Reliability indicators analysis of industrial enterprises products by using neural networks

Ya I Shamlitskiy, S N Mironenko, A V Devyatkov and N V Bezrukova

Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Ave., Krasnoyarsk, 660037, Russia

E-mail: 2538357@mail.ru

Abstract. This article discusses the organizational principles of industrial products quality control, a review of data on the purpose of artificial neural networks, as well as the possibility of their application to solving the task of reliability indicators analysis. In the study, the reliability indicators of refrigeration equipment were analyzed and an algorithm of their analysis is given. The proposed algorithm can be useful for output goods quality control monitoring, as correction of defects in production requires considerable material costs. The algorithm will allow taking timely actions in case of deviation of the specified parameters and as a result reducing the costs of the enterprise. This algorithm is not tied to refrigeration equipment manufacturing and can easily be scaled to other manufacturing. In the future, it is possible to expand this direction in the form of software development for quality control of the output goods.

1. Introduction
Industrial enterprises are an integral part of the modern world. The high demand for the products of industrial enterprises ensures a constant inflow of money, as a result of which the number of industrial enterprises is very large and the level of competition is also high. For consumers, this level of competition means a wide range of different products with varying price, quality and other characteristics. Thus, in order to remain competitive, an industrial enterprise needs not only to reduce the amount of production costs, but also to improve the quality of the product and its reliability.

The analysis of reliability indicators is closely related to quality control, because often the quality of the material or the result of work process affects reliability indicators. In order to better understand the issue, it is necessary to understand what quality control is and the principles of its implementation.

2. Quality control at the enterprise
Any goods, products have certain properties which in turn characterize quality. Among the many properties and criteria of different products can be distinguished a number of general criteria, which are established in regulatory documents: GOST (state standard), technical regulations, standards, technical conditions for specific types of products. The work of the enterprises on quality control is carried out in order to confirm compliance of a particular product unit with the requirements presented in the regulatory documentation [1].

One of the most important tasks of quality control at the enterprise is to identify and separate low-quality products from high-quality ones. Depending on the effectiveness of the quality control system we can judge on the ability of the enterprise to prevent or reduce failures and errors in the operation in a timely manner, which in turn guarantees fewer material, resource costs and financial losses.
Many processes are subject to quality control, including production, transportation, storage and shipping of products to the consumer, so these measures can be taken to ensure a stable level of product quality. Such activities provide an opportunity to track specific performance at different stages and compare them with regulatory requirements.

The job of the quality department employees, who are directly involved in the control processes, is to carry out tests on the product, in order to identify the actual values of a parameter, for its subsequent comparison with the established (specified) requirements.

Despite the fact that many enterprises have quality control departments, the problem of defective products remains relevant. Therefore, there is a need for more productive methods of product quality control. One possible option to increase productivity is to create a quality control system based on a neural network.

Let us consider the possibility of using a neural network to produce refrigeration equipment. In this case, the system will need the following indicators:

- Temperature indicators of refrigerating and freezing compartments;
- Electrical parameters (power, voltage);
- Compressor operation, which implies timely start-up and its failure interval;
- Indicators of durability, reliability, stability of technical characteristics;
- Noise level;
- Absence of gaps and displacement in doors and other parts.

3. Materials and methods
For analysis of product quality indicators, we will use the Weibull distribution, as it most accurately describes the mean time between failures for the produced product. The Weibull distribution is a two-parameter distribution. It is universal because, with the appropriate parameter values, it turns to normal, exponential, and other kinds of distributions. Distribution density is described as

$$f(x) = \alpha \lambda x^{\alpha - 1} \exp(-\lambda x),$$  \hspace{1cm} (1)

where $\alpha$ is a shape parameter; $\lambda$ is a scale parameter; $e = 2.71828$ is the base of the natural logarithm.

The formula for the cumulative distribution function of the Weibull distribution is

$$F(x)=1 - \exp(-\lambda x\alpha).$$ \hspace{1cm} (2)

The Weibull reliability function is

$$P(x) = \exp(-\lambda x\alpha)$$ \hspace{1cm} (3)

The wide application of the Weibull distribution is due to the fact that this distribution is generalizing the exponential distribution and it contains an additional parameter $\alpha$. Selecting parameters $\alpha$ and $\lambda$ the right way, it is possible to obtain the best compliance of estimated values to the experimental data in comparison with the exponential distribution which is one-parametrical (parameter $\lambda$).

Thus, for products that have latent defects, the danger of failure is most important in the initial period, and then quickly falls. The reliability function for such an article is well described by the Weibull distribution with parameter $\alpha < 1$. On the contrary, if the product is well controlled in manufacture and barely has any latent defects, then the reliability function is described by the Weibull distribution with parameter $\alpha > 1$. At $\alpha = 3.3$, the Weibull distribution is close to normal.

4. Artificial Neural Networks
After determining the indicators, consider information about artificial neural networks and the areas of their application.

Artificial neural network (ANN) is a mathematical model, as well as its software or hardware embodiment, built on the principle of organization and functioning of biological neural networks -
networks of nerve cells of a living organism. ANN is a system of connected and interacting simple processors (artificial neurons). Such processors are usually quite simple (especially in comparison with processors used in personal computers). Each processor of such a network deals only with signals it periodically receives and signals it periodically sends to other processors. And yet, being connected to a sufficiently large network with managed interaction, such individually simple processors are able to perform rather complex tasks together [2].

A distinctive feature of neural networks is that they cannot be programmed in the usual sense, for successful implementation of neural network it is necessary to train it. Learning is one of the main advantages of neural networks over traditional algorithms. From a technical point of view, the essence of neural network training is to find the coupling coefficients between neurons. In the course of training, the neural network is able to detect complex dependencies between input data and output data, as well as perform generalization. This in turn means that if properly trained, the neural network will be able to return the correct result even in the absence of a series of data in the learning sample, as well as regardless of the completeness and distortion of the data.

ANN can be used quite widely in an industrial plant, but below we will look at those areas of its application that may relate to the stages of quality control. Let's move to the areas of application of ANN and the possibility of applying a certain area to industrial enterprises:

1. **Image recognition and classification** - Images can be different: text symbols, images, sample sounds, etc. Network training offers different image samples, indicating which class they belong to. The sample is generally represented as a vector of characteristic values. At the same time, the set of all characteristics must uniquely identify the class to which the sample belongs. If there are insufficient characteristics, the network can associate the same sample with multiple classes, which is incorrect. At the end of the network training, you can analyze previously unknown images and receive an answer about their belonging to a certain class. The topology of such a network is characterized by the number of neurons in the output layer being generally equal to the number of classes to be determined. A correspondence is established between the output of the neural network and the class it represents. When a network is analyzing an image, one of its outputs should show a sign that the image belongs to this class. At the same time, on other outputs there should be a sign that the image does not belong to this class. If there is a sign of belonging to a class on two or more outputs, it is believed that the network is “unsure” of its response. This application area can be applied at the stage of the final quality check for compliance of the appearance of the finished product with all kinds of advertising materials, which can affect the aesthetic perception of the product by the customer, but does not affect the reliability of the product.

2. **Clustering** - Clustering refers to partitioning multiple input signals into classes, with neither the number nor the characteristics of the classes known in advance. Once trained, such a network is able to determine which class the input signal belongs to. The network may also signal that the input signal does not belong to any of the allocated classes - this is a sign of new data that is missing in the training set. The correspondence between the classes allocated by the network and the classes existing in the subject area is established by human. This application area is useful for faster identification of the production stages at which the defect occurred, but this depends on the correct allocation of classes. Application is the most effective with large volumes of monitored parameters.

3. **Prediction** - The ability of a neural network to predict directly follows from its ability to generalize and highlight hidden dependencies between input and output data. After training, the network is able to predict the future value of a certain sequence based on several previous values and/or some current factors. The application of this area may allow to predict the value of a parameter in the early stages of production, if the system is correct, it will be possible to change (adjust) the production process or to remove subject to defect products from production at all, which will reduce money and resource costs.

The most difficult step in solving the problem with the help of neural networks is the selection of
data for training and its processing. The training dataset must meet several criteria:

- **Representativeness**: data should illustrate the true state of affairs in the subject area;
- **Consistency**: Conflicting data in the learning sample will result in poor network learning quality.

To transmit source data to network inputs, it must be converted to a network-readable format. A data file consists of entries; each is called a learning pair or learning vector. The composition of the learning vector can be defined as the value for each network input, and based on the type of learning (with or without a teacher), the value for each network output. In order to avoid incorrect network training, the data should be carried out through the normalization procedure. Normalization is performed when data of different dimensions is transmitted to different inputs of the network.

For example, the first input of the network is working with values from zero to one, and the second input is working with values from one hundred to one thousand. If the normalization procedure is not performed, the value supplied to the second input will always have a significantly greater impact on the network output than the values at the first input. When you normalize the dimensions of all input and output data, they are combined together.

In order to solve problems related to quality control, it is necessary that the neural network can obtain data about each parameter and compare it with the required values, which in turn must be predetermined. In case the actual value of a parameter goes beyond the allowable limits, the neural network should move to a deeper level, where by means of expert assessments it is determined whether the deviation of this parameter is critical and whether this unit of product should be considered defective.

Depending on the task and available data, the network type is selected for training. The supervised learning type implies that expert assessment must be present for each sample element. In some cases, especially when the data array is too large, it is not possible to provide such assessments; in such cases networks capable of unsupervised learning are used. It is necessary to take into account that in some tasks (such as time series forecasting), the initial data already contain an expert assessment.

Data representing a training sample is viewed by the neural network in a certain order; this order can be sequential, random, etc. Also, different networks may have a different number of views, some may view the sample once (mostly unsupervised learning networks), and others many times (mostly supervised learning networks). One complete run through the sample is called the learning era. In the process of learning with a teacher, the initial data is divided into training and test data, this division can be absolutely arbitrary.

Training data is supplied to networks for training, and test data is used to calculate network error (test data is never used for network training). Thus, if the error is reduced on the test data, the network does perform generalization. If the error on the training data continues to decrease and the error on the test data increases, then the network has stopped generalizing and simply “remembers” training data. This phenomenon is called network retraining or overfitting. In such cases, training is usually discontinued. Other problems such as paralysis or network getting into the local minimum of the error surface may occur during training. The main difficulty of neural network training is the inability to predict the appearance of errors [3].

That being said only applies to iterative algorithms for finding neural network solutions. For them, nothing really can be guaranteed and neural network training cannot be fully automated. However, along with iterative learning algorithms, there are non-iterative algorithms that have very high sustainability and allow the learning process to be fully automated.

5. **The use of artificial neural networks in the enterprise**

Now let us consider the use of an artificial neural network to solve the problem of improving the quality and as a result improving the reliability of industrial enterprise products. Implementation of such a system in production will take quite a long period of time, successful implementation will require coherent and competent work of all participants from programmer to employee of quality department. First, it is necessary to determine the exact list of data that will be monitored and transmitted to the inputs of the neural network. Once all the data is determined the next step is to train the neural network,
in this case it will be necessary to assist the employees of the quality department in drawing up expert assessments for the criteria.

It is also necessary to equip a test station that will be used to obtain data on product reliability indicators by means of their prediction by a neural network. Thus, it is possible to bring the assumed algorithm of work on prediction of reliability indicators taking into account the use of ANN, this algorithm is shown in Figure 1.

![Algorithm of enterprise operation using neural network.](image)

Operation of neural network at the stage of analysis and output of results of its operation consists in comparison of real values with established values. Then, based on the conditions of normal operation of the product, the neural network predicts parameters of reliability, durability and others, for a specific product. If these results meet the requirements of the designer, marketing department and management department, the data on successful manufacturing is transmitted to the relevant departments.

Note that this algorithm is only working when the neural network is properly trained and meets all user requirements (accuracy, speed, etc.).

After completion of the training process, it is necessary to check the correctness of this training, for this purpose it is necessary to provide the neural network with data for a certain period and compare the results of the neural network with the real results, if they are as close as possible, the training process can be considered successful. It should be understood that the criteria for the correctness of neural network training primarily depend on the task and the limit of permissible inaccuracies established by the enterprise, the customer, etc.

Thus, it is not possible to answer unambiguously how close the result of the neural network should be, in some cases it is possible to limit itself to ninety-five percent, and in some cases the accuracy should reach almost one hundred percent. After training the neural network, there will be a need to reorganize the production processes, the essence of which will be to provide the instrumentation with all stages of production, which will allow to quickly transmit data to the inputs of the neural network, where by comparison with the threshold values the quality of execution of each process will be defined. This will allow the problem processes to be identified and this information transmitted to the managers.
6. Conclusion
According to the suggested algorithm and on the basis of neural network operation it is possible to plot the graph on product reliability. Figure 2 shows the example of plotting distribution graphs based on enterprise archive analysis.

![Graph showing distribution of defects](image)

**Figure 2.** Example of plotting distribution graphs based on enterprise archive analysis.

The Weibull distribution plot, actual product defect value and forecasted defect are shown on the chart. All this will make it possible to predict product failures and take preventive measures.

References
[1] GOST R ISO 9001-2015 Quality management systems. Requirements (Approved by Order of Rostekhregulirovanie of 28 September 2015 art. 1391)
[2] Glassner A 2019 *Deep Learning without Mathematics. Vol. 1. Basics* (Moscow: DMK-Press) p 578
[3] Kadurin A A, Nikolenco S I and Arhangel’skaja E V 2018 *Deep Learning. Immersion in the World of Neural Networks* (St. Petersburg: Piter) p 481
[4] Zhang X, Li Y, Ran Y and Zhang G 2020 Stochastic models for performance analysis of multistate flexible manufacturing cells *Journal of Manufacturing Systems* 55 94-108
[5] Gyulai D, Pfeiffer A and Monostori L 2017 Robust production planning and control for multistage systems with flexible final assembly lines *International Journal of Production Research* 55(13) 3657-3673 doi: 10.1080/00207543.2016.1198506
[6] de Kok T G 2018 Modelling short-term manufacturing flexibility by human intervention and its impact on performance *International Journal of Production Research* 56(1-2) 447-458 doi: 10.1080/00207543.2017.1401750
[7] Jawahar N and Subhaa R 2017 An adjustable grouping genetic algorithm for the design of cellular manufacturing system integrating structural and operational parameters *Journal of Manufacturing Systems* Part 1 (44) 115-142 doi: 10.1016/j.jmsy.2017.04.017
[8] Naderi B and Azab A 2015 Modeling and scheduling a flexible manufacturing cell with parallel processing capability *CIRP Journal of Manufacturing Science and Technology* 11 18-27 doi: 10.1016/j.cirpj.2015.05.006
[9] Roessler M P and Abee E 2015 Enhancement of the overall equipment effectiveness measure: A contribution for handling uncertainty in shop floor optimisation and production planning *International Journal of Industrial and Systems Engineering* 20(2) 141-154