Early Warning System for Complex Products Quality Improvement using Data Mining and Neural Network

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Abstract
Products quality improvements are important competitive tools for manufacturing enterprises to gain a sustainable competitive advantage. Through the use of quality control and management system, a lot of manufacturing firms have made great strides in improving quality, reducing waste and increasing productivity. Unfortunately, in many manufacturing companies, this is especially challenging for quality managers who are responsible for improving products quality. The purpose of this paper is to present an early warning system for complex products quality, which describes the value of quality improvements and provides the decision basis for quality managers. Firstly, the theory of data mining and neural network is introduced. Secondly, the implementation framework of an early warning system is proposed to predict product quality. Then, a case study of complex mechatronic products is developed by the approved warning methods and technology. Finally, we get some useful conclusions and give some suggestion.
Key words: QUALITY IMPROVEMENT, PRODUCT QUALITY MANAGEMENT, QUALITY, DATA MINING, NEURAL NETWORK

1. Introduction

In today's competitive manufacturing environment, investment in quality improving technology may be one of the best investments available to many companies. Because competition is rather intense nowadays, product quality also becomes more and more important for enterprises[1]. Across the world, manufacturing is undergoing great changes necessitated by fierce competition in an expanding global market. In order to be internationally competitive, we need to continue to raise the level of quality and productivity even higher[2]. Therefore, manufacturers devoted to ongoing quality improvement use many quality control processes and warning tools to obtain it. Indeed, one important focus of quality improvement in manufacturing enterprises involves all kinds of managerial staffs and other professionals. Specifically, using quality improvement techniques, managers strive to improve performance in key processes so that high levels of customer satisfaction are achieved[3]. There is also an overall belief that higher quality will result in lower product life-cycle costs, which may give allowances for price reduction and more importantly lower field failures once the product has reached its rightful destination. In a word, many manufacturing enterprises always pay attention to improving products quality for their customers.

On the other hand, quality improvement is essentially an enterprise's attempts at improving its products and quality control processes in terms of meeting the expectations of their customers. Recent research has shown that product quality is positively correlated with customer confidence and profit margins[4]. Many manufacturing enterprises have just

focused on quantity expansion of their products, but neglected quality improvement[5]. So product quality focuses on the voice of the customer, making sure the customers' needs and wants are reflected in the product or service[6]. In order to improve product quality, the manufacturing enterprises make strict policy of quality control and perfect after-sales service. In a general sense, implementing quality improvement initiatives to improve customer satisfaction can enable manufacturing firms to position themselves for success in today's global and increasingly competitive environment[7]. And the way customers perceive the value of a product is a function of the value of quality improvements, where it is assumed that the product function is positive and increasing. For pro- duct quality improvement, depending on the quality of life of the manufacturing enterprises have been their management idea[8]. So basically, quality improvement is essentially a mindset issue for manufacturing enterprises. Similarly, quality improvement is a well-known concept in the area of quality management and gains much attention from the academic society as well as companies, government agencies, academic institutions, civil society organizations, and so on[9]. Above all, the effect of quality improvement as a competitive weapon has not utterly been taken into account during the development of products.

In a word, quality assurance system development is a key ingredient for improving the quality performance of manufactured products. To summarize, it is conclusive that achievement and improvement of product quality is primarily dependent on the advanced forecasting technology[10]. Improving the early warning technology is an important part of the larger picture of improving product quality[11]. In addition, an early warning system can improve product productivity and improve quality. And the quality improvement is often employed after a monitoring process has identified a problem with a warning system used or a product produced by a manufacturing enterprise[12]. Moreover, the monitoring process and warning system may take the form of a quality control data, or it may be feedback from a customer or from some other source[13]. The quality improvement should be addressed as early as possible in the development lifecycle at early design stage. By describing the perceived customer value in a dynamic term, it becomes possible to derive an analytical model and early warning system that recognizes the implication of a company's efforts to improve the quality of complex products.

However, the effect of product quality improvement on a company's short-term profitability is difficult to assess. This article describes how quality controllers identify and measure data associated with product quality. Therefore, in this paper, product quality improvements are investigated in an exploratory way. The remainder of this article is organized as follows: Firstly, the implementation framework of an early warning system for complex products quality improvement was approved. Secondly, the theories and methods of data mining and neural network were introduced. Then, this paper presents a case study in an expensive advanced-technology manufacturer, where complex products were measured and predicted by using the approved new methodology, and the applicability of proactive quality warning system. After discussion of the results and the findings, the authors end with conclusions.

2.The implementation framework based on data mining and neural network

Better early warning system will lead to better quality improvement. Despite literature emphasizing the more mathematical modeling and predictive aspects of this theme subject, there are numerous methods and tools in existence to cope with product quality warning issues[14]. From an industrial and academic research perspective, many authors have distinguished numerous methods and tools which have a direct impact on the achievement and improvement of product quality[15]. There is also a general indication from the review of the literature that new quality warning tools and techniques evolve and are promoted separately as the tool for solving problems[16]. More and more, manufacturing enterprises consider quality control and warning system as an inevitable instrument to improve products and services in order to better meet customer needs[17]. In general terms, the design and development of an early warning system is a key factor in reducing cost, improving products quality, timely delivery against schedule, and delivery against customer requirements.

Unfortunately, manufacturing enterprises rarely give as much credence to justifications, such as cost reduction, quality improvement, or improvements in quality process and execution. The manufacturing enterprises can control quality processes across and between software and early warning systems to achieve continuous quality improvement[18]. This paper discusses how to use data mining and neural network to enrich and consummate the function of an early warning system for complex products quality improvement. The early warning system seeks input from quality control processes from design to production, sales and service at several different points. This

may come directly from quality engineers or from other monitoring processes.

This paper combines data mining and neural network by network mode and distributed database through advanced web base for quality level of complex products. First and foremost, the an early warning system for complex products quality improvement from other design of experiment based on the method of data mining and neural network in that it does not require any sample be made at design stage. In this way, we tried to supply ingredients for building the implementation framework of a general theory on product quality improvements by using data mining and neural network. Then, our early warning technology forms the basis for innovative customer servi- ces. We look forward to helping other quality management personnel use these systems for their own decision action and products quality improvement plans. The implementation framework of an early warning system for complex products quality improvement by using data mining and neural network was shown in Figure 1.

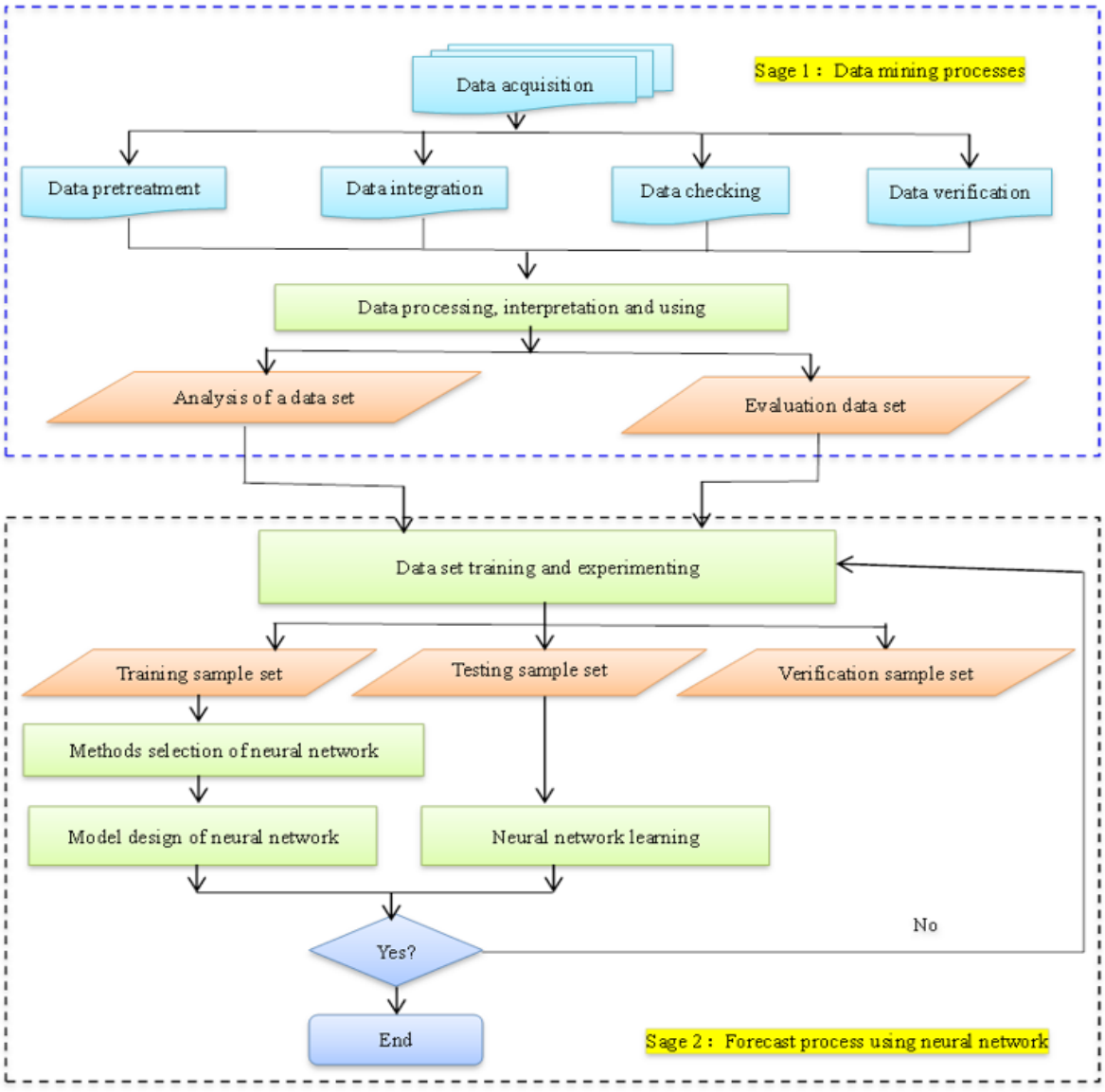

Figure 1. The implementation framework using data mining and neural network

In the first stage, data mining technology was used to resolve the problem of abundant data and scanty information as an effective approach. Quality data is also considered as a downstream quality characteristic, particularly measurable during the useful life of a product. Additional data provided by quality engineers may help clarify the nature of the problem, point to its root cause, or even identify additional symptoms of the quality problem. Once corrective action has been taken, new data may be collected quality engineers to accomplish check results to ensure that the quality problem has been eliminated. On the other hand, classification is an important subbranch of data mining, which can find out a model

describing a predetermined set of data classes or concepts as used to predict the class label for a test sample by using the method of neural network.

In the second stage, neural network technology was applied to automatic recognition and warning system. The addition to the early warning system reflects considerable quality improvement made by manufacturers, and an increasing interest in being part of the superior product strategy. Consequently, we define a product quality level as an improvement of the augmented product based on all the quality characteristics in the early warning system[19]. Through the optimization of components of a complex product that are redundant or cause of loss of functionality can be determined in the early development process. As far as we know, the reaction of competitors on quality improvements is established empirically for the first time. In recognition of the urgency to take action to improve complex products we are sparing no effort in introducing early warning systems. These early warning systems for complex products quality using data mining and neural network are all critical for quality improvement.

2.1. The basic theory of data mining

Generally, data mining is defined as mining the useful information from plenty of data. So data mi- ning is an advanced technology for automatic acquiring knowledge. Besides that, data mining is the process of applying all kinds of algorithms to data to uncover patterns that match a given context or query[20]. Large and complex data sets escalate traditional data mining techniques to new levels of processing demand. So, understanding data mining may be important to the implementation framework. The techniques of data mining can mine available information from the sea of data, eliminating the unavailable data mounting the file system[21]. As the research field expanded constantly, data mining has always been widely used in commercial bank, telecom industry, psychology, biomedicine, manufacturing industry, and so on[22, 23].

Moreover, the task of data mining is to finding useful information in large datasets. The function of data mining includes pattern matching, change detection, similarity search and detection, data annotation, semantics, and so on. Data mining is the transformation of large amounts of data into meaningful patterns and rules for decision makers[24]. Data-hungry applications such as automatic document managing system and data mining are cropping up everywhere, and access to stored information is essential[25]. As data miners drive deeper into ever-larger data warehouse databases, requirements for complex data types are translated into a need for more complex requirements[26]. Through building data warehouse, using data mining, can build up model from complicated strategic information, improve quality and increase efficiency.

This paper discusses how to use data mining to enrich and consummate the function of data processing. The data mining process of establishing the quality warning system is introduced, that could predict the complex products quality with the technological parameter. Thus, the early warning system for complex products quality improvement based on data mining technique consists of data storage, multidimensional data analysis, data mining, model storage, method storage, and data transport.

2.2. The neural network theory

The neural network can preferably solve the non-linear problem during quality control procedure. In order to eliminate affection caused by non-objection parameter, neural network data fusion is adopted as a standard. Generally speaking, any neural network consists of some number of interconnected nodes in the same way[27]. Therefor not only the neural network algorithm be more efficiently, but also the store place will be much less. The type of neural network includes polynomial function, neural networks, or radial basis function classifiers[28]. And a neural net that uses the rule is known as a perceptron, and the rule is called the perceptron learning rule. In general, any neural network consists of some number of interconnected nodes[29]. In the last few years, artificial neural network was widely applied in breakdown diagnosis, pattern recognition, signal processing, pattern classification, and so on[30-32].

In this paper, a new approach is put forward for early warning system based on the multi-layer artificial neural network model. According to the complexity and non-linearity of early warning system, the data mining and neural network are applied to forecast complex products quality improvement. The models for predicting the complex products quality have been established with the artificial neural network. By means of the trend prediction analyses with neural network based early warning system and the artificial intelligent prescient maintenance system, automatic online judging and fault forecasting to the conditions of the complex products quality can be attained in this paper.

Then, the basic algorithm of neural network for achieving the above objectives is discussed in the following section.

In the standard back propagation (BP) neural network, the k is the number of iterations, the weights of

each layer and the press type modified threshold can be defined by:

$$x(k+1) = x(k) - \alpha g(k) \quad (1)$$

Where $x(k)$ represents the connection weight vector or threshold at all levels.

$$g(k) = \frac{\partial e(k)}{\partial x(k)} \quad (2)$$

Where k represents the weight of threshold gradient vector, which is also the output error for neural network. The opposite direction of gradient minus sign is represented by the gradient of the decline in the direction. And α is the learning rate in the process of training.

So, the input sample sets are normalized as:

$$x(k) = \left(x_1(k), x_2(k), ..., x_n(k)\right) \quad (3)$$

In the same way, the input sample sets are then normalized as:

$$d(k) = \left(d_1(k), d_2(k), ..., d_q(k)\right) \quad (4)$$

Then, the input hidden layer neurons can be calculated as follows:

$$hi_h(k) = \sum_{i=1}^{n} w_{ih} x_i(k) - b_h \quad (5)$$

Where $h = 1, 2, ..., p$, $x(k)$ represents the connection weight vector of hidden layer.

Next, the output hidden layer neurons can be calculated in the following:

$$ho_h(k) = f(hi_h(k)) \quad (6)$$

The training study pattern is given as follows:

$${}^{l}w_{ij}(t+1) = {}^{l}w_{ij}(t) - \lambda \frac{\partial e_{all}}{\partial {}^{l}w_{ij}} \quad (7)$$

Where $\lambda > 0$, w is the connection weight of the neural network.

Moreover, a new quantitative criterion, called error rate, is proposed by the following equation:

$$e_p = \frac{\sum_i (d_{ip} - y_{ip})^2}{2} \quad (8)$$

In order to achieve robustness, the total error rate is defined by:

$$e_{all} = \sum_{p=1}^{P} e_p \quad (9)$$

The algorithm can be done when the error reaches the preset accuracy or learning set number is greater than the maximum times. The consistency of learning convergence condition of neural network and final control target was proved by this way.

3. A case study

In this case study, we will develop an early warning system for complex products quality improvement based on data mining and neural network. This paper covers three aspects: the process method of data mining, the research of forecast model and the software development of product quality forecast. In waiting for a definite technical solution of the prediction problem, a careful monitoring and early warning system of high-speed stamping machine had to be performed in this paper. Firstly, establishment of the early warning system for continuous information gathering is necessary. Based on artificial neural network theory, work conditions of transmission system of high-speed stamping machine are monitored intelligently and the failures are diagnosed via collecting and processing machine's fault frequency. Then, a simple and effective method of fault diagnosis is to classify the transmission systems in different fault conditions by using neural networks and data mining.

The paper briefly introduced the approved early warning system of quality improvement transmission system of high-speed stamping machine made in Chinese manufacturing enterprises. The major research tasks for the proposed system aims to deal with the input data by the mathematical model which consists the dynamic quality assessment model, dynamic forecasting model and dynamic quality warning model.

The main software function should be the data flow control between data collector, computer memory and data storage. At the same time, the data collecting system are made up by sensor, intelligent instrument, data collector, and computer and configuration software. The original values of fault frequency of transmission system of high-speed stamping machine were shown in Table 1.

This raw material was processed into useful information. Computer cannot deal with the data unless it is installed the software system. Then, we introduce and generalize the technology theory of the data mining development process, the structure system of the data mining, after that, we can get our data on line from the processing systems. The results of warning values of fault frequency of transmission system are shown in Table 2 below.

Table 1. The original values of fault frequency of transmission system

Time	Total fault frequency of transmission system	Fault frequency of clutch	Fault frequency of motor	Fault frequency of bar linkage
T_1	92.36%	87.54%	78.32%	90.21%
T_2	94.12%	88.13%	79.21%	91.28%
T_3	91.85%	86.12%	80.24%	91.56%
T_4	96.46%	87.01%	81.79%	92.34%
T_5	95.17%	89.15%	78.12%	91.78%
T_6	97.38%	89.52%	86.58%	92.04%
T_7	98.01%	89.77%	87.31%	93.17%
T_8	94.36%	90.12%	88.78%	93.89%
T_9	98.61%	91.34%	89.21%	94.13%
T_{10}	98.76%	89.03%	90.67%	92.57%
T_{11}	98.97%	88.69%	91.14%	90.28%

Table 2. The warning values of fault frequency of transmission system

Time	Total fault frequency of transmission system	Fault frequency of clutch	Fault frequency of motor	Fault frequency of bar linkage
T_2	0.0191	0.0067	0.0114	0.0119
T_3	-0.0241	-0.0228	0.0130	0.0031
T_4	0.0502	0.0103	0.0193	0.0085
T_5	-0.0134	0.0246	-0.0449	-0.0061
T_6	0.0232	0.0042	0.1083	0.0028
T_7	0.0065	0.0028	0.0084	0.0123
T_8	-0.0372	0.0039	0.0168	0.0077
T_9	0.0450	0.0135	0.0048	0.0026
T_{10}	0.0015	-0.0253	0.0164	-0.0166
T_{11}	0.0021	-0.0038	0.0052	-0.0247

Next, the neural networks technology is used in the practice of settlement calculation for an early warning system of fault frequency for transmission system. The values of the training error of BP neural network were shown in Figure 2.

As seen in Figure 2, the x-axis represents the number of Training-Blue and Goal-Black, y-axis represents Epochs, the performance is 0.000154447, and the Goal is 0.001.

Thus, we can get the optimum predictive value by using BP neural network in the following:

y = (0.0317, -0.0363, 0.0240, -0.0264, 0.0192, -0.0002, -0.0245, 0.0333, 0.0055, 0.0050).

The presented method applied to fault frequency forecasting, the results show that the forecasted errors were in an acceptable range.

e =(-0.0126, 0.0122, 0.0262, 0.0130, 0.0040, 0.0067, -0.0127, 0.0117, -0.0040, -0.0029).

And the total square error was given as:

Res = 0.0393.

Next, the effectiveness of the proposed model is tested by comparison of the monitoring data with BP neural network. The values of the training error of BP neural network were shown in Figure 3.

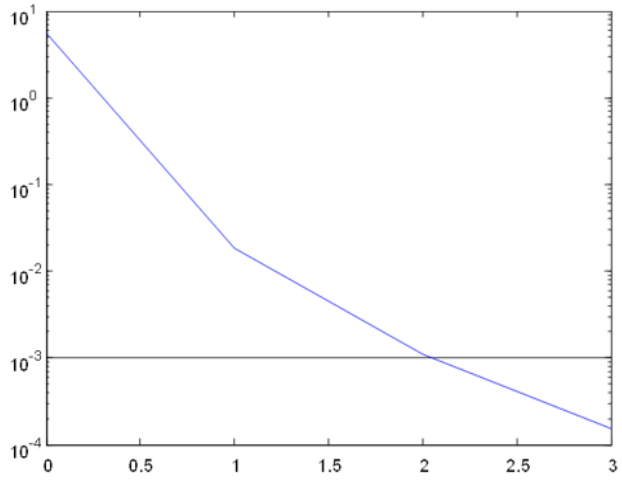

Figure 2. The values of the training error of BP neural network

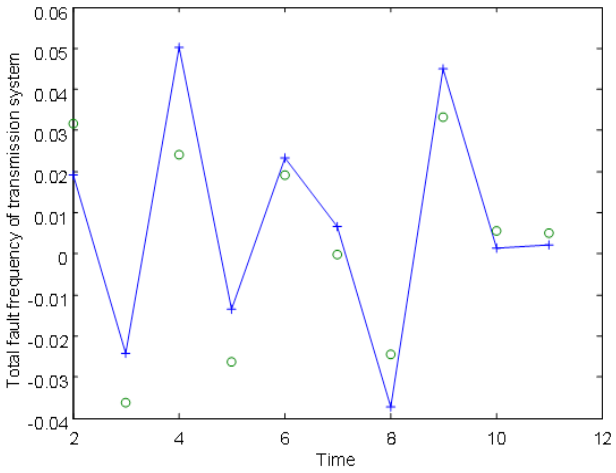

Figure 3. The values of the training error of BP neural network

As can be seen from the case study, the improving neural network subsection prediction model can take advantage of simple network structure and get a good modeling effect by varying one or more of the parameters. Pattern classification of flaw can be also carried out with BP neural network and the selection of fault characteristics. Failure identifying of transmission system of high-speed stamping machine in differ working state has been realized, in order to realizing auto failure diagnosis synthesized neural network failure diagnosis means has been put forward in this case study. The result showed that layered multi-subnet neural network was suitable to online product quality warning.

4. Conclusions

The objective of this article was to give a comprehensive account of product quality improvement and achievement across a number of different dimensions. In this way, achieving high levels of customer satisfaction through quality improvement should be one of the top priorities of any manufacturing company. This paper has developed and discussed an early warning system for complex products quality based on data mining and neural network, and presented a proactive way of improving product quality. Hence, warning quality performance should not just involve costs viewed from a producer's perspective, but it should also be about warning quality performance in terms of value seen from customers' perspective. Thus, the purpose of this paper was to suggest a proactive quality warning methodology as a mechanism to indicate if product quality improvements were valuable at high level. The new method and model using data mining and neural network have been theoretically developed and tested in the case study. In fact, we could finally identify different patterns of quality improvement action and warning method for complex products in this paper.

This paper has described a new method for warning product quality and transforming the theoretical predictions into value of quality improvements. The early warning system could provide decision information that would not only help improve existing products quality, but might aid in new product design as well. In future research, more empirical-tests will be needed to give further insights regarding practical implementation problems in other complex products.

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Intelligent Operation and Maintenance Monitoring System Based on ITIL Framework

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