Using Reliability Information and Neuro-Fuzzy to Predict Warranty Cost: A Case Study in Fleet Vehicle

Hairudin Abd Majid, Nur Izzati Jamahir, Azurah A.Samah

Abstract*— Nowadays, the great market competition makes that the companies look for high reliability and quality of the products manufacturing. The effective ways to ensure reliability signals of the product is by offering better warranty terms and period associated with sale of the product. In fact, warranty is a legal obligation of the manufacturer or dealer in connection with the sale of the product that defines the liability of the manufacturer or dealer in the event of the premature failure or defects of the product. The purpose of this paper is to propose a method for reliability analysis of the warranty data and to validate the warranty policy. In order to applied neuro-fuzzy approach by optimizing warranty cost and period, modelling the reliability of the product must be beneficial.

Index Terms*— reliability, failure rate, neuro-fuzzy, warranty cost, warranty period.

I. INTRODUCTION

Warranty in any business dealing has its own priority since it has a close relationship between manufacturers and their customers. Specifically, warranty is a contract between a manufacturer and a consumer, which requires the former statement to either repair or replace the purchased items that fail during the warranty period as specified in the contract. Both seller and buyers need the warranty to protect their own benefits. Thus, the different types of warranty policy are established in order to fulfill the demand of manufacturers and the requirement of buyers so that a win-win situation could be acquired. Warranty has become a major new direction for manufacturing industry since it plays an important role in protecting both buyers and sellers. In addition, there are market pressures from competitors to provide increased warranty coverage leading to higher warranty cost and reduce profit margins.

We believe that a major root causes, among others, is not utilizing a wealth of information hidden in warranty data to make appropriate design-manufacturing, assembly, or service-related improvements. It would not be overstatement to say that every company strives to provide the best quality products to their customers. For complex product such as an automobile, the majority of such efforts are directed at the R&D stage. At the development stage, activities such as concept or design failure mode and effect analysis, design verification planning and reporting, robust design experiments, are performed to develop confidence that highly reliable and robust products have been developed and delivered.

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Various system, subsystems, and components undergo prototype testing, life testing, and accelerated life testing for design verification and validation. In spite of employing the best quality and reliability practices, unexpected failures during the warranty period do occur and cost automobile companies billions of dollars annually in warranty alone.

The great market competition makes that the companies look for high quality of products. Basically, there are six types of warranty that can be offered either by manufacturer or dealers of a product or services which are basic warranty, extended warranty, warranty for used, repair limit warranty, service warranty and lifetime warranty.

In automobile industrial, an accurate prediction of optimal warranty period and warranty costs is often sought after by the manufacturer. It is also difficult to quantify the risks and rewards in offering a warranty as referred in [7]. According to [4], a warranty period may be unprofitable for the manufacturers if the choice of duration given is either too short or too long. Similarly, warranty cost for an underestimation or overestimation of the warranty cost may have a huge influence to the manufacturers.

Since warranty has turned from something into a strategic priority, therefore the research topic about the application of artificial intelligence in warranty area is exceptionally requisite and interesting in affirming whether the existence of hybrid of artificial intelligence in warranty area are more reasonable, logical and accurate as compared to the model without hybrid . The main purpose of this research is to simplify the two-dimensional warranty model by introducing a neuro-fuzzy approach to obtain warranty cost and period. Before getting a value of warranty period, we will first analyze the reliability of the product. In this paper, only some basic knowledge covered in applying neuro-fuzzy and method on how to get reliability of product in automobile case study.

II. PREVIOUS RESEARCH

The area of warranty has been studied by researchers from many different areas such as economic, engineering, statistics and more. A number of techniques have been used as a method in solving warranty problem. In past few years, there has been an increased used of statistical methods instead of soft computing methods in warranty related applications. However, soft computing methods have been used by many researchers in the other research area which can provide some feasible solutions for the complex real-world problems. This study discussed about the problems on warranty with using soft computing specifically by using neuro-fuzzy approach. There are several studies in warranty problem specifically by using soft computing method [16].

Fig. 1 shows the framework of some warranty issues which have

been studied from various points of view.

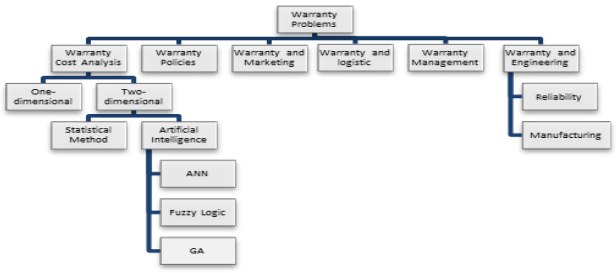

Fig. 1: Framework of Warranty

A. Previous Research on Product Warranty using Soft Computing Method

Reference [3] noted that until the 1940s, warranty studies were mainly carried out by researchers in the legal profession and thus, such articles appeared only in the law journals. Subsequently, warranty studies attracted researchers from diverse field such as economics, accounting, management, marketing engineering, operations research and statistics.

Here are some studies on soft computing method in warranty area. For example a study on two-dimensional warranty by choosing suitable fuzzy method to handle vogue data was studied by [10]. They presented a fuzzy deduction technique which is used to analyze the two-dimensional warranty based on usage and age. Reference [21] proposed fuzzy logic based for estimation of reliability improvement during product development. Example of studies in warranty area by using neural as such [5] presented a warranty cost model which predicts the warranty cost in unusual scenarios by combining the statistical components with multi-layer perceptron and a cross-entropy based learning rule. Reference [13] applied neural network learning to determine the detection degree of warranty claims data.

B. Previous Research to Model Reliability based on Product Warranty

Reference [22] state that warranty claims of the systems contain a large amount of information about reliability, such as failure times, usages and failure modes. Using warranty data to model reliability as a function of time and usage provides a more accurate and realistic estimator. They describe warranty data structure and censoring mechanism. A sequential regression method is proposed to model mileage accumulation from warranty claim data. The model and mileage failure data are used to evaluate the patterns of failure occurrences at different mileages. The paper then establishes the relationship between reliability and time in service and mileage. The unknown parameters are estimated by maximum likelihood method with time and mileage censoring. The reliability model is used to predict the number of warranty claims, and the number of failed vehicles which do not generate warranty claims due to mileage exceeding warranty limit. In their paper, an example is presented. The example shows that the predicted number of warranty claims has a good agreement with the actual number of claims.

III. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

Human are hybrid information processing machines. Our actions are governed by a combination of genetic information and information acquired through learning. Human learning consists of a variety of complex process that use the information acquired from interactions with the environment. It is the combination of these different types of information processing method that enabled humans to succeed in complex, rapidly changing environment.

This type of hybrid information processing is now being replicated in a new generation of adaptive machines. At the heart of these adaptive machines are intelligent computing systems, some of which are inspired by the nature such as neural network, particle swarm optimization, and genetic algorithm. While these intelligence techniques have produced encouraging results in particular tasks, certain complex problems cannot be solved by a single intelligent technique alone. Each intelligent technique has a particular computational property that make them suited for particular problems and not for others. Since we are studying neuro-fuzzy method, therefore three components need to know which are artificial neural network, fuzzy logic, and neuro-fuzzy system.

A. Artificial Neural Network

Neural networks are inspired by the functionality of the nerve cells in the brain. Like humans, neural networks can learn to recognize patterns by repeated exposure to many different examples. In most cases, ANN is an adaptive system whereby the structure is transformed based on external or internal information that pass through the network.

An ANN must compose of the collection of processing elements called perceptrons, arranged in differing ways to form the network structure. The perceptrons are grouped in the layers of the network. Each of the perceptron receive inputs, manages inputs and release output.

Determination of the optimal number of hidden layers and hidden nodes in each (hidden) layer is the most critical task. For instance, an ANN with no or too few hidden nodes may not differentiate among complex patterns. In contrast, if the ANN has too many nodes or layers, it might be affected severely by the noise in data due to over-parameterization, which eventually leads to a poor generalization.

An application of artificial neural network in two-dimensional warranty modeling has been studied by [1]. She proposed data from warranty claims and automobiles services from the Malaysian automotive industry were collected as input information data for ANN. A feed-forward back-propagation neutral network (BPNN) with multilayer perceptron (MLP) is introduced to simplify two-dimensional warranty with delay time approach model. The results revealed that the ANN approach which was implemented produced results that were found to be ninety percent of higher quality if measured in term of the accuracy.

B. Fuzzy Logic

Fuzzy logic is powerful problem-solving methodology with wide applications in industrial control and information processing. It provides a simple way to draw definite conclusions from vague, ambiguous or imprecise information. It resembles human decision making with its ability to work from approximate data and find precise solutions.

Unlike classical logic which requires a deep understanding of a system, exact equations and precise numeric values, fuzzy

logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy Logic allows expressing this knowledge with subjective concepts such as "very good" and "a little bit satisfied" which are mapped into exact numeric ranges.

There are 3 steps need to know in fuzzy logic method which is fuzzification, aggregation and defuzzification. In order to convert numeric data in real domain to fuzzy number in fuzzy domain which is between 0.0 to 1.0 is called fuzzification. Aggregation is computation of fuzzy numbering fuzzy domain whereas defuzzification is to convert the obtained fuzzy numbers back to the numeric data in the real-work domain.

Fuzzy method in warranty cases have been studied as in [11]. They studied on two-dimensional warranty by choosing suitable fuzzy method to handle vogue data. They presented a fuzzy deduction technique which is used to analyze the two-dimensional warranty based on usage and age. The method for the analysis of a two-dimensional warranty based on fuzzy deduction shows more reasonable results. They also consider not only fuzzy lifetimes but also situations in which the usage of fuzzy as well.

C. Neuro-Fuzzy System

The learning capability of an artificial neural network can be used for automatic fuzzy if-then rules generation. The connection of fuzzy system with an artificial neural network is called neuro-fuzzy systems. As a result, those systems can utilize linguistic information from the human expert and measurement data. In other words, linguistic prior knowledge from an expert can be corporate into neuro-fuzzy systems. Sometimes, a neuro-fuzzy system is utilizing only measurement (numerical) information, and expert knowledge cannot be used. Neuro-fuzzy refers to the combination of fuzzy set theory and neural networks. The capability of this method is to handle any kind of information either it is numeric, linguistic or logical. Neuro-fuzzy method also will manage imprecise, partial, vague, or imperfect information and also can resolve conflicts by collaboration and aggregation. There is no need of prior knowledge of relationships of data. Neuro-fuzzy mimic human decision making process and it is more effective because this method is self-learning, self-organizing, self tuning capabilities and also fast computation using fuzzy number operations.

IV. RESEARCH FRAMEWORK

In this section had presented framework of study. This is an important element to ensure every activity in this research will conduct smoothly.

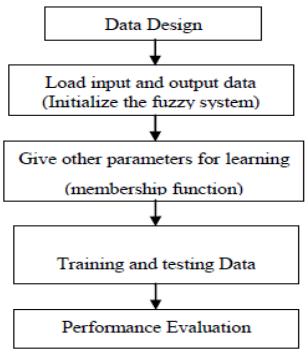

Fig. 2: Basic Flow Diagram of Neuro-Fuzzy Computation

To clarify the flow of this study, the proposed research framework on neuro-fuzzy modeling applied in warranty cost modeling and reliability. Fig. 2 shows the neuro-fuzzy framework for a two-dimensional warranty. The first step to develop the model is designing the collected data. The data were design to get the input and output design. To select the input, the selected elements must correspond to parameters, which mean it will directly or indirectly affect the prediction result. The chosen input are age and mileage. Lastly, we analyze the result which is in this case to optimize the warranty cost and period.

In this research, we are using Matlab R2009a to obtain the result. Here, we can use either fuzzy logic toolbox, or straight away using ANFIS (neuro-fuzzy toolbox) to obtain the result. While using Matlab toolbox, it is challenging because sometimes we need to modify the code to suit with what we expect to achieve. Therefore sometimes it is more applicable to create coding through Matlab to match with certain problem.

V. DATA COLLECTION

A complete data set is very important in the implementation process. In this paper, the historical maintenance data is drawn from automobile Malaysia company which concerns a single product. The collection data set is covered a five-year period from 1998-2003. There are 102 samples of the vehicles are adopted in all algorithms. From the 102 samples, once a maintenance service is made, the vehicle status and information are recorded as the historical data. There are about 726 historical data recorded from the 102 samples. Some of the historical data is the date when claims are made, failure date, sale date, production date and mileage.

In input data analysis, we have filtering all the data. The data input is selected randomly from the historical data. It is because when we want to train the data, we need to refer not only from one vehicle. This is the reason for why we are not sorting the data according to vehicle. The data are divided into two parts which is one for training and the other part for testing the models. We consider using data mileage, age, number of failure and number of defect as input data. We decided to use 581 data for training and 145 for testing to verify the accuracy of the models.

VI. RELIABILITY ANALYSIS

Reliability is characteristic of an item, expressed by the probability that the item will perform its required function under given conditions for a stated time interval. According to [2], reliability from the qualitative point of view can be defined as the ability of the item to remain functional. Quantitatively, reliability specifies the probability that no operational interruptions will occur during a stated time interval. This does not mean that redundant parts may not fail, such part can fail and repaired.

Reference [15] proposed reliability analysis based on failures reported during warranty period is presented in the flowchart in Fig. 3.

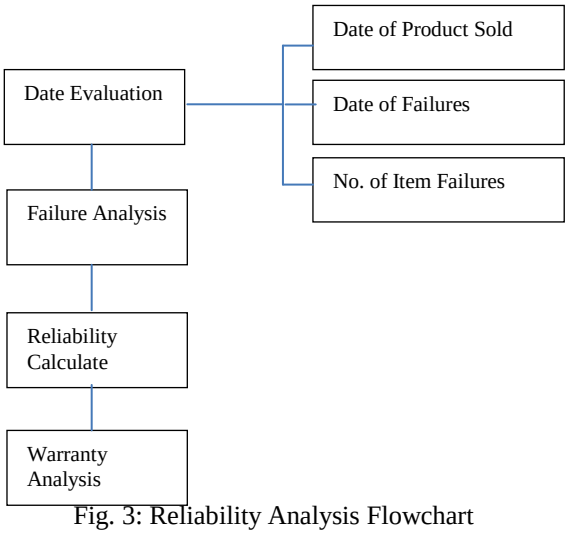

Fig. 3: Reliability Analysis Flowchart

The first step in the proposed method involves the evaluation of the first failure for each sold product in a given period of time. Considering that as soon as the components fails, the customer will notify the manufacturer and the difference between the date sold and the repaired date represent the time to failure.

The next step in methodology requires the organization of the time to failure database in failure data. For example, in our case study, there are about 102 vehicles in fleet maintenance automobile data from historical data. Table I below shows some of the important information from data. For every vehicle, there are a number of inspections recorded.

Table I Example of Information From Automobile Data

No. of Inspection	Mileage (km)	Age (day)	No of failure	No. of defect	Cost
2	1331	40	2	0	74.45
3	5096	62	0	0	189.9
4	13149	104	0	2	252.26
5	19304	182	0	0	244.95

Basically, a failure occurs when the item stop performing its required function. Failure rate plays an important role in reliability analysis. The failure is exponentially distributed as

$$F(t) = 1 - e^{-\lambda t}.$$

For this case, the failure rate λ can be estimated by

$$\lambda = \frac{k}{T}$$

where T is given (fixed) cumulative time and k the total number of failures during T. Mean of failure rate from 102 of fleet vehicles data is 0.16753. Then, reliability can be calculate by using the following equation:

$$R(t) = e^{-\lambda t}$$

VII. EXPERIMENTAL RESULT

The reliability is expressed, which curve is presented in Fig. 4, as

$$R(t) = e^{-\lambda t}, \quad \lambda = 0.16753 \; failres/month$$

where t is the inspection interval time, expressed in months.

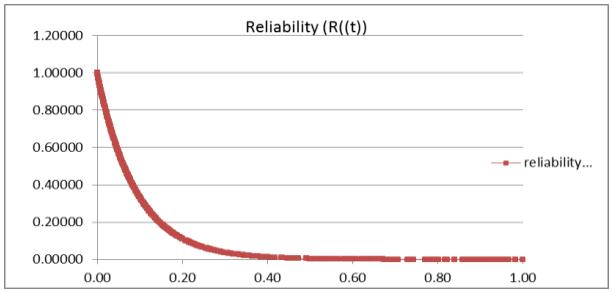

Fig. 4: Reliability Based On Automobile Warranty Data

From Fig.4, it shows that reliability of product decrease with time. This means that the reliability or the performance of product will reduce according to increasing of age month. It is due to the increase of failure and defect of the component from the vehicle needs to be replaced. From the graph in Fig. 4, we can extract the data as in Table II. Basically, modeling the reliability as a function of age and usage provides a more accurate and realistic estimator [18]. Such models are needed by manufacturers to evaluate reliability and predict warranty claims and costs.

Table II Example of Extracted Data

Time (t)	Reliability (R(t))
13.8	0.099071
29.1	0.007634
43.3	0.000707

Fig. 5 shows the reliability and cost over time. From the reliability plot, it is decreasing when time increase. This is contrary to the warranty cost which cost is always increasing when the service of vehicle is aging. Reliability is decreasing due to failure rate of the vehicle. We assumed that the intersection between reliability and cost is the optimum warranty cost and warranty period of automobile case study. Therefore, the optimum warranty cost is RM 1736.56 and warranty period is about 1 year and 3 month. From our data, the average number of inspections in a year is 5 inspections.

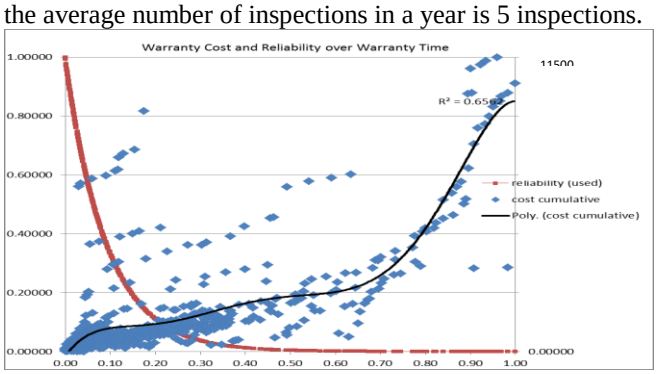

Fig. 5: Reliability And Warranty Cost Versus Time Based On Automobile Warranty

VIII. CONCLUSION

Nowadays, reliability became a point to be considered when purchasing a product. It can be assumed that if the warranty period is extended to two years, the average warranty cost would be double. This average warranty cost represents the amount of the items selling price that will used to cover warranty cost due to failures reported during warranty period. For longer warranty periods there is a great increase in the average warranty costs because of the failure probability increase. The extension of their warranty period is just one way to show to the customers how reliable a product is.

The methods used in this paper for warranty data analysis are only part of reliability analysis. Warranty data information is no doubt the best source of information from the field, reflecting the product performance and capturing the appropriate usage and environmental condition. The method is used to define the reliability of automobile based on 72 months failure database.

The next step is to implement in neuro-fuzzy and used reliability data set to optimized warranty cost and period.

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