Soft Computing Methods in Warranty Problems: Review and Recent Applications (2003-2012)

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Abstract

Warranty problems become an interesting issue among researchers in worldwide. A number of techniques have been developed in solving warranty problem specifically in reducing warranty cost. However, the applications of soft computing in warranty area receive less consideration by researchers. This paper presents a review of recent applications of soft computing methods in warranty problems of ten years research from 2003 to 2012. Three techniques are considered, specifically Artificial Neural Network (ANN), Fuzzy Logic (FL) and Genetic Algorithm (GA). Our study reveals that FL was widely applied in warranty problems.

Keywords: *Artificial Neural Network, Fuzzy Logic, Genetic Algorithm, Soft Computing, Warranty*

1. Introduction

Almost everything purchased, by an individual or an organization will be covered by a warranty. Warranty is a contractual agreement between the buyer and manufacturer upon the sale of the product where the manufacturer agrees to repair or replace the product when it fails to work as intended. Frequently, the warranty is used by manufacturer as a marketing tool to advertise the quality of the products. Thus, warranty is a part of marketing strategy.

In the last ten years, the area of warranty problem has been studied by researchers from many different areas such as economic, engineering, statistics and many more. A number of techniques have been used as a method in solving warranty problem specifically in optimizing warranty cost. 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.

The purpose of this paper is to review areas of warranty that use soft computing approach as a method in finding the solution of research problem. More specifically, this paper reviews the applications of soft computing in warranty area that were published during the period of 2003 to 2012. The paper is organized as follows. Section 2 discusses a general description of warranty studies. Section 3 presents the application of soft computing in warranty domain. The discussion of our analysis is described in section 4. Finally, section 5 provides a conclusion of this paper.

1.1 Framework

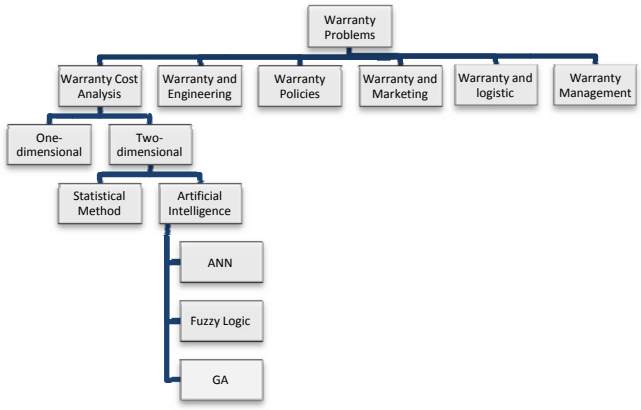

Fig. 1 Framework of Review.

Fig. 1 shows the framework of some warranty issues which have been studied from various points of view. Our review of this paper concentrates on two warranty issues namely warranty cost analysis and warranty and engineering.The literature on warranties is vast. Murthy and Djamaludin (2002) reviewed literature of new product warranty and discussed six different ranges of warranty issue during the period of 1993 to 2002. Furthermore, the research and developments in warranty data analysis has been reviewed by Wu (2012) which highlighting on models, methods and applications. In another study, Rai and Singh (2009) discuss the issues involved in warranty data and present strategies and methods for reducing warranty costs.

A number of approaches used to solve problem in warranty domain exist in literature. For example an alternative approach to model the aggregate claims over time which is based on time series models has been studied by Wasserman and Sudjianto (1996). They discussed the time series approach by using linear dynamic model based on Kalman filtering and compare it with two other approaches (static predictive models and non-parametric models). The authors also discussed the implementation of artificial intelligence and neural network in modeling process.

2. Warranty Study

2.1 Overview

Generally, warranty indicates higher quality product and provide greater assurance to customers. Blischke and Murthy (2002) stated that warranties serve different purposes for buyer and manufacturer. A warranty can be used to provide protection to buyer when an item is unable to perform satisfactorily. Warranty can also be used as an effective advertising tool since buyers often view products as reliable product when a long warranty is offered. Sometimes, competition may force company to provide more warranty coverage to gain buyer confidence. In literature, Blischke and Murthy (1994) considered cost and optimization problems from both manufacturer's and customer's points of view.

There are two dimensions of warranty policy which are one- and two-dimensional. The one-dimensional warranty is characterized by an interval with either product usage or product age. In contrast, two-dimensional warranty involves both product age and usage which characterized by a region in a two-dimensional plane with one axis representing age and the other one usage. For example, usually a new vehicle is sold with 3 years or 36000 miles warranty, whichever comes first. Under this warranty, the buyer is provided with warranty coverage for a maximum time period of 3 years or a maximum usage of 36000 miles. If the usage is heavy, the warranty can expire well before 3 years otherwise, if the usage is very light, the warranty can expire well before the limit of 36000 miles is reached.

Different region define different warranty policies. In the case of involving time and usage limitation, it would be a two-dimensional warranty. Both one- and two-dimensional warranty have been proposed and studied by researchers. Unfortunately, the two-dimensional warranty is very rare case study. This is supported by Murthy and Djamaludin (2002) which indicates that the two-dimensional warranties have received a lot less attention compared to the one-dimensional case.

2.1.1 Warranty Policy

Different types of warranty policy have been studied and proposed by many researchers. Free replacement warranty (FRW) and pro-rata warranty (PRW) are the most common warranty policy. With FRW policy, a manufacturer agrees to repair or replace for failed items from a time of initial purchase up to the time w where w is warranty period. In PRW warranty, the replacements are given under pro-rated cost to the buyer. For more details of warranty policies, refer Blischke and Murthy (1992).

2.1.2 Type of Warranty

In brief, there are six types of warranty that can be offered by manufacturer of a product which are basic, extended, used, repair limit, service and lifetime warranty.

2.2 Warranty Cost Analysis

2.2.1 Cost Modeling

Warranty cost analysis begins with modelling the failures and the costs of rectification actions over the warranty period as stated by Murthy and Djamaludin (2002). The time to first failure is modeled by a probability distribution function. To date, the utility of probability distribution has been a very popular and famous to model the failures. Manna *et. al* (2007) suggest a new methodology for modelling the failure probability of automobile component indexed by both age and usage. The main characteristic of their model is to determine how use-rate influences life. Many researchers deal with modelling the failures based on different distribution. For example, Kim and Rao (2000) find expected warranty cost of two-attribute free-replacement warranties based on a bivariate exponential distribution.

Apart from using different distribution, various researchers model the failure by a non-homogeneous Poisson process (NHPP). For example, Majeske (2007) develop a NHPP predictive model for automobile warranty to predict claims. Comparison between the actual observed values and warranty prediction has been done and it reveals that NHPP give an accurate prediction of warranty claim. Huang and Yen (2009) derive the optimal two-dimensional warranty policy and estimate the expected annual profit for the uniform, gamma, and lognormal cases. They use a NHPP to model the deterioration process of the product, where the deterioration depends on the cumulative operating time and usage. Shafiee *et. al* (2011) developed statistical models for estimating the dealer's expected warranty cost for second-hand products sold with two-dimensional free repair/replacement warranty. The failure process is modeled by a NHPP.

2.3 Warranty and Engineering

In fact, warranty claims arise due to item failures. Item failures are influenced by several factors including the engineering decisions on its product design and the manufacturing process. Improving the design and development of a product during the manufacturing process incur an additional cost. These improvements will give a

greater reliability of the product so that the warranty cost can be reduced.

2.3.1 Reliability

A warranty cost depends on the reliability of a product. Reliability which represents quality performance is defined as the probability that the product or a system performs the intended function adequately for a specified period of time, under specific operating condition and environment. According to Verma, Srividya, and Gaonkar (2007), in reliability function, there are four components which are necessary to known which are probability of survival, intended function of product, operating environment or conditions and the time frame.

Product reliability and warranty are closely linked and have an impact on several other variables such as design, manufacturing, marketing and others. This implies that product reliability must be managed by taking into account this link and the interactions with the other variables in the product life cycle context.

Studies on reliability and warranty have been carried out by researcher such as Murthy (2006), Yang and Zaghati (2002) and Yadav *et.al* (2003). Yang and Zaghati (2002) discuss the relationship between reliability and time in service and mileage. Precisely, the purposes of the research are to model usage accumulation, to measure failure dependence on usage and to quantitatively relate reliability to time and usage. A sequential regression method is proposed to model mileage accumulation. The reliability model is used to predict the number of warranty claims.

2.3.2 Manufacturing

Warranty has become an important component for manufacturing industry since it is significance in protecting both consumers and manufacturers. The relationship between warranty cost and engineering decisions were established by Blischke and Murthy (1994). They developed a manufacturing cost model which was dependent on warranty and manufacturing costs. A good quality of a product is depending on the design characteristics, material used and the manufacturing process. Monga and Zuo (1998) use genetic algorithm to obtain optimal values of system design, burn-in period, preventive maintenance intervals and replacement time.

3. Soft Computing in Warranty Domain

Soft computing concerns the use of theories of Artificial Neural Network (ANN), Fuzzy Logic (FL), and evolutionary computing to solve real-world problems that cannot be satisfactorily solved using conventional crisp computing techniques (Karray and Silva, 2004). Key characteristics of soft computing which are the representation and processing of human knowledge, qualitative and approximate reasoning, computational intelligence, computing with words, biological models of problem solving and optimization are directly related to intelligent systems and application.

The main components of soft computing are ANN, FL and Genetic Algorithm (GA). They are able to perform various types of tasks. For example, FL is a powerful tool for dealing with imprecision and uncertainty. On the other hand, ANN is a potential tool for learning and adaption. GA is identified to be an important tool for search and optimization (Pratihar, 2008).

Artificial Intelligence (AI) is an intellectual that trying to capture all aspects of human intelligence in computers. AI seeks to use human inspired algorithms to approximate conventionally intractable problems. There are many application on artificial intelligence have been studied since it was first introduced fifty years ago. However the contribution of soft computing in warranty study can be considered small compared to other area such as in engineering and manufacturing. The application of Artificial Intelligence in warranty area is discussed in the subsequent paragraph.

3.1 Artificial Neural Network

3.1.1 Overview

Artificial neural networks (ANN) are inspired by biological role of nerve cells in the human brain. ANN consist of a group of a number of interconnected cells called as neurons with weight running together to create learning in machines (Karray and Silva, 2004). Basically, ANN consists of three interconnected layer which are input, hidden and output layer. The input and output layer consist of a collection of neuron which represents input and output variables or data. The hidden layer also consists of a series of specific neurons and is connected in between the input and output layer.

ANN involves two process which is training and testing process. Firstly the training process is being executed to the ANN model. This process is a learning process for the known set of data in the network. The training process proceeds continuously by adapting its weight and biases through activation function. The training process will work until the error is reduced to error that is acceptable for a particular task. There are varieties of learning algorithms that can be used to train, depending a specific problem. The most popular training algorithm is feed forward back propagation neural network (BPNN) algorithm.

3.1.2 ANN Application

Hairudin *et al.* (2011) studied on application of artificial neural network in two-dimensional warranty modeling. They proposed data from warranty claims and automobiles services from the Malaysian automotive industry as input information data for ANN. To simplify the two-dimensional warranty with delay time approach model, BPNN with multilayer perceptrons (MLP) was introduced. From their analysis, ANN approach which was implemented produced results that were found to be ninety percent of higher quality if measured in term of accuracy. The author found that ANN work faster in order to predict minimum warranty cost and optimal inspection interval during a warranty period.

Hrycej and Grabert (2007) 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. They stated that, the millions of historical warranty data is the only reliable resource for modelling the warranty costs. Moreover, they believed that the only dependent on a single parameter such as mileage or age is not sufficient to produce the automobile warranty policy. The real failure process should rely on both parameters. Furthermore, they emphasized that to obtain the different intension of failure upon different countries, the road conditions factors has to be considering in the failure distribution parameterization. By using MLP as a functional approximation, and training the parameters of MLP with help of minimum cross entropy rule, they consider that the failure probability as general point.

Lee *et al.* (2007) applied neural network learning to determine the detection degree of warranty claims data. The proposed early claim warning system protects both manufacturers and consumers. It monitors various claim data, hence provides an “earlier warning” about the unusual increase of claim rates at a certain point based on trend and prediction. Rai and Singh (2009) in their book chapter have applied neural network in forecasting of automobile warranty performance problem. They described the application of neural networks to predict warranty performance in the present of warranty growth phenomena. There are three forecasting method which are log-log plot, dynamic linear models and neural network introduced in this book, but to alleviate the issues faced by log-log plot and dynamic linear models, they develop an artificial neural network black-box model for year-end warranty performance forecasting.

3.2 Fuzzy logic

3.2.1 Overview

Fuzzy Logic was primarily introduced by Zadeh in 1965 as a mathematical way to represent vagueness in everyday life. The significance of fuzzy logic proved from the fact that most modes of human reasoning, especially common sense reasoning, are approximate in nature. The proposed overall procedure for approximating the impact of corrective actions on product reliability is shown in Fig. 2, which consist of four components, namely fuzzy rule bas, fuzzy inference process, fuzzification process, and defuzzification process.

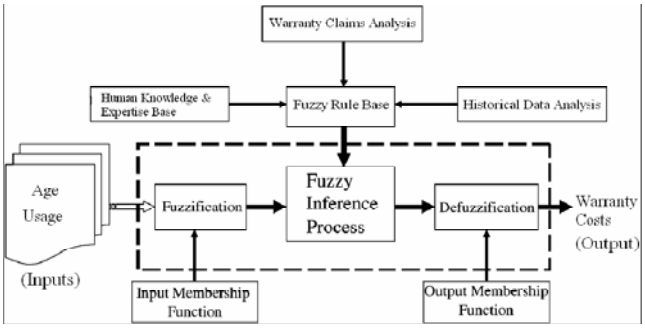

Fig. 2 Fuzzy logic framework for modelling two-dimensional warranty (Lee *et al.*, 2008).

The basic unit of fuzzy system is the fuzzy rule base. The components of the fuzzy logic system are used to apply these rules in a reasonable and efficient way. The fuzzy inference process combines the rules in the fuzzy rule base and then carries out a mapping. The most applications the input and output of the fuzzy system are real valued numbers, one must construct interfaces between the fuzzy inference process and the environment. These interfaces are the fuzzification and defuzzification process. To convert numeric data in real domain to fuzzy number in fuzzy called fuzzification whereas defuzzification is to convert the obtained fuzzy numbers back to the numeric data in the real-work domain.

3.2.2 FL Application

Yadav *et. al.* (2003) proposed fuzzy logic based for estimation of reliability improvement during product development. They provide a case study on automotive subsystem by using failure warranty data. It is great help to build fuzzy IF-THEN rules by using warranty data because it will present system behavior and determine the mechanism in system failure.

Verma, Srividya, and Gaonkar (2007) also have applied fuzzy in warranty area according to their book in fuzzy-reliability engineering. They discussed on software cost model with penalty, warranty and risk costs. They analyzed

on the trend of software release time. From their study, they found that cost trends can be worked out for other presumption levels. However these trends remain same with the only difference is the decreased cost flexibility at higher presumption levels.

Lee *et al.* (2008a) suggested different techniques which are suitable for modelling a two-dimensional warranty plan, and chooses a suitable fuzzy method to handle vague data. The techniques for the analysis of a two-dimensional warranty based on fuzzy inference shows more reasonable results. Alternatively, the rate of an increase in the number of claims changes more rapidly while the accumulated ratio of usage is higher. They presented a fuzzy deduction technique which is used to analyze the two-dimensional warranty based on usage and age.

Lee *et al.* (2008b) presented a fuzzy inference technique which is used for analysis of the two-dimensional warranty data based on usage and age. In fuzzy rules system, their used is formulated as IF-THEN rules, with one or more antecedents linked to a consequent via operators like AND, and OR operator. In this analysis, the change in age and the limit for usage are critical elements for evaluating the effect on the number and amount of the warranty claims. They stated that, according to the result of conventional studies, the accumulated ratio of the usage greatly affects the number of warranty claims. In addition, the ratio of increase in the number of claims varies with the change in age and usage while there exist various accumulated ratios of usage. In general, when the accumulated ratio of usage is high, the expectation of the warranty claim is higher than when the ratio is low.

Lee and Moon (2009) suggested different tools appropriate for modelling a two-dimensional warranty plan, and a suitable fuzzy method to handle vogue data. They study on fuzzy failure analysis of automotive warranty claims database using age and mileage rate. They developed a method to approximate number of claims for a specific sub-system of a vehicle at various combinations of use period and mileage limit of warranty. The purpose of estimation method being discussed is to be able to evaluate the impact of changes in time and mileage limits on number of claims. It is necessary to perform a multi-dimensional analysis in consideration of these elements simultaneously since there exist various elements affecting warranty claims.

Lee, Cho and Moon (2010) indicated a fast reasoning model based on fuzzy logic to handle multi-attribute and vogue warranty data. They recommended another generalization of the classical two-attribute warranty plan. They consider not only fuzzy lifetimes but also situations in which the usage is fuzzy as well. Particularly, they improve the fuzzy inference warranty of the two-dimensional warranty claims system. They used a heuristic approach, which can be applied for a wider set of membership functions in view of warranty data set. The suggested system is applied to a particular automotive warranty system in Korea. They claimed that the proposed fuzzy warranty system showed more reasonable result in the two-attribute automotive warranty application.

Lee *et al.*(2011) studied on application of fuzzy feedback control for warranty claim. They proposed a model that captures fuzzy events to determine the optimal detection of warranty claims data. The model considers fuzzy proportional integral derivative (PID) control actions in the warranty time series. This paper also transforms the reliability of a traditional warranty data set to a fuzzy reliability set that models a problem. The model is useful for companies in deciding what the maintenance strategy and the length of warranty period for a large warranty database. It also allows for an extended warranty price to be derived if the cost elasticity function is available.

3.3 Genetic Algorithm

3.3.1 Overview

According to Jones (2008), Genetic Algorithm (GA) is the most popular and most flexible algorithm. GA is one of the useful techniques in Artificial Intelligence which is based on the natural evolution. It is an adaptive method that uses the basis of natural selection and genetics which may be used to solve search and optimization problem. GA is very effective in finding a reasonable solution to a complex problem.Genetic Algorithm can also produce solutions close to optimal solutions. This is supported by Gen and Cheng (1996) which proved that GA gives better results than the traditional optimization method in solving real life problem.

The idea of GA was first introduced by John Holland in 1975 as a population-based algorithm. GA is an algorithm which makes it easy to search a large search space. Three main operators in GA process that were used to find near-optimization of specific problem are reproduction, crossover, and mutation. The fittest individual will survive more frequently and have high chances for reproduction.

3.3.2 GA Application

The application of GA has been studied in many different areas. For instance, Chaudhry and Luo (2005) reviewed the application of GA in twenty-one major production and operations management journals during the period of 1990 to 2001. They found that most researchers implementing GA in scheduling and facility layout topics. In literature, there have been few reviews of GA in warranty areas. Coit and Smith apply GA to optimize a reliability design

problem and it is proven that the GA optimization approach is robust for reliability design of complex systems.

Sohn, Moon and Seok (2009) proposed a dynamic pricing model for mobile phone in order to find an optimal pricing policy based on genetic algorithm. They found that GA gives higher profit in a series of optimal price for mobile phone. In the same year, Jin and Ozalp (2009) proposed a stochastic reliability model to minimize warranty cost through design for reliability. Based on the model, an optimization process is performed by using genetic algorithm.

Although GA takes plenty of time to provide a good result, they are robust in producing near-optimal solutions and it can handle varieties of objective function and constraint. The capability of GA in optimization problem becomes famous in research field.

4. Discussion

Here, we classified the results according to years and type of method used. Fig. 3 shows the soft computing techniques applied in warranty problems namely ANN, FL and GA. From the graph, fuzzy logic shows the highest number of published paper compared to the other two methods. Fig. 4 presents the published paper of soft computing methods in warranty area. Over ten years, the highest number of published paper is in 2009. Our analysis indicates that the number of research showed an unconstant trend from 2003 to 2012 which may be due to several reasons. In our opinion, this trend may be due to lack of exposure and not yet fully familiar in soft computing methods among warranty researchers.

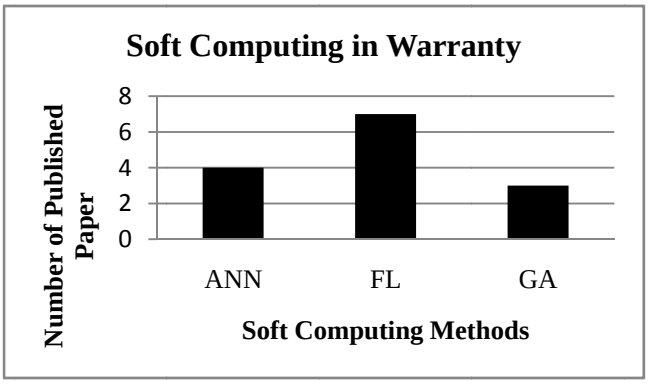

Fig. 3 Warranty problems considered in ANN, FL and GA.

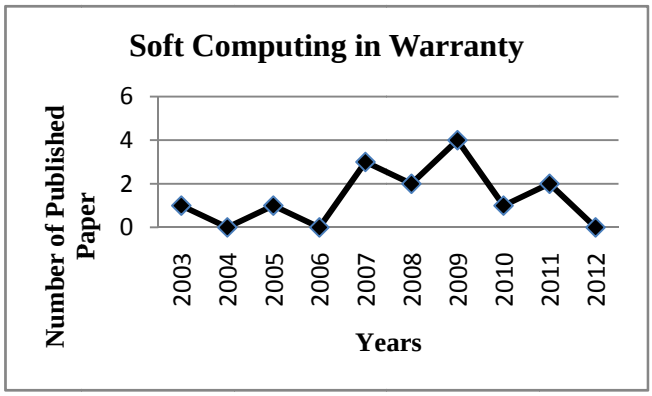

Fig. 4 Published paper of soft computing techniques in warranty area.

Although there are lack number of publications of soft computing methods in warranty area, it is not a sign that these methods cannot be applied. Instead, we strongly believe that there are chances for researchers to use soft computing techniques in addressing warranty problems. Thus, we would expect more warranty researchers will get involved in implementing the soft computing methods in warranty domain.

5. Conclusion

This paper provides a review of soft computing methods applied in warranty domain from 2003 to 2012. Our findings show that FL was widely applied in warranty problems. Also, we see that the application of soft computing methods in warranty domain is less given consideration. This paper will encourage people who are interested in conducting research to use soft computing as a method in solving warranty problems. Warranty problems also may be solved effectively by combination or hybrid computing such as neuro-fuzzy systems. This is supported by Aliev (2001) which indicates that the combinations of the components of soft computing are more effective due to different capabilities and can minimize their individual limitations.

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