

A data-based investigation of vehicle maintenance cost components using ANN

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Abstract. Vehicle maintenance is a critical and vital operational component that determines vehicle performance and service longevity. The severity of vehicle usage has been defined as one of the key factors that determine vehicle maintenance requirements. Nigeria is a tropical country with intense heat, poor road network and quality. These factors severely affect car performance and raises maintenance demands toward ensuring vehicle reliability and optimum performance. In this study, vehicle maintenance cost and fuel consumption data in terms of cost and volume, together with the mileage coverage as the vehicle usage data, for two corporate organizations were analyzed. The data was collected and systematically analyzed. The common faults were categorized and their frequency of occurrence was determined. An artificial Neural Network (ANN) model was developed for predicting future maintenance cost, given a set of anticipated vehicle usage inputs. The model has an overall correlation R-value of 0.76645.

Keywords: ANN model, vehicle maintenance, predictive cost analysis, data pattern recognition, road transportation, statistics

1. Introduction

Supply chain reliability is the back bone of many commercial operations, and it also ensures adequate distribution and availability of various products, supplies and equipment for both domestic and industrial uses. Product and material distribution can be via air, water, rail and road transportation. Transportation is vital for socio-economic interactions. Freight transportation must be cost effective, efficient, safe, fast and reliable to ensure itchy-free national distribution of goods and economic development. According to [1], road transportation is the most active mode for haulage transportation. It was estimated that 75% of the total 2200 billion tonne-kilometres of freight transportation in Europe was via road. In the Nigerian transport industry, the road transport sub-sector contributes about 90% to the Gross Domestic Product. As at the end of 2017, the estimated number of vehicles in Nigeria was 11,583,331 [2, 3].

The transportation industry in Nigeria is plagued by many challenges due to poor planning, poor road network and condition, scarce funds, corruption and defective policies, insufficient vehicle fleets, and so forth. Vehicles daily ply poorly constructed, and poorly maintained roads with pot holes and many unpaved road sections which create inherent hazards [4]. This negatively impacts vehicle reliability, resulting in repetitive vehicle breakdowns with an attendant increase in maintenance cost. To ensure vehicle availability for service, corporations need to dedicate a sizable amount of their budget towards vehicle maintenance and overhaul. Most of the vehicles in Nigeria were imported. It is only in recent times, due to new Government policies that both indigenous and foreign car assembling plants are springing up again in the country,

after decades of zero production due to various economic challenges.

Foreign Exchange (FOREX) issue is a recurrent problem in Nigeria due to FOREX scarcity and price fluctuations. Currently, one US dollar is around 365 Naira. This makes vehicle importation very expensive, and as a result of the high cost, most of the cars and trucks imported into the country are fairly-used, and they are rarely brand new. This implies that a good percentage of the service life of the vehicle is used up before arrival in Nigeria, and upon arrival into the country, deterioration sets in due to many factors and realities of the Nigerian society. The only way to ensure vehicle reliability and prolong



vehicle service life is through adequate and timely vehicle maintenance [5], but this is often challenged by the need to manage scarce resources.

A visit to the car park and maintenance warehouse of some organizations will reveal run-down and abandoned vehicles, with the tyres of some of the vehicles already removed, and the chassis supported by stone slabs. A number of times, this occurs as a result of scarce spare part, low maintenance budget and excessive car breakdowns leading to abandonment. Vehicles abandoned in this way end up deteriorating further with time, and this increases the cost of restoration, and reduces the sale value, if the vehicle is sold off in that state. If such cars are parked in open and unfenced locations in front of factories without adequate security, the car parts end up being stolen by scavengers. Cases of stolen head lights, tyres, batteries and so forth, have been reported.

In maintenance engineering and management, a number of maintenance components and parameters can be extracted for objective analysis [6]. This study presents and examines the maintenance data of two corporate organizations for fault frequency trending and for data parameter relationship identification. An ANN model was developed using the fuel consumption, cost of fuel, mileage covered and the maintenance cost data for the sampled period as model parameters.

2. Case study: haulage company truck and corporate pool car maintenance

The effect of the harsh economic conditions and poor infrastructural development is quite severe on haulage company vehicles that need to move bulk load from one point to another [7]. The trucks are the lifeline of the companies and must be operational to deliver value. According to the study in 2009 by AAA Car Care, more than 62% of vehicles are operated on severe service conditions, some of these conditions include:

- Driving in hot weather under frequent stop and start traffic
- Driving on dusty or muddy roads and on roads with gravel spread
- Driving below 50 miles per hour over long distances
- Transporting heavy loads or towing a trailer

Nigeria is a tropical country, with an average temperature of about 28°C, which could rise to about 35°C in the northern region. When haulage trucks travel between local communities, a number of unpaved roads will be encountered. Most of these roads are unpaved, dusty and muddy, and the pot holes in some road sections are filled with stones and pebbles. Poor roads and insufficient road network creates heavy traffic along major roads, and this induces stop and start vehicle movement. Since there is no dedicated lane for trucks and bulk vehicles, heavy loaded trucks caught up in traffic are also forced to stop and start with the slow moving traffic. By these realities, most vehicles in Nigeria are operating under severe conditions, and this requires frequent maintenance and oil change to limit damage, and prolong vehicle service life. Frequent maintenance has an associated cost implication which may result in non-compliance in a bid to reduce expenses. In Europe, road transport accounts for 17.5% of total greenhouse gas emissions [8], and this will be aggravated in developing countries by poorly maintained vehicles with sooty vehicle exhausts.

A. The haulage company truck maintenance analysis

Commercial trucks travel thousands of kilometres with heavy loads every year, and this journey is most times under severe conditions. Prior to embarking on a journey, trucks ought to meet the minimum safety and maintenance requirement to prevent sudden breakdown en route to their destination. This is often not the case; a number of broken down trucks can be seen on major highways and on interstate routes in

Nigeria. Some of these loaded trucks are sometimes at the breakdown spots for weeks, with the driver and driver assistant sleeping in, or around the truck to protect the cargo until the truck is fixed. Often the needed technical assistance, funds and or spare parts is coordinated from the office of the logistic company which is in one state, while the broken down truck is in another. The repair process is sometimes slow and this can lead to cargo theft and product damage for perishable goods.

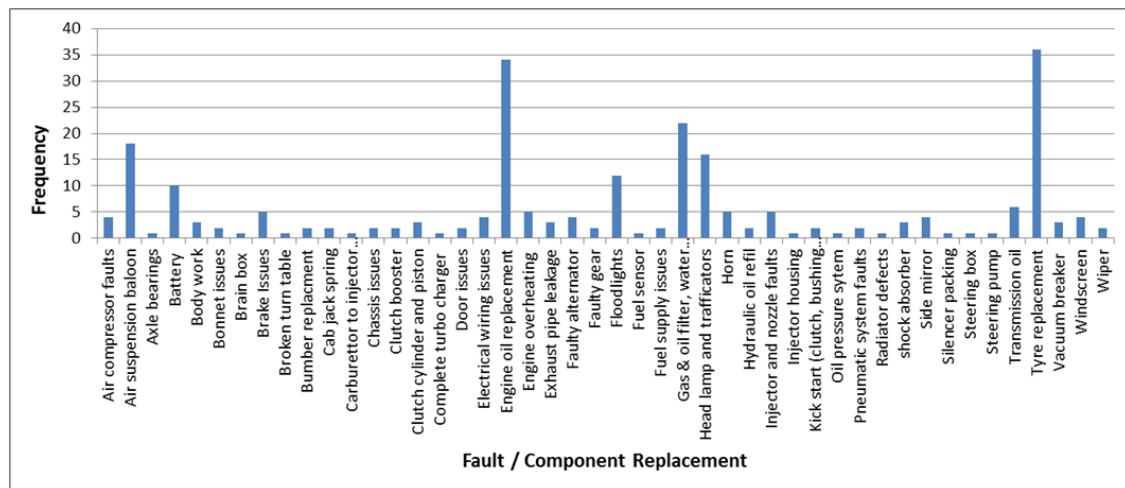


Fig.1 Faulty components and their frequency of occurrence

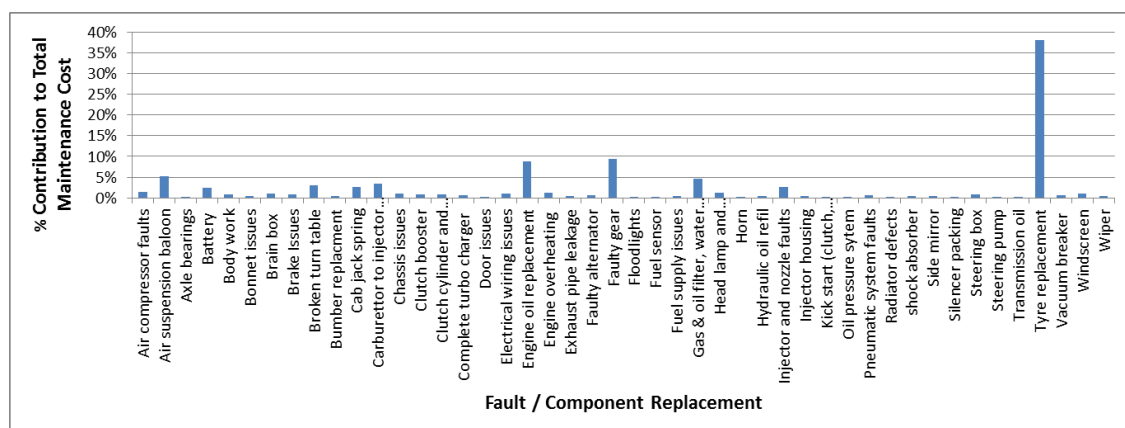


Fig.2 The contribution of each fault and repairs to total maintenance cost

Figure 1 shows the fault log and their frequency of occurrence for 15 haulage trucks, for one operational year. Figure 2 shows the contribution of each fault and repairs to the total maintenance cost, based on the average cost of each, expressed in percentage. The availability for service of each of the truck throughout the year could not be established via records. It is possible that some of the trucks were out of service for extensive periods within the year. The data set shows that the gas filter, oil filter and the water separator were replaced 22 times, while engine oil replacement was done 34 times. For the 15 trucks, if oil and filter replacements were done at least once in 6 months, the filters would have been replace 30 times. This indicates a possible cost saving measure by topping the engine oil without a complete replacement of the filtration system, and this could negatively impact the engine performance of heavy duty trucks. This could also imply that some of the trucks as earlier suggested were out of service for certain periods, and as such there was no need to perform some periodic maintenance.

Depending on the type and design, the number of trailer truck tyres can be 10 and up to 18 per truck. Substandard tyres are gradually flooding the market, though they are sometimes cheaper but they do not last long, and are usually replaced more frequently. Poor Nigerian roads, heavy loading of the trucks and the spread of low quality tyres are likely factors that may have resulted in the replacement of 36 tyres representing 37.97% of the total maintenance expenses.

B. The corporate pool car maintenance analysis

Pool cars are vital in corporate environment for conveying personnel from one place to another for various business purposes. In some organization, each car is assigned to a specific unit or department, but the maintenance of all the cars is often managed by the maintenance department. This study analyses the maintenance and fuel related data for 25 pool cars of a corporate organization. From the plot in Figure 3 and Figure 4, periodic maintenance (filter and oil replacement) occurred 16 times and this is followed by brake related issues that occurred 14 times. Labour charges for various services contributed significantly to the maintenance cost profile. The highest maintenance cost is 15.6397% of the total maintenance cost, and it was incurred for replacing a single propeller shaft. This emphasises how the nature of the fault and the affected component determines maintenance expenses.

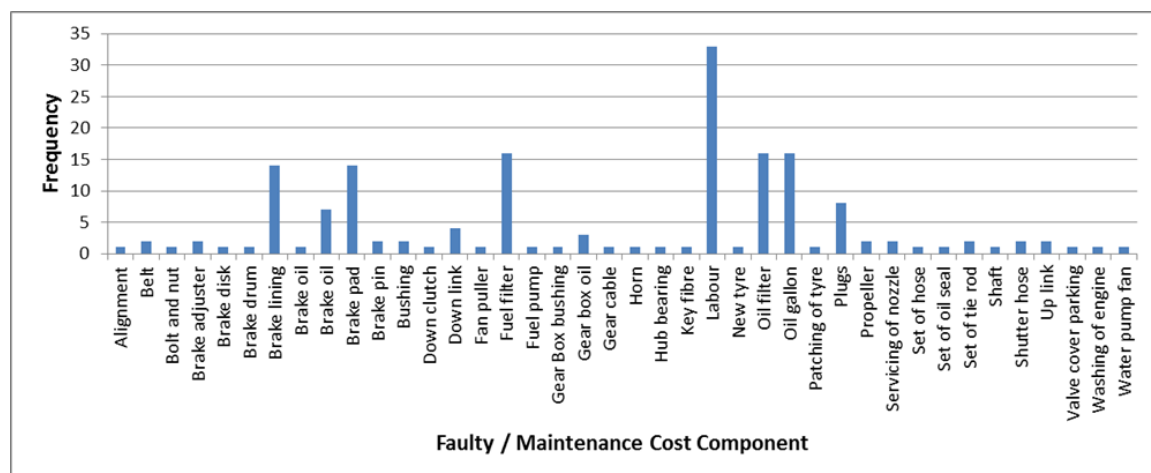


Fig.3 Frequency of occurrence of various car faults

For the 5 months of maintenance cost data for the pool cars, a single tyre was not replaced, this is in contrast to the haulage truck scenario. This could be due to the significant difference in car and truck loading or it could imply that some tyres were recently replaced outside of the 5 months window data. For the cars, the frequency of brake related issues is quite high as compared with that of the trucks. Since the two organizations are in different states, this could be an indication of a more intense stop-and-start traffic in the state of the pool car organization.

Traffic and vehicle statistics can be applied for various studies and analysis. In [9], crash data was collected and analysed for acquiring valuable information about traffic safety. Maintenance planning and management can also be improved by providing valuable statistics about past trends and by showing the relationships between various maintenance parameters. This can help in making informed management decisions. This study carried out prediction analysis for the pool car data using the ANN model in Figure 7. The model was implemented in MATLAB.

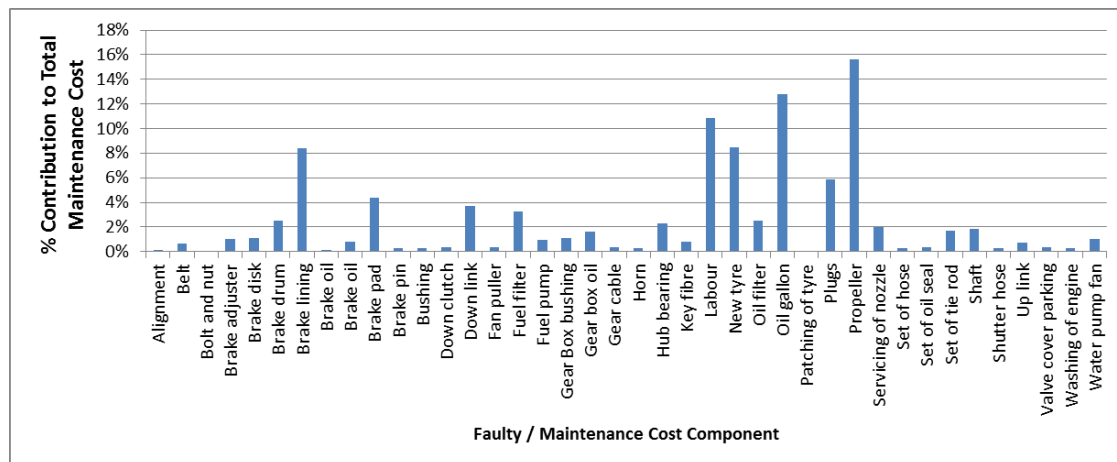


Fig.4 Total car maintenance cost breakdown

3. Maintenance cost prediction using ANN

ANN has found application in various fields of life for data cluster analysis, prediction and so forth. In the study by [10], neural network was applied for vehicle maintenance scheduling. In this study, the goal of the pattern recognition and relationship identification among the parameters is to determine the extent to which the collected vehicle usage parameters can be used to predict the vehicle maintenance cost of the pool cars, and this is achieved using an Artificial Neural Network (ANN) model. The ANN model is deployed using the Nonlinear Input-Output time series tool box in MATLAB. The model is a dynamic neural network, which include tapped delay lines. Through dynamic filtering, the ANN model uses past values of the six vehicle usage parameters, that is, the Fuel Cost (FC) in Nigerian Naira, the Fuel Volume in litres, the car Mileage in km, the Normalized Fuel Cost, the Normalized Fuel Volume, and the Normalized Mileage as model inputs, to predict future Maintenance Cost as the model target.

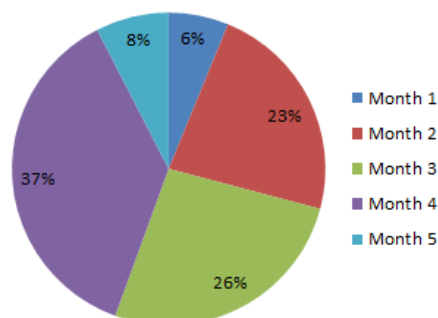


Fig.5 Percentage monthly contribution to the total maintenance cost for 5 consecutive months

The ANN model comprises the inputs, the hidden layer with delays, and the output layer. The hidden layer has 2 delays and 20 neurons with sigmoid activation functions. The analysed data is for a period of 5 months, comprising 111 days of vehicle usage data. The 111 sample dataset is divided into three sets, in the ratio 70:15:15 for training, validation and testing. The ANN network training was performed using the Levenberg-Marquardt back-propagation algorithm, and the performance after the implementation was analysed using Regression Analysis and the Mean Squared Error (MSE).

The monthly contribution to the total expenditure on fuel and maintenance is shown by the pie charts of Figure 5, while Figure 6 shows the variation in the four key data parameters across the months

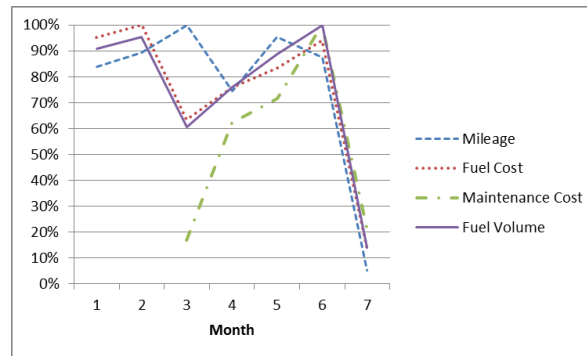


Fig.6 Percentage variation of the 4 study data components across the months

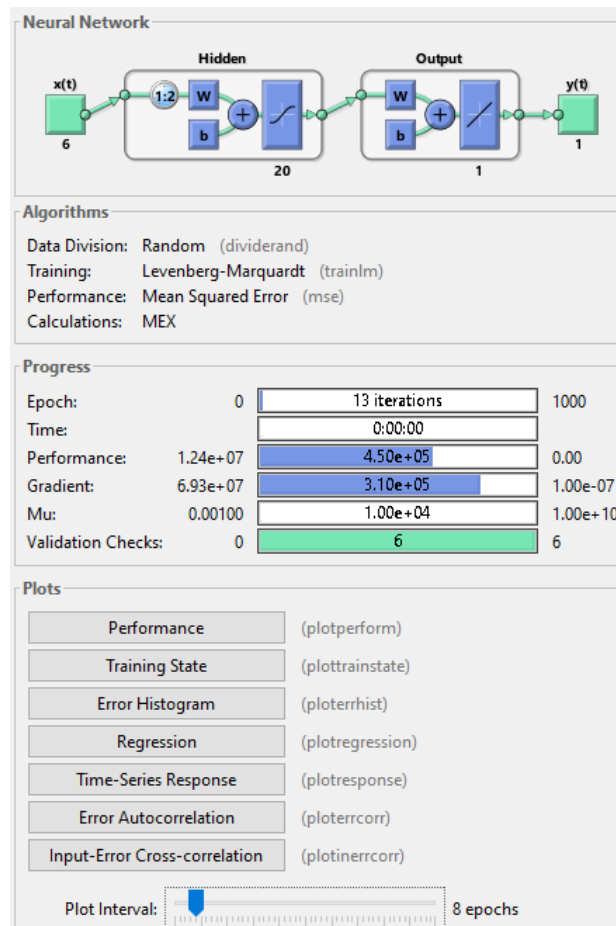


Fig.7 The neural network

4. Results and Discussion

The performance of the model can be analysed using the MSE and the correlation coefficient (R-value) of the regression, which indicates how close the model output prediction is, to the target (maintenance cost). As shown in Figure 8, for the training data set, the R-value is 0.76833, it is 0.76893 for the validation, and 0.80774 for the test. The overall R-value for the three analyses is 0.76645. As shown in Figure 8, the dashed lines in the regression plot represent a perfect line of fit, when the output is exactly equal to the target; this is an ideal situation. The solid lines in the regression plot stands for the real regression line showing the true relationship between the target and the predicted maintenance cost. The R-value can be increased by using more data, say for a period of two years in order to increase the training dataset. The best validation performance of the model as measured using the MSE occurred at epoch (iteration) 7, as shown in Figure 9. The MSE gradually reduced from the peak value until the model execution was terminated after 6 consecutive validation failure checks. Figure 10 shows the variation of the gradient coefficient, the Marquardt adjustment parameter (μ), the total validation fails and the number of iterations.

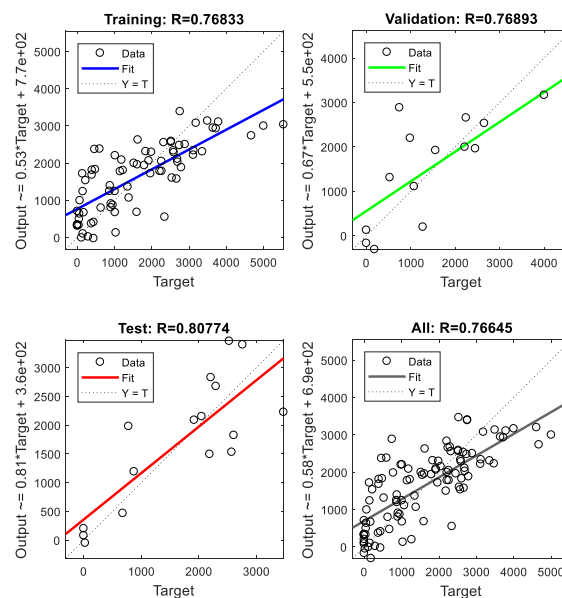


Fig.8 Regression plot

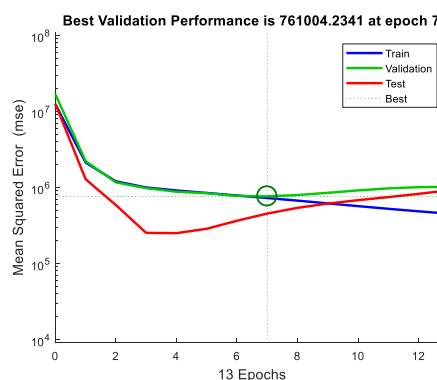


Fig.9 ANN model validation performance plot using mean squared error

Figure 11 shows the output of the model and the desired target (MC) for the training, validation and model test analysis. The error histogram is shown in Figure 12, and it reveals that the maximum model error for the maintenance cost prediction is 2397 Naira. The error is computed as the difference between the target and the model output. . The magnitude of the error can be reduced by using more training data to improve the accuracy of the model.

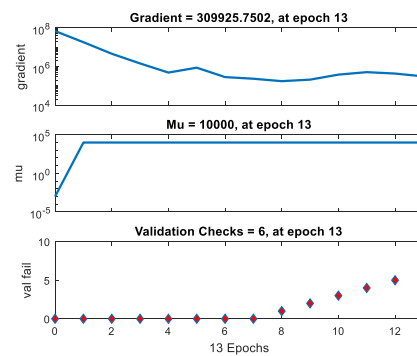


Fig.10 Network Training State

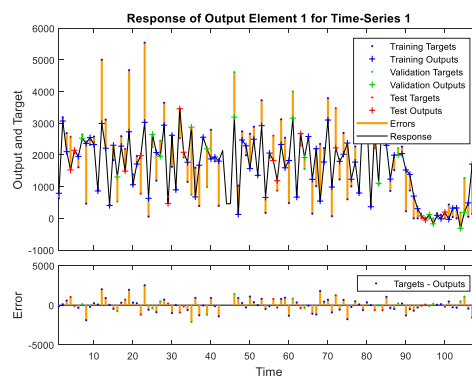


Fig.11 Output element response plot

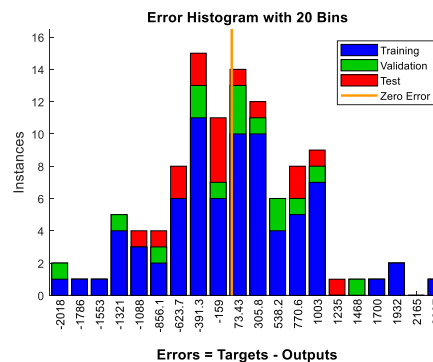


Fig.12 Error Histogram

Using the trained ANN model, different sets of the vehicle usage parameters were supplied as inputs to the model, and the model predicted the equivalent maintenance cost in Naira. This implies that given an anticipated vehicle mileage, fuel consumption in litres and fuel cost over a period of time, the company can predict how much will be spent on maintaining the pool cars, thereby making this ANN model a useful tool for maintenance budgeting.

5. Conclusion

Maintenance expenses makes up a sizable portion of an organization's budget, and as such it must be cost effectively managed by making informed decisions. Vehicles are vital to corporate business, either as a direct source of income (haulage) or for business support (pool cars). In this study, the maintenance and vehicle fuel consumption operational data of two corporate organizations were collected, studied and analysed. The different types of vehicle faults that make up the maintenance cost components were identified together with their frequency of occurrence. An ANN model was developed using the pool car usage data as input to predict the car maintenance cost. The result shows that there is a significant correlation between the predictor inputs, and the predicted maintenance cost, using a set of fuel volume, fuel cost and car mileage input data. This model can provide useful information for vehicle maintenance cost budget planning. The scope of this research can be extended by collecting other parameters, both qualitative and quantitative to enable the implementation of an improved prediction model.

Acknowledgment

The Authors appreciate Covenant University Centre for Research, Innovation and Discovery for sponsoring our participation at the conference.

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