Of discrepancy prediction algorithm in the model of improve the quality of serial processes of engineering production

L A Ivanova, E B Charushina and E V Khodareva
Omsk State Technical University, 11 Mira pr., Omsk, 644050, Russia

Abstract. The article discusses the decision-making model for managing inconsistencies in serial production processes based on the integrated use of statistical methods and expert assessment methods for processing information. The proposed model allows to reduce the number of non-conforming products through the forecast of inconsistencies in serial processes, both within the production process and delivered to the consumer.

1. Introduction
An analysis of the experience of applying [1-3] throughout the world of a quality management system indicates its effectiveness in matters of achieving the satisfaction of all stakeholders.

Therefore, the basis for the management of technological processes in the organization should be a model of the quality management system proposed in [4]. For effective management of the quality of technological process outputs, it is important for staff to have an idea of potential discrepancies and standard solutions to eliminate discrepancies and their causes, which will allow to quickly make adequate decisions at workplaces. To provide personnel with such information, it is necessary to solve the problem of forecasting inconsistencies in the technological process. Nonconformities or hazards can affect product safety and product quality. At the same time, there is a justified need for differences in the methods of managing safety and the quality of the outputs of technological processes.

The safety management model recommended [5] is a good solution to product safety issues. However, its application to address issues of quality assurance entails unreasonable management decisions in the form of a large amount of control at the stages of the technological process and an unreasonable increase in costs. Such an approach may not be effective and not effective.

2. Formulation of the problem
However, without applying the methodology of statistical thinking to control the quality of the technological process, incorrect or suboptimal decisions can be made. However, the application of statistical forecasting methods does not always allow us to solve the tasks in full. If under conditions of lack of statistical information or its absence there are reasonable assumptions about inconsistencies that may hypothetically occur, then it is advisable to turn to expert decision-making methods.

Thus, an integrated approach to forecasting inconsistencies in the technological process, combining the methods of mathematical statistics and expert decision-making methods, seems especially effective, because compensates for the shortcomings of the statistical apparatus and expert decision-making methods in case of their independent application.

3. Theory
In [1-3, 6] an approach is proposed to create a model for improving the quality of serial processes (figure 1).
The primary task is to determine product requirements, the so-called quality indicators, which it becomes possible to identify when referring to regulatory documentation (technical regulations, standards, sanitary rules and norms, etc.).

The next step is to stratify quality indicators on the basis of the influence of danger on the quality and safety of products. The task of predicting an adverse event when implementing product safety is solved by using the developed algorithm (figure 2), based on the one given in [6].

According to the proposed model, work begins with the construction of a process flow diagram. The depth of the decomposition of the technological process depends on the set of selected quality indicators determined during the analysis of regulatory documentation (technical regulations, sanitary rules and norms, contract, statistics on non-conformities). Depending on the results of the analysis of the identified requirements of normative documentation, the structure signs its quality to a level whose elements are not subject to further decomposition.

To exclude the possibility of the presence of unaccounted factors during the analysis, according to the requirements of [5, 7], the areas of use of the product are determined, including attention is drawn to possible options for its use for other purposes.

The final step in collecting information for analysis is to identify all potential product discrepancies. Hazardous factors given in the Sanitary Rules and Norms are taken into account primarily and without change, the information obtained from the normative documentation for the products and information on the occurrence of hazardous factors in practical activities are also used.

The next stage is the analysis of hazardous factors; according to the standard, it is recommended to use risk management ideas. The probability of the occurrence of a hazardous factor and the severity of the consequences during the implementation of an adverse event by the Delphi method are estimated [8, 9].
Figure 2. Block diagram of an algorithm for predicting adverse events for product safety.

The next stage is the analysis of hazardous factors; according to the standard, it is recommended to use risk management ideas. The probability of the occurrence of a hazardous factor and the severity of the consequences during the implementation of an adverse event by the Delphi method are estimated [8, 9]. The result of this analysis will be two lists of hazardous factors: with risk assessments of low and assessments of the degree of danger - medium and high. The first group of hazardous factors does not pose a threat to the consumer and is not considered at the next stages of the analysis of nonconformities. The second and third groups - the so-called considered hazard factors - are examined for the need to establish control at the stages of the possible implementation of the hazard.

The next step defines the stages at which the danger exceeds the acceptable level - critical control points (CCP). For each identified risk factor, an analysis is carried out using the Decision Tree method [10]. The result of this step is a list of CCPs and a list of control points for which existing measures are sufficient in terms of ensuring product safety. CCP defines critical limits.

The results of this analysis are the basis for the development of corrective and preventive actions and the establishment of a monitoring system where existing control measures have been identified as ineffective.

4. Results
The forecast model for the implementation of an adverse event while ensuring product quality (figure 3) is based on the combined use of expert information assessment methods and mathematical statistics methods.

According to the proposed model, the first step is the process flow diagram and its decomposition. In this case, the approach to the depth of the decomposition of the process is similar to the approach for predicting hazards to product safety.

In the course of the analysis of the obtained process flow diagram, hazards to product quality that are characteristic of certain stages of the process are determined. Identified hazards to product quality should be differentiated by the presence of cases of detection in production activities.

In order to assess the feasibility of taking measures to prevent the occurrence of potential non-compliance and corrective actions, an assessment is made of the degree of risk of each type of hazard.

An assessment of the risk of hazards that have not occurred in practice, but hypothetically may appear, should be carried out using the method of expert assessment of information. To achieve this goal, it is proposed to use the Delphi method [8].
Figure 3. The block diagram of the algorithm for predicting adverse events for product quality.

Assessment of risk of risk to product quality, which met in manufacturing practice (hereinafter - NC) is expected to be conducted from the position of the estimate of costs when they occur. This assessment consists of the average number of nonconformities over a period of time of observation and the cost of quality, which depends on the most likely solutions to any discrepancies. Consider the kind of inconsistencies can be systematically identified within the production process and the consumer and only within the production process. Depending on the stage of identifying discrepancies requiring corrective actions and their composition will be different. The risk assessment will determine priority work that must be performed in the first place and work that can be delayed in time and modified the structure without losses in product quality and increase the quality costs.

The risk assessment formula includes an assessment of the severity of the nonconformity. The severity of occurrence of non-compliance is calculated taking into account the average number of non-
compliance in the observed time period. Thus, risk assessment is equivalent to assessing the severity of an adverse event.

Quality costs at the stages of the production process and when identified by the consumer are compared with the criterion - an estimate of the estimated costs of corrective actions (table 1).

Table 1. Analysis of types of discrepancies based on customer complaints.

| Quality Cost Estimates | Management decision |
|------------------------|---------------------|
| $S_e > S_{c,act}$     | Non-conforming products fall to the consumer, while there are significant losses in product quality as part of the production process. Existing measures to prevent the occurrence of non-conformities of this type are not effective and require revision. It is necessary to determine the causes of the discrepancy, develop corrective actions, assess the possibility of establishing additional control of this discrepancy at the stages of the process. |
| $S_p < S_{c,act}$     | Non-conforming products fall to the consumer, while in the framework of the production process, the costs of non-conforming products are lower than the estimated costs of developing and implementing corrective actions for this type of non-compliance. The first priority is to prevent non-conforming products from entering the consumer. Corrective actions include work to establish the causes of an adverse event and their elimination and the development of a monitoring system and its implementation. If the exclusion of the costs of eliminating the cause of the discrepancy allows the following ratio to be fulfilled: $S_p < S_{c,act}$ or $S_p \approx S_{c,act}$, then it is advisable to limit the priority task only to correction. In the future, it is possible to re-analyze the discrepancy and eliminate the causes of its occurrence. |
| $S_e \approx S_{c,act}$ $S_p > S_{c,act}$ | The cost of losses when non-conforming products reach the consumer is approximately equal to the cost of the estimated costs of corrective actions. Existing measures to prevent the entry of low-quality products are not effective. At the same time in production, there are also losses from defective products. Accordingly, the urgent task is to prevent the ingress of non-conforming products to the consumer, and to reduce the cost of losses from marriage as part of the technological process. To solve this problem, it is necessary to establish the causes of the discrepancy and eliminate them, as well as consider the feasibility of establishing additional control. |
| $S_p \approx S_{c,act}$ | This situation is similar $S_e \approx S_{c,act}$ and $S_p > S_{c,act}$, however condition $S_p \approx S_{c,act}$ makes the correction task the first priority, i.e. establishing additional control in the first place. Solving the problem of determining the causes of non-compliance and eliminating them does not require priority attention. |
| $S_p < S_{c,act}$ | Non-conforming products fall to the consumer, while the costs of corrective actions and the cost of losses from such a defect are comparable. The cost of corrective actions exceeds the losses from defective production. This may mean that existing measures to prevent non-conforming products are not effective. Accordingly, the primary task is to create stages of additional control. If, with the introduction of additional control, the ratios $S_e < S_{c,act}$ and $S_p < S_{c,act}$, then it is not economically feasible to carry out measures to identify and eliminate the reasons. |
| $S_e < S_{c,act}$ $S_p > S_{c,act}$ | There are production losses associated with defective products. It is necessary to establish the causes of their occurrence and develop measures to eliminate them. Additional control is not advisable. |
| $S_p \approx S_{c,act}$ | Fixed costs for corrective actions exceed the expected effect - losses from poor-quality products are much lower. The development of corrective actions is not economically feasible. Additional control is not required. |
The following notation is accepted: $S_e$ - evaluation of quality costs when identifying product mismatch by the consumer; $S_{c,act}$ - assessment of quality costs during corrective actions; $S_p$ - estimation of quality costs in case of non-compliance in the production process.

5. Discussion of results

The analysis of the types of discrepancies based on the lack of complaints from consumers and on the basis of quality losses in the production process is carried out according to the scheme proposed in Table 2.

Table 2. Analysis of the types of discrepancies based on the lack of complaints from consumers and the basis of quality losses in the production process.

| Quality Cost Estimates | Severity | Management decision |
|------------------------|----------|---------------------|
| $S_p > S_{c,act}$      | 3        | The cost of corrective actions is lower than the cost of loss from marriage as part of the production process. To reduce losses within production, it is advisable to determine the causes of inconsistencies and how to eliminate them. Existing measures to prevent the entry of low-quality products to the consumer are effective and additional control is not required. |
| $S_p \approx S_{c,act}$| 2        | With an equivalent ratio of the costs of corrective actions and the costs resulting from defective products, the development and implementation of corrective actions is not a priority in the hierarchy of planned activities. But ceteris paribus it is advisable to identify the causes of non-compliance and their elimination. Additional control at the stages of TP is not required. |
| $S_p < S_{c,act}$      | 1        | Carrying out corrective actions is not economically feasible. |

Data on consumer complaints indicate that products with this type of discrepancy were not detected. Hypothetically, the cost of the appearance of this type of non-compliance cannot be calculated taking into account the estimate of the number of units of non-compliant products. Thus, the assessment of the severity of the consequences is carried out taking into account losses from marriage within the production process. According to the types of inconsistencies, for which it is supposed to develop and carry out corrective actions in accordance with the proposed scheme (Tables 1 and 2), which include determining the causes of inconsistencies and eliminating them, an analysis of the causes of their occurrence is carried out.

For this, the Delphi method [9] determines the factors involved in the formation of each type of discrepancy.

For a certain list of factors, an assessment of the completeness of information is carried out to assess the law of distribution of observations and conduct regression analysis.

The data sampling as given in [11] should be representative and meet the condition of a sufficient minimum of observation units. The law of distribution of random variables in [12] is determined for small samples by the Shapiro-Wilk criterion [13, 14].

The small sample in this case has a volume of at least 30 observations. The results of the regression analysis are considered adequate if each factor corresponds to 6 to 7 observations. Identification of more than 6 influencing factors is considered impractical. Thus, the sample size should not be less than 30 observations [13]. If the amount of information available does not meet the established requirements for its completeness, then it is necessary to evaluate the possibility of collecting data by the Delphi method [9]. If data collection is possible, then the data type is determined. Data may be collected on an alternative or quantitative basis. Whenever possible, preference is given to collecting data on a quantitative basis, as processing and interpreting alternative data is more complicated than quantitative data.
Data is collected on nonconformities and the factors that shape them. From this group of factors that influence the appearance of inconsistencies, factors that contribute most to the risk of an undesirable event are identified. This problem is solved by applying regression analysis.

If the data collection is carried out according to an alternative criterion, then it is assumed to use the Poisson regression provided that the observations are distributed according to the Poisson law [12] and the use of regression for the binomial distribution [11].

The factor with the highest estimate of the regression coefficient makes the greatest contribution to the studied quality indicator.

The final step is to document the management system. The basis for managing nonconformities in the serial process is a plan that records information about nonconformities, corrective and preventive actions, a monitoring system, responsible personnel for the implementation of activities and the form of records.

6. Summary and conclusions

Thus, discrepancies are identified, both encountered in practical activities, and potential discrepancies, for which it is necessary to develop corrective and preventive actions. Also, for these discrepancies, priorities have been identified that allow to establish the priority of managerial decision-making for the category of discrepancies in terms of risk. The causes of inconsistencies are identified and the contribution of the causes to the formation of an adverse event is assessed, which will make it possible to make informed decisions to eliminate the causes and their priority.

Thus, there is sufficient information that allows us to develop adequate corrective and preventive actions and establish the need for additional monitoring and determine the stages of monitoring [16], if required.

The proposed model allows to reduce the number of non-conforming products through the forecast of inconsistencies in serial processes, both within the production process and delivered to the consumer.

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