weights (existing between all pairs of neurons in each successive layer of the network) so as to maximize the difference between the network's output of each input fact and the output with which the given input is known (or desired) to be associated. The NN using the BA includes an input layer, a hidden layer and an output layer. The number of hidden layers used depends on the structure of the problem. Learning is the process of modifying the weights in order to produce a network that performs some function. After training, the neural network model must be validated.

3.1. Neural network based supplier selection system

Use of the NN technique in the supplier selection process is a new approach. Incorporation of both quantitative and qualitative supplier attributes by using the NN technique is a suitable method for manufacturers, especially for those who outsource a significant part of their business.

In this research, a NN based supplier selection system for JIT manufacturers and a NN based supplier performance evaluation system are presented. A back-propagation supervised learning model was designed by using a NN software package, Matlab.

The NN based supplier selection system includes the following steps:

Step 1: Construction of NN.
Step 2: Training of NN.
Step 3: Validation of NN.

Construction of NN: The construction of the NN includes the determination of input and output parameters, the training algorithm and hidden layer design. There are several criteria related to the supplier selection process described in the literature. In this research, four criteria that are suitable for JIT manufacturers were determined through interviews with administrators of automotive manufacturers and inspection of literature. They are as follows:

– Quality
– JIT delivery performance
– Location for transport
– Price

Table 1 presents the input data properties for the supplier selection system.

The quality, JIT delivery performance and price criteria are quantitative data. An interval is determined for the location criterion. When determining an interval, reference values are considered as follows:

0.50: Very near. (Located in the same city, same industrial community)
0.45: Near. (Located in the same city, different industrial community)
0.35: Slightly far. (Located in a different city, same geographic zone)
0.30: Fairly far. (Located in a different city, different geographic zone)
0.10: Very far. (Located in a foreign country)

In this research, suppliers are represented as input vectors in terms of quality, JIT delivery performance, location for transport and price. The output vector is either “1” or “0”, where 1 means “supplier is selected” and 0 means “supplier is not selected”. Fig. 1 shows the general structure of the neural network for the supplier selection.

The NN is trained by using historical performance data of the suppliers. A supervised learning technique is used for training so the user/trainer can confirm that the output is desirable.

Table 1
Input parameters for supplier selection system.

No.	Input	Interval	Explanation
1	Quality	0–1	Percentage of acceptable parts in the past “*n*” supply
2	JIT delivery performance	0–1	Percentage of JIT delivery performance in the past “*n*” supply
3	Location	0.10 – 0.30 – 0.35 – 0.45 – 0.50	0.10: Very far – 0.30: Fairly far – 0.35: Slightly far – 0.45: Near – 0.50: Very near
4	Price	0–1	Proposed price by supplier/Max price for part

Training of NN: The training of the network involves the following steps:

Step 1: Initialize all of the weights to random values
Step 2: Present the training data set to the network in terms of input and output
Step 3: Compute the error between the desired and computed outputs
Step 4: Adjust the weights of the network to minimize the error
Step 5: Check that all of the training data has been presented; if so, then go to step 6, otherwise go to step 2
Step 6: Check the total error; if it is within acceptable limits, then stop adjusting the weights and store the results

In this research, the training data set with 200 cases was used to train the NN. The training data set was acquired through interviews with automotive manufacturers.

Validation of NN: Validation consists of analyzing the network performance using examples (*validation set*) not employed in the learning stage. To verify the constructed network, the NN must be validated. In this research, the validation data set with 40 cases was used to analyze the network performance.

The architecture of a NN depends on the problem to be solved. In this research, the input layer consists of four neurons. After the experiments, two hidden layers with eight and four hidden neurons for each layer were obtained as best network architecture for the present problem. The architecture of the NN used in this research is shown in Fig. 2.

The network is trained with training datasets in such a way that for a given input, the output must be obtained to select the appropriate suppliers. Test examples were used to validate the effectiveness of the neural network structure. The results of the experiments indicate that the appropriate parameters are learning rate (η) = 0.4 and momentum (μ) = 0.8.

3.2. Neural network based supplier performance evaluation system

Although many methods have been used for supplier performance evaluation, the NN technique is a new approach for supplier performance evaluation. The NN based supplier performance evaluation system includes the same steps defined in the supplier selection system. The construction of the NN based supplier performance evaluation system includes the following stages:

– ***Selection of input parameters:*** There are many criteria for the supplier performance evaluation system, as described in the literature. The criteria generally depend on the manufacturer. Based on interviews with automotive manufacturers, the following criteria were determined for the supplier performance evaluation system:
– *Quality level:* Suppliers are divided into two categories according to their quality level. The suppliers in the first level are the suppliers with all of the required quality certificates. The

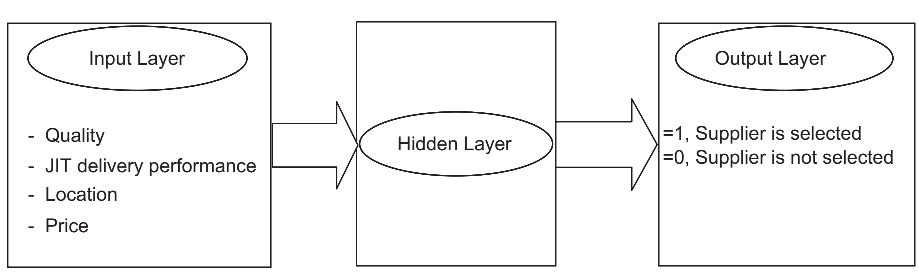

Fig. 1. Neural network general structure for the supplier selection.

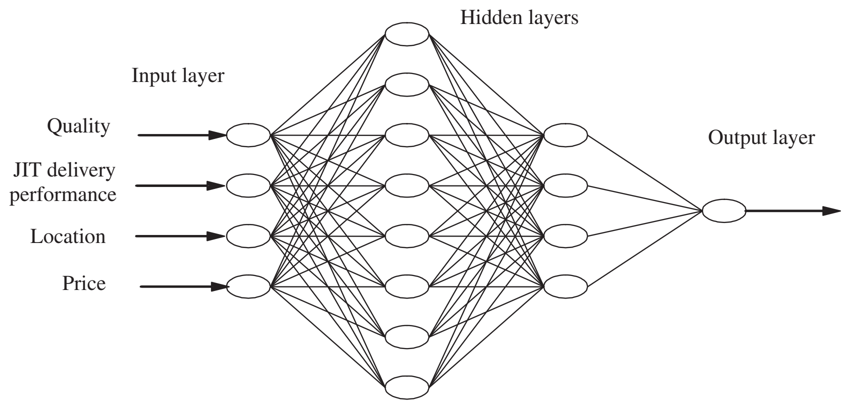

Fig. 2. Architecture of NN for supplier selection system.

suppliers in the second level are the suppliers that do not have all of the required quality certificates, but are in the process of obtaining them.

- *Percentage of rejected parts:* There are different targets of rejected parts regarding suppliers' delivered parts. The percentage of rejected parts is calculated by dividing the target number of rejected parts to the current number of rejected parts.
- *Index of performance*: The index of performance is related to performance penalty points. Each supplier has performance penalty point targets. The index of performance is calculated by dividing the target performance penalty point to current performance penalty point.
- *Result of process audit:* Suppliers are divided into two categories according to results of OEM audits. The suppliers in the first level are successful after the audit. The second level suppliers must correct some parts of their process.
- *Performance of sample:* The performance of sample relates to how much time is spent in properly producing the sample.
- *Authority of non-supervised delivery:* Suppliers are classified into two groups according to their authority of non-supervised delivery. In the first class, suppliers have this authority; parts supplied from these suppliers are sent to the production area directly. In the second class, suppliers do not have this authority or the authority is temporarily revoked (i.e., due to quality problems, etc.).
- ***Selection of output parameters:*** In this research, eight output parameters were determined. The characteristics of the output parameters are shown in Table 2.

Depending on the output, suppliers are classified into three groups:

- Class A Suppliers: They have good results with respect to the supplier performance evaluation, and the manufacturers continue to work with them.
- Class B Suppliers: They have some defects in their system. These suppliers need to improve.
- Class C Suppliers: They have poor results with respect to the supplier performance evaluation, and the manufacturers stop working with them.

The supervised learning technique and back-propagation algorithm were used in the training phase of the NN. The training and validation sets of the NN were developed through interviews with automotive manufacturers. The training data set includes 244 cases and the validation set includes 76 historical cases.

In this supplier performance evaluation system, the input layer consists of six neurons. After the experiments, two hidden layers with ten and fourteen hidden neurons for each layer were obtained as the best network architecture for the present problem. The architecture of the NN used in this study is shown in Fig. 3.

Table 2
Output parameters for supplier performance evaluation system.

No.	Value	Explanation
1	0–1	1, The supplier is in class A 0, otherwise
2	0–1	1, The supplier is in class B and '*Quality level*' of the supplier needs improvement 0, otherwise
3	0–1	1, The supplier is in class B and '*Percentage of rejected parts*' of the supplier needs improvement 0, otherwise
4	0–1	1, The supplier is in class B and '*Index of performance*' of the supplier needs improvement 0, otherwise
5	0–1	1, The supplier is in class B and '*Result of process audit*' of the supplier needs improvement 0, otherwise
6	0–1	1, The supplier is in class B and '*Performance of sample*' of the supplier needs improvement 0, otherwise
7	0–1	1, The supplier is in class B and '*Authority of non-supervised delivery*' of the supplier needs improvement 0, otherwise
8	0–1	1, The supplier is in class C 0, otherwise

The network was trained with training datasets. Test examples were used to validate the effectiveness of the neural network structure. The results of the experiments indicate that the appropriate parameters are learning rate $(\eta) = 0.5$ and momentum $(\mu) = 0.6$.

4. Application examples and results

The proposed neural network based supplier selection and supplier performance evaluation systems were applied to automotive factory data, and the results show that the proposed systems can be used effectively. Some application examples are shown in Tables 3 and 4. Table 3 presents two application examples and results for supplier selection in a JIT production environment. In a long-term relationship, after selecting the suppliers, purchasing departments need to periodically evaluate the performance of suppliers in terms of critical criteria. Table 4 presents four application examples and results for supplier performance evaluation.

5. Discussion and conclusions

Most companies have begun to apply JIT production systems as a tool to become competitive. Companies applying JIT production

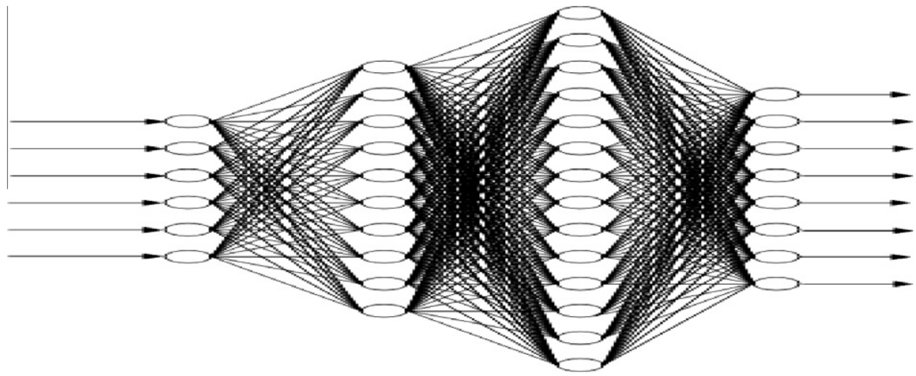

Fig. 3. Architecture of NN for supplier performance evaluation system.

Table 3
Application examples and results for NN based supplier selection system.

	INPUT		OUTPUT	
	Input No.	Value	Value	Result
Example 1	1	0.96	1.0000	Select this supplier
	2	1.00		
	3	0.50		
	4	0.20		
Example 2	1	0.85	$4.61\ 10^{-6}$	Do not select this supplier
	2	0.60		
	3	0.30		
	4	0.10		

systems aim at minimizing all inventory levels and delivering goods and services to customers on time.

Just-in-time manufacturing involves producing the necessary items in the necessary quantities at the necessary time. It is a philosophy of continuous improvement in which non-value-adding activities (or wastes) are identified and removed. Many companies are now applying JIT production system in order to provide their customers with goods and services on time and to minimize all kinds of inventories in order to minimize inventory-related costs.

If a company wants to establish a JIT production system, its supplier must be able to provide raw materials on time because in a JIT setting, there is no allowance for delays resulting from a lack of raw materials. If any delays occur, the company will not be able to offer the product to their customers on time. In other words, the lead time will be longer. Furthermore, waste will increase due to a shutdown of the production line. Therefore, successful JIT production depends largely on working with cooperative and reliable suppliers.

Supplier selection and supplier performance evaluation are necessary tools for successful JIT implementation. Suppliers are selected through the consideration of critical criteria such as product quality, on time delivery and location. However, selected suppliers have the ability to respond to the manufacturers' requirements. Their performance can vary in a long-term partnership. For this reason, in order to improve the suppliers' performance and product quality, buyer firms must periodically evaluate their suppliers' performance.

In this research, as introduced in the above sections, a novel approach based on a neural network is used for supplier selection and performance evaluation in JIT production environments. In the neural network based supplier selection system, suppliers are represented as an input vector in terms of quality, JIT delivery performance, location and price, and they are presented to the NN to successfully select the appropriate suppliers. If required, more criteria in the proposed approach can be considered by the user.

Table 4
Application examples and results for NN based supplier performance evaluation system.

	INPUT		OUTPUT		Results
	Input No.	Value	Output No.	Value	
Example 1	1	1.00	1	0.9351	Class A supplier (Continue to work with this supplier)
	2	0.20	2	0.0004	
	3	0.40	3	0.0077	
	4	1.00	4	0.0061	
	5	1.00	5	0.0003	
	6	1.00	6	0.0010	
			7	0.0057	
			8	0.0008	
Example 2	1	2.00	1	0.0001	Class B supplier (Specifications of input Nos. 1–3–4–6 need to develop)
	2	0.90	2	0.9920	
	3	1.30	3	0.0197	
	4	2.00	4	0.9974	
	5	1.10	5	0.9965	
	6	2.00	6	0.0028	
			7	0.9988	
			8	0.0000	
Example 3	1	1.00	1	0.0004	Class B supplier (Specifications of input Nos. 2–3–5 need to develop)
	2	1.08	2	0.0092	
	3	1.30	3	0.9937	
	4	1.00	4	0.9984	
	5	2.00	5	0.0140	
	6	1.00	6	0.9999	
			7	0.0025	
			8	0.0013	
Example 4	1	1.00	1	0.0002	Class C supplier (Stop to work with this supplier)
	2	1.70	2	0.0000	
	3	0.90	3	0.0102	
	4	2.00	4	0.0003	
	5	1.40	5	0.0058	
	6	2.00	6	0.0001	
			7	0.0011	
			8	0.9991	

In the supplier performance evaluation system, suppliers are evaluated according to their quality performance, which includes six sub criteria. The neural network based supplier evaluation system classifies suppliers into three groups:

- Class A suppliers: Continue to work with this group of suppliers.
- Class B suppliers: Suppliers have some defects. These suppliers need to improve.
- Class C suppliers: Stop working with this group of suppliers.

For Class B suppliers, the decision-maker can see the points that need to be developed in the output value of the NN system.

In this research, it is shown that the proposed neural network based approach can cope with the limitations of traditional techniques and support efficient SCM applications in the manufacturing industry for JIT production environments. The results for automotive factory data show that NN based supplier selection and supplier performance evaluation systems can help manufacturers select the most appropriate suppliers and evaluate supplier performance effectively and simply. Further research can be carried out by adding new criteria, if required, according to different application areas.

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