Equipment quality management based on a mathematical model to detail its life cycle

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Abstract. The equipment quality management program at the production stage provides for the use of statistical information on the most characteristic conditions of equipment during its operation as initial data. In this assessment, both operational and reliability characteristics of the equipment are subject, which are the criteria for establishing mutual compliance of the conditions of its production with real operating conditions. In accordance with the foregoing, the basis for the implementation of equipment quality regulation is its failure flow of abnormally high intensity. At the same time, two particular cases of high failure rate are distinguished: as the first one, a mismatch of the production conditions of the equipment with the current technical requirements is accepted, the result of which is products with a hidden factory defect. As practice shows, it is impossible to establish its presence with high accuracy as a result of performing input control, which leads to equipment failures during operation at various operating times. The second one is the discrepancy between the production conditions of the equipment and the actual operating conditions. In this case, due to the design features, the equipment is not able to withstand typical operational loads, which causes a high failure rate.

A necessary step in creating a methodology for controlling the quality of equipment at all intervals of its life cycle is to determine the likelihood of a defect in the equipment during its production, given the complexity of technological processes, as well as the phasing of production.

To determine the mathematical probability of a defect, each of the complex composite technological processes is divided into a group of small simple subprocesses.

For example, consider a group of defects of a hidden factory nature. The product manufacturing process is conditionally divided into a subprocess system. In a simplified form, this diagram is presented in figure 1.

The following steps are included in this diagram [1,2]:

- stage of the supply of raw materials (components to the plant);
- stage of diagnosis of incoming raw materials (input control);
- the stage of assembly of the product from components;
- product testing phase;
- the stage of transportation of the product to the consumer (to the place of production).
Moreover, the full probability of a positive or negative result for the entire technological process is determined on the basis of the conditions for using particular models to determine the balance of probabilities at individual stages of production [3,6]:

- the cubic probabilistic model is used to describe technological subprocesses that have two input parameters (in this case, the possibility of transmitting to the stage under consideration positive and negative results from the previous production stage);
- the tetrahedral probabilistic model is used to describe technological subprocesses that have one input parameter (in this case, the possibility of transmitting to the considered stage a positive or negative result from the previous production stage).

![Diagram of a mathematical model for detailing the life cycle of equipment.](image)

**Figure 1.** Diagram of a mathematical model for detailing the life cycle of equipment.

As can be seen from figure 1, for this case, two models are proposed for describing each individual stage: depending on the number of input parameters, this is either a cube or a tetrahedron. Accordingly, for a cube, the number of input parameters is two, for a tetrahedron - one. In this case, the input parameter is a positive or negative outcome that goes from the previous subprocess to the current one. The output parameter is a positive or negative outcome that moves from the current subprocess to the next one (by default, for each model, the number of output parameters is always equal to two). Here a positive outcome is the absence of a defect, a negative outcome is its presence. It is worth noting that in this case there is a statistical probability [1], since each of the described events will not be considered equally probable, thus, the concept of “event probability” will be absent in this research, and the concept of
“event frequency” will be used instead. Let us consider the cubic probabilistic model presented in figure 2.

In this case, the input parameters are some of the variables L and L’:

- L is the particularity of the event, consisting in the absence of a defect in a previous subprocess;
- L’— particularity of the event, consisting in the presence of a defect in the previous subprocess.

These particulars are located on the upper face of the cube at the corner points, respectively, so that the two corner points located on the left have only a positive outcome, and the two corner points located on the right have only a negative outcome [3].

The middle parameters will be the variables x, x’, x”, characterizing the particular absence and appearance of defect at this stage.

Respectively:

- x – the particular event, which consists in the absence of defect in this subprocess;
- x’ – is the particularity of the event, which consists in the appearance of defect in this subprocess due to the technological nature;
- x” – is the particularity of the event, consisting in the appearance of defect in this subprocess due to the human factor.

These variables are located on the lower edge of the cube at the corner points so that the two corner points located on the left have only a positive outcome, and the two corner points located on the right have only a negative outcome.

Since the particulars L and x, x’, x”, as well as L’ and x, x’, x”, are parts of independent events, the output parameters V and V’ can be represented as the products of the corresponding particulars [2]:

- V is the output parameter characterizing a positive outcome for a given subprocess (that is, the absence of a defect at the exit of the stage);
- V’ – output parameter characterizing a negative outcome for a given subprocess (i.e., the presence of a defect at the exit from the stage).

Note that the corresponding products of the frequencies on the extreme left side of the cube (that is, the edges L x and L x) give only a positive outcome, while the products of the corresponding partial on the right side of the cube (that is, the edges L’x’ and L’ x”) - only a negative outcome. Based on this, we can conclude that the left extreme side of the model will characterize 0% of the resulting defect, while
the right extreme side of the model will characterize 100% of the resulting defect, which can also be seen in figure 2.

As can be seen from figure 3, at the intersection of the lines L · x' and L · x'', a plane forms, which also characterizes the presence of 100% occurrence of defect. That is, at this stage, we can conclude that the model segment lying below this plane has a certain number of both positive and negative outcomes, while in the segment of the model lying above this plane an extremely negative outcome is possible (that is, obtaining as an output parameter variable V', which will indicate the appearance of a defect at this stage). In figure 3, the red line marks the approximate direction of the gradient vector of the function q, which describes the growth of a particular occurrence of a defect in a given subprocess of part production.

\[ L \cdot x + L \cdot x' + L \cdot x'' + L' \cdot x + L' \cdot x' + L' \cdot x'' = V + V' \]  

Equation (1) describes all possible combinations of the products of the input and middle parameters, which will lead to the appearance of two output parameters V and V'.

Consider a tetrahedral model, which is characterized by the same input, middle and output parameters: x', x'', x, L, L', V, V', but in contrast to the cubic model described in the above paragraph, there is only one input parameter, in this case it is L or L'.

A graphical representation of the tetrahedral mathematical model is shown in figure 4.
Based on figure 4, we can conclude that the facet of the tetrahedron painted in blue characterizes the absence of an operation defect (that is, its frequency of occurrence of the defect is zero), the face painted in red indicates the presence of an absolute occurrence of an operation defect (that is, its frequency of occurrence is 1). The vector-gradient of the function $q$ characterizing the increase in the frequency of occurrence of an operation defect is respectively directed from any point on the face highlighted in blue, perpendicular to absolutely any point on the face highlighted in red.

The product of the corresponding frequencies at the nodal points of a certain edge determines the output parameter of this model (as well as its frequency of occurrence):

$$V=L \cdot x, V' = L \cdot x', V = L \cdot x''$$

As a result, the equation describing the output parameters of the tetrahedral model takes the form:

$$L \cdot x + L \cdot x' + L \cdot x'' = V' + V$$  \hspace{1cm} (2)

The next step is the conduct of correlation and regression analysis for these conditions with parameters that will characterize the frequency of the event (i.e., input, median, output parameter) [4, 6, 7]. The final stage of the correlation and regression analysis is the construction of a final table of the priority of the influence of an independent parameter on the dependent parameter, taking into account the results of the correlation and regression analysis, as well as assessing the significance of the relationships established between the various combinations of “output parameter - input parameter”, “output parameter - middle parameter”. After conducting a correlation analysis, the corresponding combinations of the analyzed parameters are arranged according to the priority of influence (based on a decrease in the correlation coefficient, and as a result of a decrease in the degree of connection).

Thus, we can conclude that if there is sufficient information about the main shortcomings and failures of technological processes during production of an enterprise, this methodology can allow a fairly accurate assessment of the main factors that affect the appearance of factory defects, the likelihood of occurrence at the exit from technological process and, as a result, evaluate the total amount of defective products, which is expected to be delivered to the production facilities of the customer company [5].

References
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