

# Artificial Neural Networks for Internal Combustion Engine Performance and Emission Analysis

Anant Bhaskar Garg  
Centre for Information Technology  
University of Petroleum &  
Energy Studies, Dehradun

Parag Diwan  
Vice Chancellor  
University of Petroleum &  
Energy Studies, Dehradun

Mukesh Saxena  
Head, Dept. of Mechanical  
University of Petroleum &  
Energy Studies, Dehradun

## ABSTRACT

This paper presents an analytical work for better design system that contributes to the reduction of fuel consumption and emission for vehicle performance. The main technological issue on engines today is to comply with emission standards with cost-effective measures in order to keep the engine price still attractive to customer. The experimental research of engine performance are time consuming and quite expensive. The purpose of this work is to optimize engine performance using artificial neural networks (ANN). Back propagation neural network was used to optimize prediction model performance. The paper analyzed data from various experimental tests in which different engine operating parameters are measured. The paper highlights the framework and suitable model of ANN to optimize several operating parameters of the engine. The optimization includes a range of standards engine-operating conditions, with specified limits in emissions.

## General Terms

Artificial Neural Networks, Engine Operation, ANN approaches to management of Engine operations, ANN algorithms, architecture

## Keywords

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## 1. INTRODUCTION

The liquid petroleum fuels are a limited and the demand is enormously increasing. The cost of fuel is ever increasing. In order to comply with increasingly stringent emissions standards and meet drivability requirements, modern automobile engines are equipped with an increasing number of subsystems and controlling elements. The result has been increase in the calibration effort required to find the parameter settings that offer the best global competitiveness. Reducing pollutant emissions is a vital and a continuous challenge for the automotive industry. New technologies are being investigated, often with the aim of simultaneously improving performance, fuel economy, and emission characteristics. Thus for obtaining engine fuel consumption and emission in terms of calibration parameters, an engine model is required. Because of highly complex and nonlinear nature of internal combustion engines models used to study are in the form of black-box models [1], [2], [3], [4], and [5].

A very powerful method among black-box modeling techniques is the artificial neural network modeling which has been widely used in various branches of engineering in recent years [5]. This technique aims to significantly decrease dynamometer test requirements by generating mathematical

models of the engine outputs using a smaller subset of dynamometer tests. Once the mathematical models have been developed, the calibration maps can be optimized using techniques such as gradient procedures [2]. Various approaches have been proposed for using ANN to promote modelling and calibration of engines [4]. The ability of Artificial Neural Network as a system identification tool is used to model non-linear behavior of engine operations. Many researchers used ANN for predicting torque, power, specific fuel consumption, and soot formation with speed and injection pressure [6], [7], [8], [9], [10], and [5] found the ANN provides accuracy and simplicity in the analysis of the engine performance. Wu and Gisca described ANN to model for determining the functioning parameters of the internal combustion engine, such as pressure in cylinders or the air-fuel ratio [11], [12].

But in neural network design selection of network topology, the trigger function, learning rule and the criteria or permissible error for stopping the training phase is crucial and done by the designer/engineer. So, it is difficult to predefine the size of the network as there is no fixed method to do it. Despite this issue, neural networks based solution is very efficient in terms of development, time and resources. By experience and working on different architecture, size, and models we can provide real solutions. Thus, we conducted detailed study using different algorithms and chose the one that provides the best results for given set of data of engine parameters. ANN modeling explores the performance and emission of vehicle engine. Based on collected experimental data, ANN correlates engine-operating parameters with the performance parameters and emission characteristics.

Garg discussed extensive literature Review and various applications of ANN [13]. Thus, real-time operation and mapping of complex, non-linear and dynamic patterns in engine operations are challenges to be met in today's engine development. Neural networks architectures, combinations of networks, and different algorithms play an important role on the performance. There is a need to use ANN as a performance critical tool that saves cost and time in developing new models and methodologies for overall engine management. Further it will help in accessing which algorithm is best suitable for a particular situation.

## 2. RESEARCH METHODOLOGY

The ability of ANN to understand and properly classify a problem of highly non-linear relationship has been established and the significant consideration is that once trained effectively ANN can classify new data much faster than it would be possible with analytical model. A neural network is

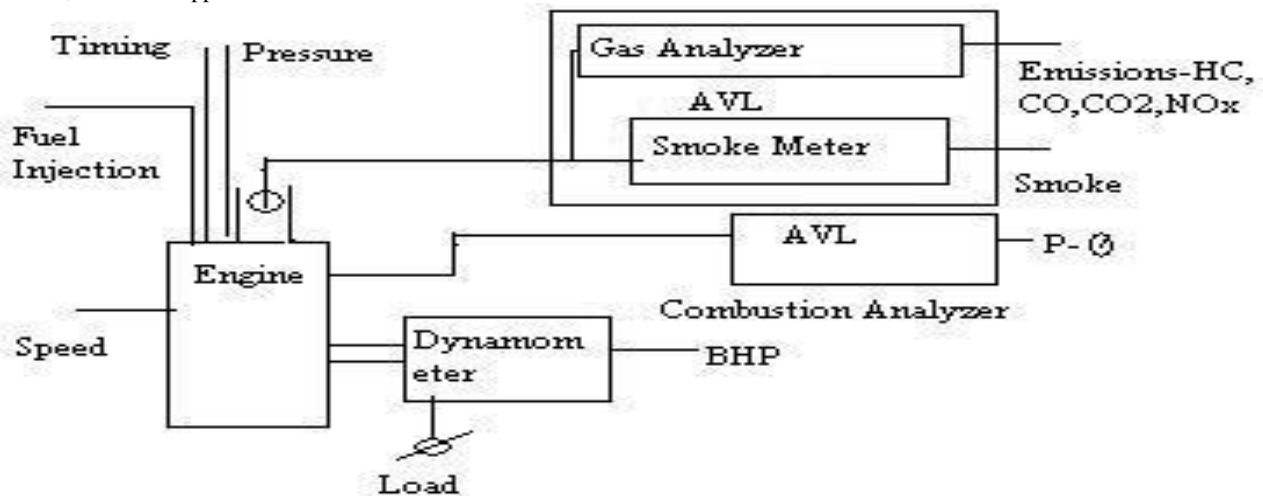
a massively parallel-distributed processor that has a natural propensity for storing experimental knowledge and making it available for use. It resembles the brain in two respects [14]:

1. Knowledge is acquired by the network through a learning process.
2. Inter-neuron connection strengths known as synaptic weights are used to store the knowledge.

Our inputs parameters are Fuel Injection Angle (degree BTDC), Fuel Injection Pressure (kgf/cm<sup>2</sup>), Load (kW),  $T_{\text{FUEL}}$  (Sec)(For 50 CC), Speed (RPM) and outputs are various emissions parameters CO (%Vol), CO<sub>2</sub> (%Vol), NO<sub>x</sub> (ppm), HC, SMOKE (%opacity), and efficiency parameters BTE (%), BSFC (kg/kWh).

Experimental data collected to analyze the performance of engine, and ANN architecture are set of above data for training and testing purposes. We performed design and development of alternative neural network architecture, algorithms, and other approaches for the above data and thus

finding efficient pattern for engine optimization. More detailed description on ANN can be found in [15] and related to engine in [13]. There are numerous algorithms available for training neural network models and most of them can be viewed as a straightforward application of optimization theory and statistical estimation. These algorithms generally use gradient descent form. This is done by simply taking the derivative of the cost function with respect to the network parameters and then changing those parameters in a gradient-related direction. Some of the algorithms are Gradient Descent Algorithm, and Levenberg-Marquardt Algorithm. Some types of networks architecture are feed-forward network, Radial Basis Function network that are dealt in this present study.



**Figure1. Experimental Setup of Engine**

### 3. EXPERIMENTAL SETUP

The engine selected for this research is Field Marshal IDI Diesel Engine. This is a single cylinder, water cooled, vertical engine having forced lubrication system. The engine designed for compression ratio 17:1, it is 1580 cc engine with bore x stroke 120 mm x 139.7 mm. The engine is self-governed and designed to operate at 1000 rpm. The advance angle of fuel injection for diesel fuel is 20° and the fuel injection pressure is 175 kgF/cm<sup>2</sup>. The engine is coupled with single phase AC alternator having rated capacity 7.5 kw at 1500 rpm. The efficiency of the alternator as quoted by the manufacturer is 80%. The alternator was coupled with engine with v-belt power transmission system. The main components of experimental set up are alternator, hydraulic loading unit, fuel consumption measuring unit, voltmeter, ammeter, temperature measuring thermocouples, AVL- 437 smoke meters and AVL gas analyzer used for emission measurement as shown in figure 1. The engine rpm was mounted on vibration isolators to minimize the vibrations. Training and test sample are required for building an ANN prediction models. The training sample is used for ANN model development and the test sample adopted for evaluating the prediction ability of the model. In this study three separate neural networks were developed for each performance, as ANN1, ANN2, and ANN3.

### 4. RESULTS AND DISCUSSION

Diesel engine emissions CO, CO<sub>2</sub>, NO<sub>x</sub>, HC, smoke opacity, and brake specific fuel efficiency, BTE were evaluated using predicted models and compared with experimental results. The graphs below show that the predicted values are close to experimental results which demonstrate applicability of artificial neural network in predicting diesel engine performance from figure 2 to figure 8.

As shown in graphs except CO all values for experimental and predicted values matches and in CO reason is that values are within matching criteria but range is very small -.20 to .60 (%vol). Modeling techniques such as artificial neural networks and taking their different architecture, activation functions, combination of these can affect the models of ANN. In this paper, ANN are used to create model with back-propagation methods for feed forward architecture based on different learning algorithm. The main objective of learning algorithm is to provide a methodology to teach the network for a given task and predict the output. Performance of the network is judged by calculating the mean squared error for training and test data. Besides this, calculation of coefficient of determination  $R^2$  that is absolute fraction of variation found for our model value equal to 0.81 which is more close to 1.

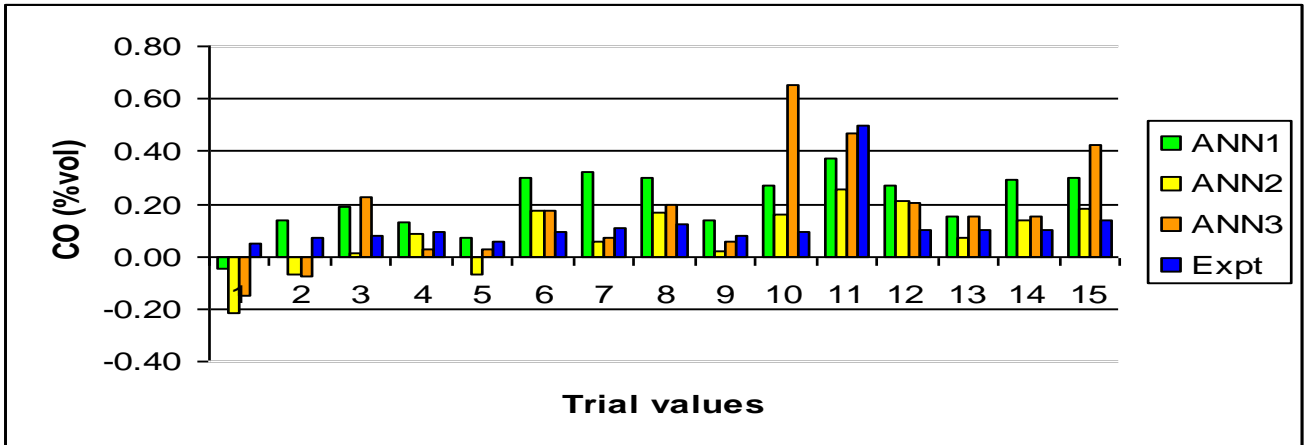


Figure2. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine CO

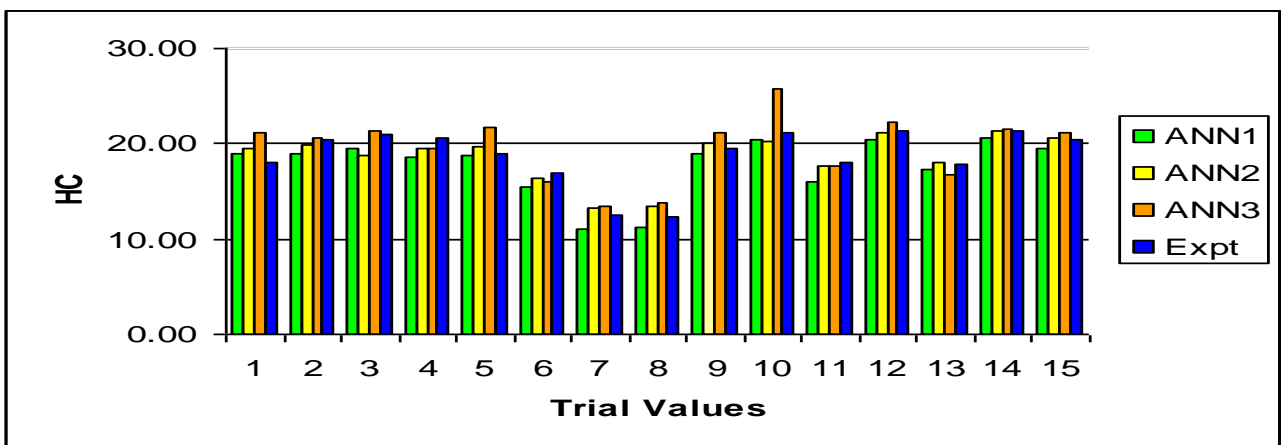


Figure3. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine HC

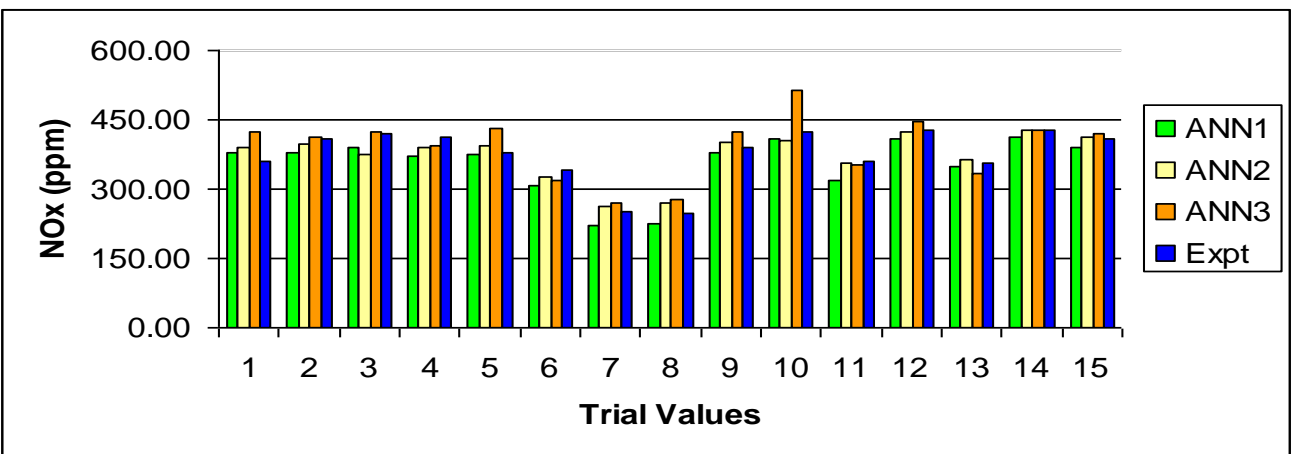


Figure4. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine NOx

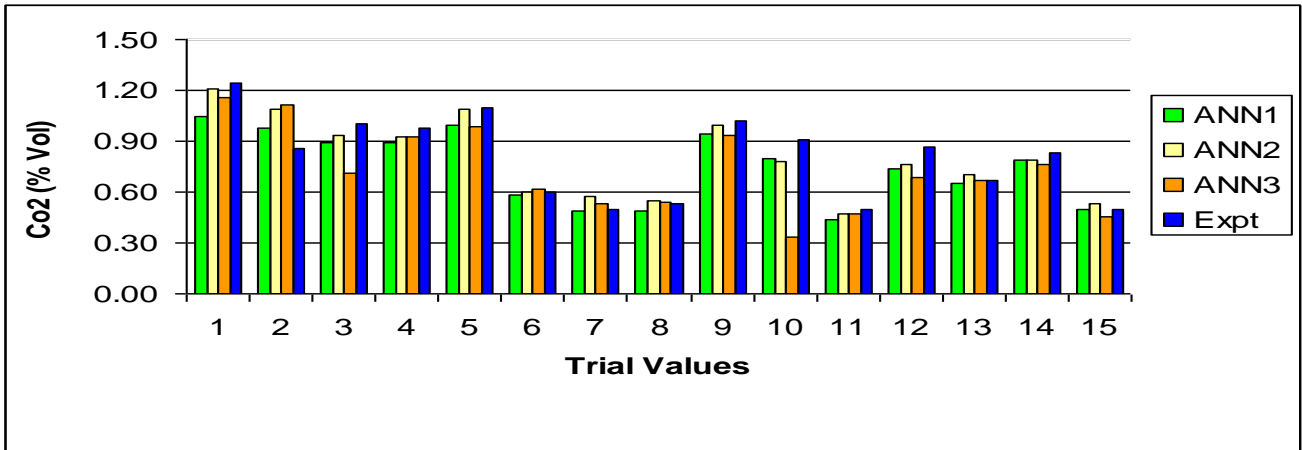


Figure5. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine CO<sub>2</sub>

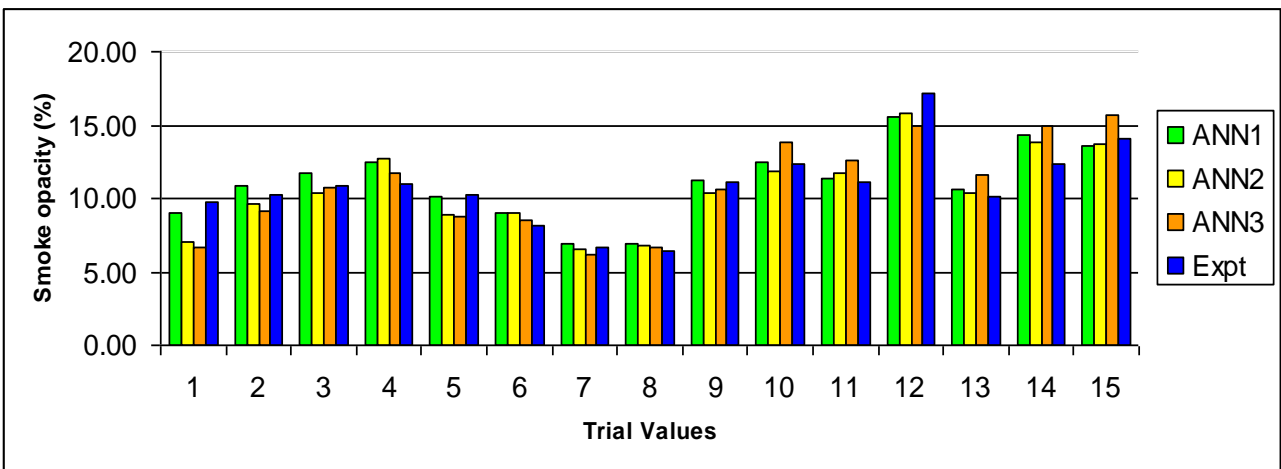


Figure6. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine Smoke opacity

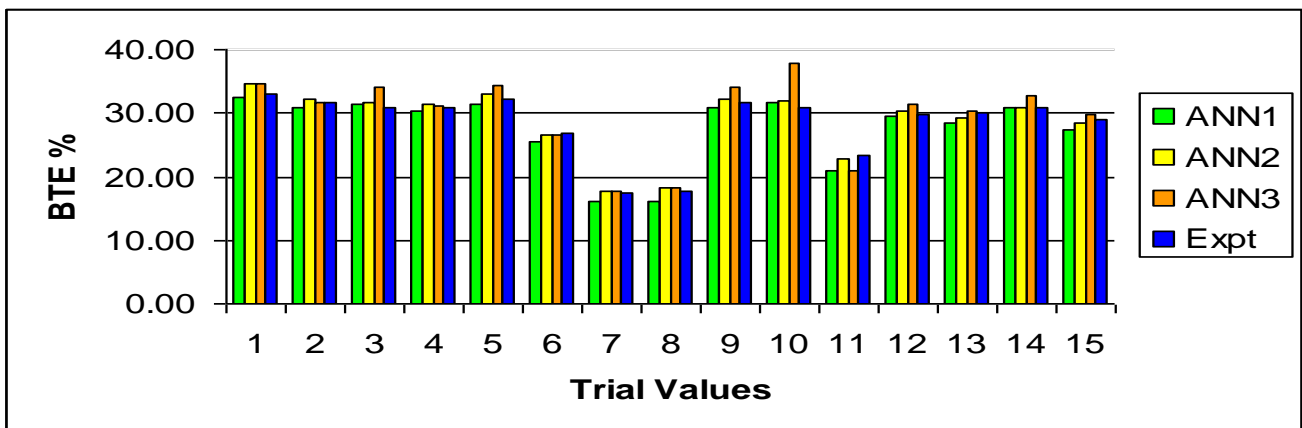


Figure7. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine BTE

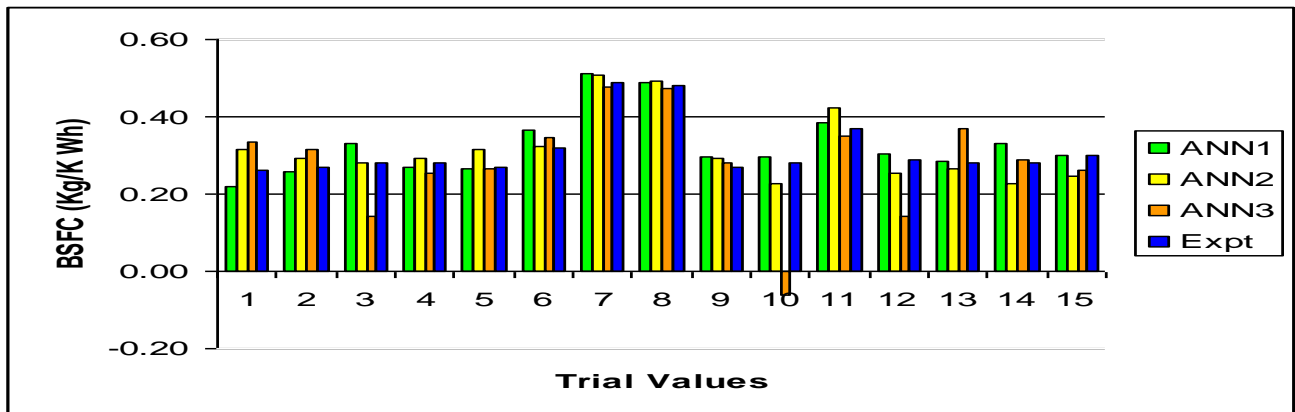


Figure8. Comparisons of ANN1, ANN2, ANN3 predicted results and experimental results for engine BSFC

## 5. CONCLUSION

The paper suggest that there is a need to use ANN as a performance critical tool that saves cost and time in developing new models and methodologies for overall engine management. Prediction models of diesel engine performance parameters have been developed using Artificial Neural Networks. Three sets of prediction model for each performance parameters have been developed by using neural networks. Further it will help in accessing which algorithm is best suitable for a particular situation and in decreasing dynamometer test requirements by generating models of the engine outputs using a smaller subset of dynamometer tests.

## 6. ACKNOWLEDGMENTS

Our thanks to colleagues in the mechanical dept. who have given us experimental data especially Narayan, Ranjit, R.K. Tripathi and P.K. Sahoo. We are thankful to Dr. S. J. Chopra, UPES Chancellor for providing research facility. Part of the work is presented in the national seminar.

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