Choosing a quality management method

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Abstract Product quality management in a modern enterprise is carried out using a set of methods. A large number of methods allow controlling product quality not only after a product is manufactured, but also during the entire production process, which is the most valuable in conditions of limited resources. The equipment is an integral part of the processes, and how well it works also depends not only on the quality of the products, but also the company's ability to deliver the goods at exactly the time that is required (Just in time), and exactly in the amount that is required (KANBAN system). Since today the current issue for organizations is the optimization of equipment operation, the information management system of prevention of equipment failures is developed and substantiated in the article.

Keywords: product quality management; business processes; production equipment; control system; research of operations.

1. Introduction

Quality is a multidimensional concept that requires combining the creative potential and practical experience of many specialists. Reaching one quality level, an enterprise starts thinking about how to reach the next level, because every day the demands of consumers change and it is necessary to satisfy them, and even better not only to satisfy existing requirements, but to anticipate them.

Product quality management in a modern enterprise is carried out using a set of methods. An extensive arsenal of methods allows controlling product quality not only after the product is manufactured, but also during the entire production process, which is the most valuable in conditions of limited resources.

Accordingly, product quality management, as well as the methods by which management is carried out, are relevant and are of particular importance in the management cycle.

The purpose of this article is to develop and justify the information and control system for preventing equipment failures.

Historically, the approaches to assessment and quality assurance have gone through the following stages in the world:

Stage 1 — 1905, the period of the formation of the school of scientific management. F.Taylor’s system; product quality was assessed at the level of compliance;

Stage 2 - 1924-1931, statistical methods and evaluation of product quality for compliance with the requirements of standards, as well as the achievement of process stability;

Stage 3 - 1950, integrated quality management; product and process quality to ensure customer satisfaction;

Stage 4 — 1980, universal quality management; quality as customer satisfaction and employee needs;
Stage 5 - 1990, Total quality management (TQM); quality as the satisfaction of the requirements and needs of society, consumers, employees, owners;

Stage 6 - 2000, the model for improving the European foundation for quality management (EFQM), the concept of business excellence.

Any enterprise that wants to be competitive and remain so, putting consumer interests on a par with its interests, strives to create products that meet the maximum level of quality or be close to it with minimal costs both for themselves and for their consumers.

Specifying process requirements allows an organization to identify areas that do not allow processes to work correctly. Having identified the problem, the organization can also identify the causes of its appearance and eliminate them at this site and other similar ones. To identify the causes of deviations, one can use the following methods: brainstorming, cause-and-effect diagram, bottleneck analysis, root cause analysis, 6 causes of productivity decline, and to control the process, there are control cards that allow to ensure that the process does not go beyond the limits of tolerances.

Speaking of continuous improvements, the first thing that comes to mind is customer satisfaction, the organization’s desire to anticipate consumer expectations, which is true, but in part. Improvement does not always mean the introduction of something new or exceptional satisfaction of customer requirements, because deviations may occur at the very stages of manufacture of a product or service, which consumers not even guess, the final result is important for it to comply with safety standards, to be easy to use, and what happens during manufacture, it does not concern. However, if an enterprise wants its goods to be of high quality and at the same time not materially costly both for it and for the consumer, it is necessary to improve the processes that are responsible for the quality, the elimination of the malfunction that arose during the manufacturing process, and also to maintain the processes for proper level. For this purpose, there are the following methods: KAIZEN – system, PDCA, DMAIC cycle, self-assessment and performance assessment of a quality management system.

After one production project is completed, the organization starts creating new products or producing old products, but using new technologies to create them, materials that are cheaper than previous ones, but better in quality, or can redirect their activities to another area, completely different from the previous one, because it understands that consumer interest begins to decline. In any case, the creation of something new is always a risk for the organization and it has to be taken into account and calculated using methods that are aimed at assessing the risk and consequences of failure: FMEA-analysis, method of functional-cost analysis, method of expert assessments, quality economics system. Also, when implementing new technologies and creating new processes, one can use the methods that are responsible for this activity: DFSS-method, reengineering of business processes; benchmarking – a method, the main purpose of which is to study and implement the experience of more competitive companies, giant companies, but this method does not involve copying the actions of these companies, but only obtaining information about possible solutions to problems. This method can also be used to create new products and new processes.

The equipment is an integral part of the processes, and how well it works also depends not only on the quality of the products, but also the company's ability to deliver the goods at exactly the time that is required (Just in time), and exactly in the amount that is required (KANBAN system). In order to stop the production of products at the moment when the problem is detected, there is a method Andon, the advantage of which is not a complete stop of the entire production, but only to the site where the problem was found, which allows to reduce downtime.
Figure 1. Classification of management methods
It is good when production stops in case of detection of some failure in the program, but a big plus of the equipment can be an opportunity to analyse itself, that is to point to a specific error, reducing the time of its search.

Figure 1 shows the classification of management methods.

2. Equipment failure prevention system

Technical and other hazards generate a flow of hazardous events $\lambda$ that can lead to equipment failure. This flow is affected by the company’s repair service, identifying hazardous phenomena with intensity $\nu_1$ and preventing their development into equipment malfunction with intensity $\nu_2$.

The flow of unpredicted and unpredictable equipment failures $\lambda^*$ is “serviced” by the information management system—the repair service. With intensity $\mu_1$, the repair service identifies equipment failures, to which it reacts, eliminates them and their consequences with intensity $\mu_2$.

The priority areas of repairmen should be monitoring, forecasting and preventing failures, therefore, let us focus on the prevention of equipment failures.

Let us consider an information management system (IMS) (Figure 2) - a management system in the field of prevention of failures, consisting of information tools and management tools - the repair service of the enterprise, ensuring the elimination of identified accidents.

Let the information system of the repair service have various means that allow detecting $\nu_1$ dangerous phenomena per unit of time. It is natural to assume that the time intervals between the moments of finding facts are random quantities. The facts discovered in time form a stream that is very close to the Poisson stream. The data of the information system about the detected hazards enter the data processing system of the repair service, which has a limited capacity for processing the received information per unit of time.

Let us denote the intensity of the action of the repair service management system by ensuring the elimination of the identified hazards through $\nu_2$. The processing time of the hazard data is random.

We consider the case when the residence time of hazardous facts in the field of repairmen is very limited and commensurate with the time needed for their identification, processing of initial data and adequate actions on these facts. Therefore, this complex system can be considered as a first approximation as a system with failures.

Let us denote the probabilities of system states:
\( P^{00} \) - the information system and the management system are free from the maintenance of features and do not manifest themselves.

\( P^{10} \) - the information system is busy with receiving information about a single hazard, the control system is free from maintenance.

\( P^{01} \) - the information system is free, and the control system is busy with processing the hazard information and developing a solution to eliminating it.

\( P^{11} \) - both systems are busy.

We make the differential equations of states of the information management system. We denote, respectively, the conditions of the system \( A^{00} \), \( A^{10} \), \( A^{01} \), \( A^{11} \).

The condition \( A^{00} \) is possible in the following incompatible cases:

1. At time \( t \), the information system and control system are free. During the time interval \( \Delta t \), no single sign appeared in the area of operation of the control system (CS). The probability of this event is equal to

\[
P^{00}(t)(1 - \lambda \Delta t) \quad (1)
\]

2. At time \( t \), IMS was in the condition \( A^{01} \). During the time \( \Delta t \), the hazard data has been transferred to repairmen. The probability of this event is equal to

\[
P(t) \nu \Delta t \quad (2)
\]

Then the ratio for the condition \( A^{00} \) is written in the following form:

\[
P(t+\Delta t) = P(t)(1 - \lambda \Delta t) + P(t) \Delta t \nu \Delta t \quad (3)
\]

After the appropriate transformations and the transition to the limit as \( \Delta t \to 0 \), we obtain

\[
P(t) = -P(t)\lambda + P(t)\nu^2 \quad (4)
\]

Let us consider the condition of IMS \( A^{01} \). It is possible in the following incompatible cases:

1. IMS at time \( t \) is in the condition \( A^{01} \). For the time interval \( \Delta t \), in the area of IMS activity, no new hazard manifested itself and the elimination of the revealed violations was not carried out. The probability of this event is equal to

\[
P(t)(1 - \lambda \Delta t)(1 - \nu \Delta t) \quad (5)
\]

2. At time \( t \), IMS was in the condition \( A^{10} \). During the time \( \Delta t \), the IS detected and issued data on the hazard of CS,

\[
P(t) \nu \Delta t \quad (6)
\]

3. At time \( t \), IMS was in the condition \( A^{11} \). During the time \( \Delta t \), IS found and issued data on the hazard of CS, but CS did not use them, as it was busy processing data on the previous fact. And therefore, the data obtained were irretrievably lost due to the short duration of the fact in the area of IMS activity. The probability of this event is equal to

\[
P^{11}(t) \nu \Delta t. \quad (7)
\]

Then the ratio for the condition \( A^{01} \) is written in the following form

\[
\frac{d}{dt} P^{01}(t) = -P^{01}(t)(\lambda + \nu^2) + P^{11}(t)\nu + P^{10}(t)\nu_1. \quad (8)
\]

When compiling a differential equation, the state of IMS \( A^{10} \) should be based on the fact that it is possible in the following incompatible cases:
1. At time $t$, IMS was in the condition $A^{00}$. During the time interval $\Delta t$, a dangerous signal appeared in the IMS area of operation, and it was identified by IS. The probability of this event is equal to

$$P^{00}(t) \lambda \Delta t$$

(9)

2. At time $t$, IMS was in the condition $A^{10}$. During the time $\Delta t$, a dangerous signal appeared in the area of IMS, and it was not identified by the IS and the data was not transmitted to CS. The probability of this event is equal to

$$P^{10}(t)(1 - \nu_1 \Delta t);$$

(10)

3. At the moment of time $t$, IMS was in the condition $A^{11}$. During the time $\Delta t$, CS issued data to eliminate the dangerous phenomenon. The probability of this event is equal to

$$P^{11}(t) \nu_2 \Delta t.$$  

(11)

Then the ratio for the condition $A^{10}$ is written in the following form

$$\frac{d}{dt} P^{10}(t) = P^{00}(t) \lambda - P^{10}(t) \nu_1 + P^{11}(t) \nu_2.$$  

(12)

Finally, the last state of IMS $A^{11}$ is possible in the following incompatible cases:

1. At time $t$, IMS was in the condition $A^{01}$. During the time $\Delta t$, new hazard data was obtained

$$P^{01}(t) \lambda \Delta t;$$

(13)

2. At time $t$, IMS was in the condition $A^{11}$. For the time interval $\Delta t$, the data on the dangerous fact of the IS and CS were not processed, new dangerous phenomena appeared in the area of the protection subsystem. The probability of this event is equal to

$$P^{11}(t)(1 - (\nu_1 + \nu_2) \Delta t);$$

(14)

Then the ratio for state $A^{11}$ is written in the following form:

$$\frac{d}{dt} P^{11}(t) = P^{01}(t) \lambda - P^{11}(t)(\nu_1 + \nu_2).$$

(15)

The general system of equations describing all possible states of IMS is represented in the following form from four differential equations:

$$\frac{d}{dt} P^{00}(t) = - P^{00}(t) \lambda + P^{01}(t) \nu_2$$

$$\frac{d}{dt} P^{01}(t) = - P^{01}(t)(\lambda + \nu_2) + P^{11}(t) \nu_1 + P^{10}(t) \nu_1$$

(16)

$$\frac{d}{dt} P^{10}(t) = P^{00}(t) \lambda - P^{10}(t) \nu_1 + P^{11}(t) \nu_2$$

$$\frac{d}{dt} P^{11}(t) = P^{01}(t) \lambda - P^{11}(t)(\nu_1 + \nu_2).$$

For stationary processes, we assume that there are no transient processes in the system. This allows to make the following property record for transition probabilities: $t \rightarrow \infty$, $\frac{d}{dt} P^{ij}(t) \rightarrow 0$, $P^{ij}(t) = P^{ij} = \text{const.}$.

Then differential equations are transformed into algebraic ones:

$$P^{00}(t) \lambda = P^{01}(t) \nu_2$$
\[ \begin{align*}
P^{01}(t) = P^{11}(t) + P^{10}(t) \quad (17) \\
P^{10}(t) = P^{00}(t) + P^{11}(t) \quad (18) \\
P^{11}(t) = P^{01}(t) \quad (19) \\
\end{align*} \]

Solving a system of algebraic equations, we can determine the probabilities of different states of the information control system:

\[ \begin{align*}
P^{00} &= \frac{\lambda (\lambda + v_1 + v_2)}{\lambda v_1 (\lambda + v_1 + v_2) + v_1 v_2} \\
P^{10} &= \frac{v_1 \lambda}{(v_1 + v_2) [\lambda (\lambda + v_1 + v_2) + v_1 v_2]} \\
P^{01} &= \frac{\lambda (\lambda + v_1 + v_2)}{v_2 (v_1 + v_2)} \\
P^{11} &= \frac{v_1 \lambda}{(v_1 + v_2) [\lambda (\lambda + v_1 + v_2) + v_1 v_2]} \\
\end{align*} \]

where \( \lambda \) is the intensity of the flow of hazardous phenomena generated by technical and other hazards.

It is possible to determine the probability that the hazard remains unidentified and unintended:

\[ P_{\text{own}} = P^{00} + P^{10} = P^{00} \left( \frac{\lambda}{v_2} + \frac{\lambda^2}{v_2 (v_1 + v_2)} \right) = P^{00} \frac{\lambda (\lambda + v_1 + v_2)}{v_2 (v_1 + v_2)} \]

\[ P_{\text{GTH}} = \frac{v_1 \lambda (\lambda + v_1 + v_2)}{(v_1 + v_2) [\lambda (\lambda + v_1 + v_2) + v_1 v_2]} \]

The likelihood that a hazardous phenomenon is identified by IS and "serviced" by CS is defined by the following:

\[ P_{\text{serv}} = [1 - (P^{10} + P^{11})] \cdot [1 - (P^{01} + P^{11})] \]

\( \lambda^* \) is the flow of unpredictable and unintended hazards:

\[ \lambda^* = \lambda \cdot P_{\text{own}} \]

Knowing \( \lambda^* \), based on the formulas (19, 21), we calculate \( \lambda \) (the flow of hazardous phenomenon). Let us substitute the obtained value of \( \lambda \) in (19) and calculate \( P_{\text{ok}} \).

3. Discussion

Let \( v_1 = 147 \) be the intensity of the activity of the repair service of the company, equal to the number of measures proposed for elimination, identified during the scheduled inspections of the equipment, and assume that \( v_2 = 110 \) is the intensity of the activity aimed at eliminating violations. The number of unwarned hazards is \( \lambda^* = 24 \).

We substitute the values of \( v_1, v_2, \lambda^* \) in (19, 21), express \( \lambda \), solve the third degree equation. We get the three roots of the equation:

\( \lambda_1 = -39; \lambda_2 = 71; \lambda_2 = -247 \)

Considering the range of permissible values, we take \( \lambda = 71 \) - the flow of hazardous phenomena. We substitute the obtained value of \( \lambda \) in (19), calculate \( P_{\text{ok}} = 0.3376 \) and the probability of detecting and preventing each hazardous phenomenon \( P_{\text{serv}} = 0.6624 \).

The equipment failure prevention performance indicator is calculated as the number of detected and prevented hazards not led to equipment failures.
Let us consider the probability of failure at the different intensity of activities aimed at eliminating violations:

When \( \nu_2 = 120 \) it follows that \( P_{\text{otk}} = 0.3173 \)

When \( \nu_2 = 130 \) it follows that \( P_{\text{otk}} = 0.2992 \)

When \( \nu_2 = 140 \) it follows that \( P_{\text{otk}} = 0.2830 \)

When \( \nu_2 = 147 \) it follows that \( P_{\text{otk}} = 0.2727 \)

It is seen that increasing this intensity decreases the likelihood of equipment failure. The probability of failure is quite high. An increase in control measures is needed to increase the number of detected and prevented hazards.

Figure 3 shows the dependence of the fact that a hazardous phenomenon will be identified and “serviced” by repairs from the intensity \( \nu_2 \).

\[
I = \int_{0}^{\lambda \cdot P_{\text{serv}}} dt = \int_{0}^{\lambda \cdot (1 - P_{\text{otk}})} dt = 47.
\]

Figure 4 shows the probability that the required hazard will be identified by IS and “serviced” by CS.

According to Figure 4, when the intensity of preventive maintenance activities increases, the probability of equipment failure prevention increases.
Figure 4. The dependence of the probability of service on the activities of the repair service $\nu_1$ and the intensity of preventive activities $\nu_2$.

The presented management system and simulated simple situations in which the company can use quality management methods are only a small part of their application. Because, depending on the problems and goals that the organization pursues, management methods can be intertwined with each other. One thing is important: using one method does not guarantee the achievement of the desired result, since each of these methods supplements the previous one, makes it clearer and more efficient.

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