A neural networks model for green supplier selection

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Abstract: There have been studies on supplier selection in the past. But organisations today are also interested in evaluating their suppliers on green and sustainability criteria. With increasing awareness of green and sustainable processes and products, there is pressure on the organisations to select only green suppliers for their operations. While this is a step towards more responsible organisations, managing the suppliers of an organisation becomes an important task. This clearly warrants a structured approach for evaluation of suppliers on green and sustainability criteria. This paper models the relationship between these criteria and the supplier selection. A neural networks model is used for analysis of the data obtained from samples in the Indian automotive industry. MATLAB is used for analysis of the neural networks model. This model captures any nonlinear relationship between the inputs and performs better compared to many other techniques. The output of the neural networks model is used for rating a supplier and hence to arrive at a decision. This model is helpful for managers as it acts as an objective assessment criterion for suppliers.

Keywords: green supplier selection; sustainability; green supply chain management; feedforward neural networks; MATLAB.

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1 Introduction

Supplier selection forms an important activity of supply chain management. Several criteria have been put forth for supplier selection by authors (Chopra and Meindl, 2007; Gunasekaran et al., 2004). According to Deng et al. (2014), supplier selection is an activity which involves fuzziness and uncertainties due to the subjective nature of the activity. Govindan et al. (2015) identify the multi-criteria nature of the green supplier selection problem and propose an appropriate model for problem. Lee et al. (2009) study the high-tech industry and propose a green supplier selection model using a fuzzy AHP technique considering the uncertainties involved in the selection process. Bakeshlou et al. (2017) use a fuzzy multi-objective decision making algorithm for solving a linear programming problem involving five criteria. According to the authors, the problem of green supplier selection involves decision-making with five criteria. According to Qin et al. (2017), decision-makers do not exhibit complete rationality during decision-making for green supplier selection. Hence, the decision-making involves some fuzziness.

Increasing awareness among public and the organisations, towards environmental causes has led to greening the supply chains. The stock exchanges of different countries have launched their sustainability indices to evaluate organisations for their sustainability. For instance, Dow Jones Sustainability Indices (DJSI) launched in the USA by the Dow Jones Stock Exchange evaluates top 2,500 organisations for their sustainability (ROBECOSAM, 2016). Similarly, STOXX Europe sustainability index represents stocks from 18 European countries. BSE in India has its own Sustainability indices.

Sustainability, in general, refers to the use of resources in such a manner that the needs of the present generation are fulfilled without affecting the needs of the future generations. Organisations are trying to create green and sustainable supply chains in order to achieve sustainability. For green supply chains, selection of a green supplier becomes an important function which could play a vital role in fulfilling the environmental expectations of the customers (Walton et al., 1998). Thus, selecting a green supplier becomes one of the very important steps towards greening the supply chain apart from greening one's own operations, green marketing and green collaboration with other stakeholders from an organisation's point of view. A reverse channel for logistics and green packaging also contribute to the cause of green supply chain management.

Selecting a supplier after evaluating him on sustainability performance provides several benefits, one benefit has the purpose of meeting the environmental standards, a second benefit relates to the efficient usage of the available resources, a third benefit is the goodwill, reputation and brand-equity earned through sustainable performance. There is also the satisfaction of the employees resulting from the sustainability measures. Customers are also increasingly interested in green products now (Juwaheer et al., 2012).

This paper provides a neural networks model for the selection of suppliers on green criteria for players in the Indian automotive industry. The analysis has been performed using MATLAB.

2 Literature review

In this section, literature relevant to green supplier selection is discussed.

According to Benn Lawson et al. (2006), technological integration also has triggered in collaboration on monitoring on environmental standards. Vachon (2007) finds environmental collaboration with suppliers, result in investments in clean technologies. Vachon and Klassen (2008) discuss that environmental collaboration with suppliers were linked to process-based performance. Eltayeb and Zailani (2009) study ISO 14001 certified Malaysian firms and find green purchasing as the second most frequently adopted function towards attaining GSCM objectives. Gunasekaran et al. (2010) in their paper make recommendations for green supplier management using the analytical network process. Gold et al. (2010) explain the importance of collaboration for competitive advantage and sustainability. Diabat and Govindan (2011) in their paper discuss green purchasing as one of the critical means to achieve green supply chain management. Large and Thomsen (2011) conduct a study in Germany and claim that degree of supplier assessment and collaboration with suppliers are drivers of green supplier management performance. Fu et al. (2012), in their paper, provide a structured approach for evaluation of green supplier development programs. Mahdiloo et al. (2012) use data envelopment analysis (DEA) – a multi-criteria decision making tool, for supplier evaluation considering the multiplicity of criteria involved in decision making. Govindan et al. (2013) present a fuzzy multi-criteria approach for measuring sustainability performance. Akman and Pışkın (2013) evaluate green performance of suppliers using ANP and TOPSIS. Dou et al. (2014) in their paper evaluate green supplier development programs using a grey-ANP approach. Ramanathan and Gunasekaran (2014) discuss the role of collaboration with suppliers in green supply chains in the UK. Kazemi et al. (2015) use a mathematical programming model for multi-objective supplier selection and order allocation problem using fuzzy techniques and claim that the technique used by them in their paper is superior to another technique which used a compromise solution of weighted max-min method in an earlier paper for the same problem. Mavi (2015) uses a fuzzy AHP technique and fuzzy additive ratio assessment technique for evaluation of suppliers for green supply chain management and rank them on the basis of a few criteria. HakimiAsl et al. (2016) study the problem of supplier evaluation of a solar power plant using green criteria employing a fuzzy AHP-VIKOR method. Sen et al. (2017) use a fuzzy-MULTIMOORA technique for evaluation of suppliers for green criteria. Use of this technique helps them overcome the inherent uncertainties in this problem of evaluating the suppliers for green criteria.

This paper uses a neural networks model for grading the green suppliers in the case of Indian automotive industry. Such a study is among the first few studies of its kind.

3 Research objectives and methodology

3.1 Objectives

The objective of this study is to predict the green supplier selection rating on the basis of certain predictor variables. These variables are mentioned below in this section and also how these variables were arrived at is discussed. Nonlinear regression is used for

predicting the green supplier selection output variable and neural networks modelling is used for predicting this output variable.

3.2 Methodology

The data used for the analysis were collected from 501 executives from ten automotive players in various geographical locations in the Indian automotive industry. Each automotive player had maximum six suppliers and minimum one supplier and rated their principal supplier on the following ten criteria mentioned. Totally, ten suppliers were rated by the 501 executives on the basis of the ten criteria. The items used for the study were obtained from a study made by Min and Galle (1997) and were slightly modified to suit the needs of this study. Experts' opinions on the questionnaire formed were sought. The face validity of the questionnaire was verified by consulting ten experts. All the experts' comments relating to the content of the questionnaire were found satisfactory. The items which affect green supplier selection are:

1 potential liability for disposal of hazardous materials

2 cost of disposal of hazardous materials

3 state environmental regulations

4 national environmental regulations

5 cost of environmentally-friendly goods

6 cost of environmentally-friendly packages

7 buying firm's environmental mission

8 supplier's advances in providing environmental-friendly packages

9 supplier's advances in developing environmental-friendly goods

10 environmental partnership with suppliers.

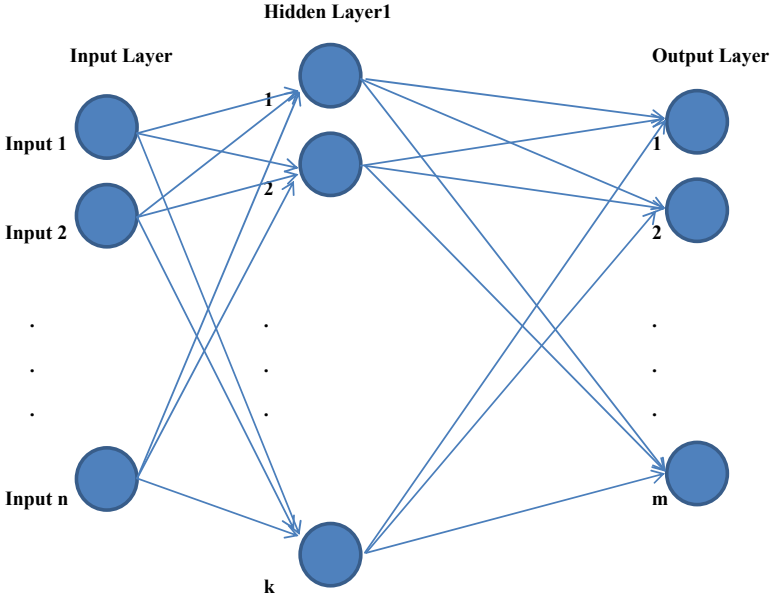
Likert scales were used as in the paper. It was made sure that the sample data were representative by collecting data proportionate in size to the composition of population. Non-probability Convenience sampling was used for the study. Items for the study consisted of ten input variables and one output (target) variable. MATLAB 7.9 was used for the analysis purpose.

3.3 Neural networks (theoretical background)

Feedforward neural networks were used for modelling the relationship between the input variables and the single output variable in our case. The input variables were the ten criteria and the output variable was the rating for green supplier selection. The neural networks could be used for capturing the possible nonlinear relationships between the dependent and independent variables. In a feedforward neural network, all the neural activations take place in the forward direction and there is no feedback. The neural networks considered in this work are essentially static networks, i.e., once they are trained, they do not learn after the training process is done. One of the most common algorithms used for training the feedforward net is the backpropagation algorithm (Leung

and Haykin, 1991). In this study, 70% of the data has been used for training the network for the model, 15% of the data is used for validation of the model and the remaining 15% of the data is used for testing the final model. The neural network creates a model for green supplier selection on the basis of the data available and predicts the rating for the same for any supplier based on the model.

Figure 1 Feedforward neural network with 1 hidden layer (biases are not indicated in the diagram) (see online version for colours)



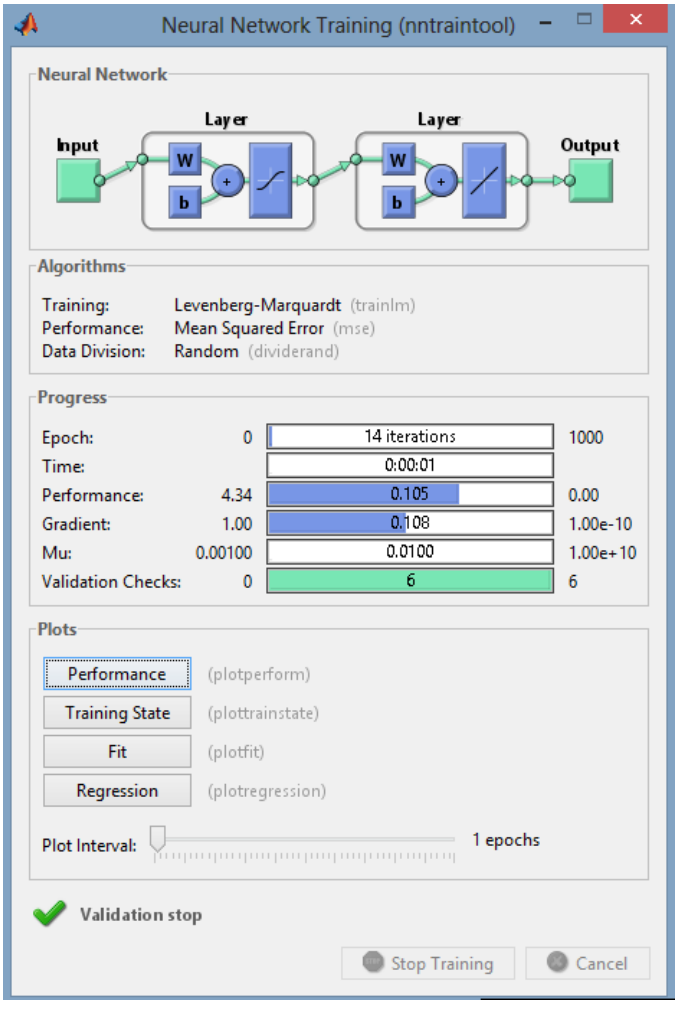
Learning in feedforward networks is supervised learning, where learning takes place over several cycles repeatedly until the relationship between the input and output variables is captured with sufficient accuracy based on some predefined criteria. For backpropagation learning, the output of each training value (o) is compared with the expected output (e). The parameters of the network are adjusted in such a manner that the sum of the squares of the difference between 'o' and 'e' over all observations is minimised. This sum of the squares of the difference between 'o' and 'e' is the error function in the backpropagation algorithms.

4 Analysis, inference and discussion

MATLAB 7.9 was used for analysing the data with the custom neural network model with ten inputs which are based on the ten criteria and one output which is the green supplier selection rating. A hidden neurons layer is available in the neural network. The purpose of these hidden neurons is to convert the outputs in the form required by the output layer. The number of hidden neurons was assessed using the trial and error method. Initially, analysis was performed with 15 hidden neurons. A few trials were made before settling with 20 hidden neurons for improvement of the performance of the

model. Further, no increase in the number of hidden neurons was done to ensure there was no over-fitting of the data. A MATLAB file was created for coding for the analysis. The results of the analysis are presented in Figure 2.

Figure 2 Training window (see online version for colours)

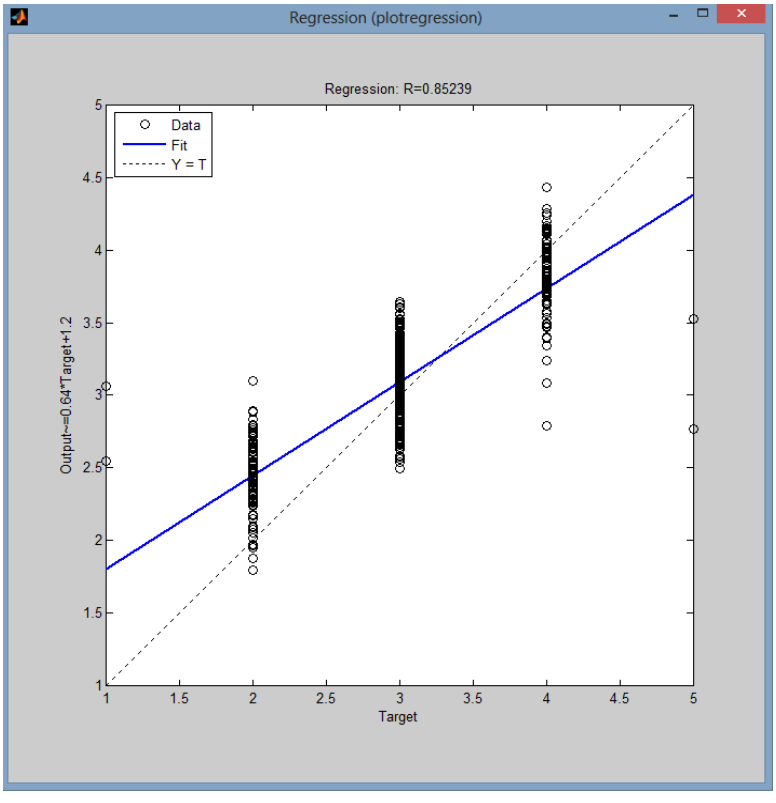


The training window in Figure 2 shows that Levenberg-Marquardt backpropagation algorithm was used for the training data. Epoch indicates a single iteration. Hence, epoch in this figure indicates the number of iterations. 'Performance' in the figure indicates the value of the performance function. Mean square error (MSE) is the performance function:

$$\text{MSE} = \left(\frac{1}{N}\right)\sum_{i=1}^{n} e_i^2 = \left(\frac{1}{N}\right)\sum_{i=1}^{n} (t_i - a_i)^2$$

MSE is the mean of the sum of squares between the actual and the expected values of the output variable. The gradient becomes very small when the performance function reaches the minimum. When the gradient goes below a criterion, the training stops. 'mu' is a parameter which decides the extent of the change in weight age in each iteration. 'Validation checks' represents the number of successive iterations over which the performance function does not decrease. The data available is split into training data (70%) (i.e., data used to learn the model), test data (15%) and validation data (15%).

Figure 3 Regression plot between outputs and targets (see online version for colours)



In Figure 3, the regression plot between outputs and targets are shown. The 'R' value of 0.85239 indicates a reasonably good fit. The R value indicates the fit between the outputs (actual values) and the targets (expected values). A high value of 'R' indicates that the variations in the model have been well captured by the neural network.

Figure 4 Performance plot (see online version for colours)

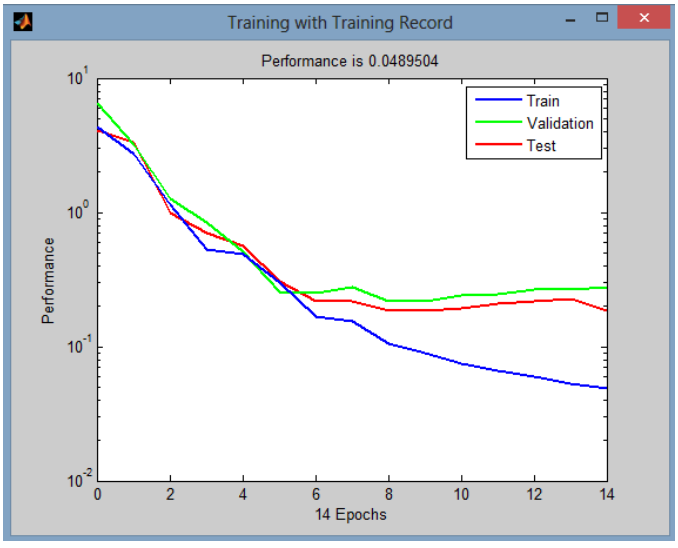
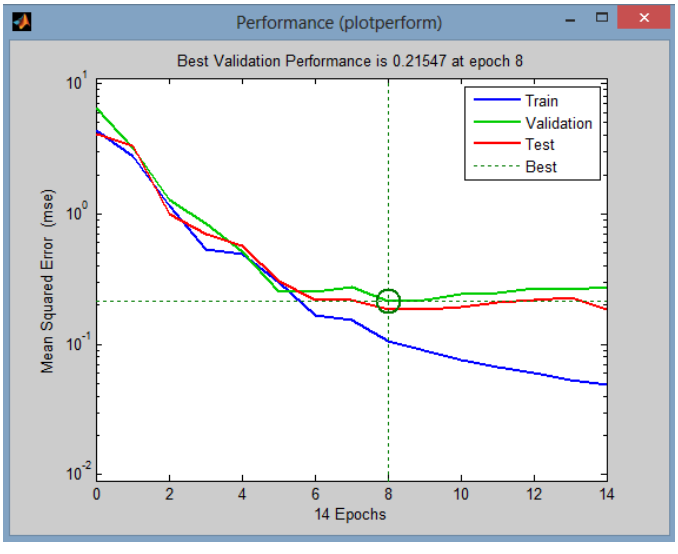


Figure 5 Performance plot to show best validation performance (see online version for colours)



The performance plot shown in Figures 4 and 5 indicate that test curve and validation curve are pretty much similar. Also, test curve does not increase significantly before validation curve increases, which indicates the absence of any over-fitting. Over-fitting is a phenomenon that indicates the error in the sample data rather than indicating the regression model. Minimum (best) validation performance occurs at epoch 8 as indicated in Figure 5. A test set of inputs were fed to the neural network using a dataset to check the output. The value of the target variable for this input was found to be 3.4783. Thus, the rating recommended by the model for the supplier (inputs given) is 3.4783, which is reasonably good. This rating is based on the neural networks model

created by analysing the data. It can be compared against a cut-off value of rating and decisions can be taken accordingly. Also, green supplier selection ratings for 10 suppliers were compared which were: Supplier1: 3.6293, Supplier2: 3.6039, Supplier3: 4.0994, Supplier4: 3.6447, Supplier5: 3.7808, Supplier6: 3.9330, Supplier7: 3.7755, Supplier8: 3.4345, Supplier9: 3.7417 and Supplier10: 3.8598. Thus, based on these ratings, Supplier3 seems to be the best supplier on green criteria. This gives a useful metric for all stakeholders to understand and promote 'green' philosophy in their supply chains.

In the supervised learning, the predicted output variable is compared with the expected output variable. This function is performed repeatedly and the performance function in a backpropagation algorithm which is the sum of the squares of the difference between the observed and expected output variable over all observations, is calculated repeatedly with different parameters for the network until the performance function reaches a minimum and does not change beyond a certain value significantly. Nonlinear regression can be performed with the neural networks modelling.

Thus, the nonlinear regression model is fitted for the data and the model obtained is used for predicting the rating for green supplier selection. The backpropagation algorithm is used to minimise the performance function and the iterations stop if the validation performance function fails to change significantly for six iterations (default value). The rating value predicted for the supplier given by the 'op' variable indicates whether the supplier can be selected for purchasing based on green criteria. There is pressure on the organisations to employ green practices in their operations and thus employing green suppliers and evaluating partners and customers for green operations and sustainability becomes a natural extension of these activities. Hence, organisations which employ green practices tend to have a better brand-image among its employees and the public alike.

5 Conclusions and directions for future studies

A neural networks model for rating and selecting the green supplier has been created. This model takes ten inputs, has one output and 20 hidden neurons in a single hidden layer. Part of the data was used for training. The remaining data were used for testing and validation. The model also captures any nonlinear effects present in the data. The use of neural networks for capturing the nonlinear effects results in a more accurate model of the relationships.

This paper is among the few studies done for green supplier selection in the automotive industry, especially with an emerging economy backdrop. This paper gives a neural networks model for predicting the supplier selection based on a few selection criteria. This paper uses nonlinear regression for predicting this relationship, and is clearly one of the first of its kind.

This study establishes the use of neural networks for green supplier selection. It also establishes the criteria used for green supplier selection based on the study done in this paper. These criteria can be used for green supplier selection in other studies and the relationships validated and verified for their research backdrops. This study is clearly a direction towards an objective management of the suppliers of an organisation on the basis of green criteria.

The model gives a direction to the managers for selecting a supplier based on his performance on certain green criteria. It is therefore a very useful tool for managerial decision-making while selecting a green supplier. With increasing pressure on

organisations to go in for green processes and to produce green products, it has also become necessary to select green suppliers. Managers need an objective assessment tool for assessing their suppliers. While the assessment of suppliers itself has some uncertainties involved as discussed by several authors, the assessment of suppliers for green criteria could involve this process with still more uncertainties (Sen et al., 2017), as assessment of suppliers for green criteria has been something that is followed relatively more recently. Thus, a direction for managers for green supplier selection is clearly a need and this paper serves that purpose.

Future studies could focus on creating models for evaluation of programs of collaboration with partners and customers. Such collaboration on green initiatives has been found to produce mutual benefits for both the parties. Studies could also be taken up on the evaluation of logistics providers and outsourcing partners for green and sustainability criteria. The study could also be repeated in industries other than the automotive industry and other countries including developed nations and the criteria for green supplier selection assessed. Objective assessment criteria for green supplier selection can go a long way towards enhancing green supply chain management, which is why studies in green supply chain management have emerged with increasing attention among researchers.

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