Sampling method for evaluation and control of industrial product quality

S V Lukina¹*, V M Makarov¹, S A Ovchinnikov² and O E Zimovets¹

¹Moscow State Technological University «STANKIN», 1 Vadkovsky line, Moscow 127055, Russian Federation
²Moscow State Technical University of Radio Engineering, Electronics, and Automation (MIREA), 78 Vernadsky avenue Moscow, 119454, Russian Federation

*lukina_sv@mail.ru

Abstract. The article develops a sampling method to control and evaluate the quality of industrial products. The method allows for a comprehensive quality evaluation at designing and controlling industrial product manufacture. The method is based on a set of mathematical and statistical models of forming a sampling frame of industrial product parameters. It takes into account the factors of the company’s external and internal environment, control over decision making process (DMP), quality evaluation by a sum of partial indicators of ten groups. The method developed is automated with the help of the software MathCad Prime. The industrial approbation of the method showed its efficiency for the solution of production tasks related to the evaluation and control of industrial product quality at various stages of product and manufacturing life cycles.

1. Introduction

Today's situation and prospects of industrial manufacture development are characterized by increased requirements to the manufactured products [1-3]. Mechanical engineering products are characterized by the discretization and diversity of the products. A frequent change of product variety brings about the issue of reducing the terms and expenditures for product design engineering and improving the quality of design and control solutions.

The fact that products are manufactured in small batches contributes to the selection of economically reasonable and predictable ways to control and evaluate the industrial product quality [4-7].

Sample quality evaluation makes it possible to predict those properties of products which define their serviceability by studying some formed set of representative samples. Sampling allows reducing the time and cost of industrial product quality evaluation, speeds up management decision making [3,4].

It is widely agreed that sampling methods are based on general scientific principles used for research planning, statistical methods and computer technology. They form dataware methodological basics at solving various control and quality evaluation problems. Sampling methods allow estimating the product properties at various stages of a life cycle for a wide range of indicators [8-14].
However, according to the information from available references, despite the current development of statistical methods there is no method for a comprehensive evaluation of the industrial product quality at the stages of product manufacture design and control.

In this respect, the relevant problem is to form the algorithms for a comprehensive evaluation of quality taking into account a multiplicity of production factors and evaluation criteria. These algorithms should allow controlling the DMP in industrial production planning and organization.

The aim of the paper is the development of a method for comprehensive product quality evaluation on the basis of mathematical and statistical modeling methods.

2. Key method provisions

In the paper the model of DMP in the area of production control and evaluation of the quality of industrial manufacture is presented as the interconnection of two types of models - evaluation control and control object modeling [15].

A control object is assumed to be an arbitrary item construction developed for uncertain production conditions, characterized by a full set of geometric, construction and operation parameters defined for various groups of industrial products. In the general case industrial products are viewed as a materialized result of some operational activity having useful properties and intended for the consumer use to meet their needs, both social and personal. In the paper the practical application of the developed method is made by the evaluation of high-tech engineering products of modular structures with various intended uses, in particular, assemblies and units of technological machines, cutting and auxiliary tools, etc.

The control object is a complex discrete system the state of which can be described by a set of some analytical and statistical equations. The control object is a part of a subsystem of a common technological system and is functionally connected with all system components.

The model of a control system stipulates for the availability and use of a set of control object models for DMP. The object is considered at three abstraction levels: conceptual, task-oriented and physical.

A conceptual level stipulates for the development of a single concept model for control and evaluation abstracted in the form of some theories for various problems being resolved and user intentions.

At a problem-oriented level one builds the partial models of an industrial product in the framework of a developed concept model. These partial models describe some subsystem or some set of the product technical-economic indicators oriented at the application of specific methods of problem solution.

At a physical level the model for production control and evaluating the industrial product quality is implemented as an automated decision-making algorithm.

A theoretical control object model is presented as a total of sets or subsets of heterogeneous components with arbitrarily introduced components and ratios:

\[ Y = f(X, Q) \]  

Here \( Y \) – set of control and evaluation criteria; \( X \) – set of control object parameters; \( Q \) – set of confounding and mediate variables from the impact of the external and internal environment factors of the control object.

The condition (1) is considered to be specific when all its constituent parts are also determined, i.e., the sets \( Y, X \) and \( Q \).

Consider the subject content of sets \( Y, X \) and \( Q \).

The quality of industrial products shall be interpreted in this paper as a set of properties making them suitable for meeting one’s needs in compliance with their intended use. The industrial product quality indicator is a quantitative characteristic of one or several properties of industrial products forming its quality. This characteristic is considered with the account of specific conditions of product manufacture and operation or consumption. The level of industrial product quality is defined.
by a relative characteristics of the product quality based on the comparison of the values of the evaluated product quality indicators with the basic values of corresponding indicators.

In the general case the level of industrial product quality shall be evaluated by a total of ten main indicators: intended use characterizing the main properties of industrial products, which define their key functions; reliability defining the consistency of the industrial product quality due to the preservation of high designed parameters during a stipulated time; ergonomics that combines physiological, anthropometric, hygienic and psychological parameters; aesthetic qualities, defining the properties of industrial products which allow for an optimal sharing of materials, means, labor and time at the preproduction engineering, manufacture and operation; unification showing the amount of standard and unique constituents of a product as well as the level of unification with other constituents of a technological system; patent and legal parameter characterizing the patent clearance of industrial products; ecological compatibility defining the level of negative environmental impact; safety characterizing the safety for a user during industrial product operation; cost-effectiveness showing the expenditures for the manufacture and operation of industrial products.

Thus, a set of control and evaluation criteria is defined by a set:

\[
y_{ij} = \bigcup_{j=1}^{10} \bigcup_{i=1}^{I} \delta_{y_{ij}}
\]

(2)

where \(y_{ij}\) – partial control and evaluation criterion, \(I\) – total number of criteria in a current group.

A set of the control object parameters \(X\) is defined by integration:

\[
X = \bigcup_{p=1}^{P} \bigcup_{k=1}^{K} \delta_{x_{kp}}
\]

(3)

where \(x_{kp}\) – local product parameter; \(K\) - general amount a local parameters in a group; \(P\) - number of product group parameters, for example, structural, design, geometrical, etc. parameters forming the product intended use.

The estimatedincrement of a partial quality index specified by the item intended use should meet the condition:

\[
\delta_{y_{ij}} \text{min} \leq \sum_{p=1}^{P} \sum_{k=1}^{K} \delta_{x_{kp}} \delta_{y_{ij}} \leq \delta_{y_{ij}} \text{max}
\]

(4)

where \([\delta_{y_{ij}}]\text{min}, [\delta_{y_{ij}}]\text{max}\) minimum and maximum accessible increments of a partial quality indicator specified by the product intended use.

For the enlarged evaluation of the industrial product quality level it is sufficient to calculate a composite quality index \(F\); this index is an additive convolution of partial criteria:

\[
F = \sum_{j=1}^{10} \sum_{i=1}^{I} y_{ij} m_{ij} \rightarrow \text{(max)}
\]

(5)

where \(m_{ij}\) — weight parameter of the \(i\)-th quality index of the \(j\)-th group.

A set of confounding and intermediate variables from the impact of external and internal environment of the control object \(Q\) is defined by integration:

\[
Q = \bigcup_{c=1}^{8} \bigcup_{n=1}^{N} \delta_{q_{cn}}
\]

(6)

where \(q_{ij}\) – local confounding and intermediate variable from the impact of external and internal environment of the control object, \(N\)–general number of local variables in a current group.
In the general case, to evaluate the impact of external and internal environment factors at the company, eight groups of local variables were formed $q_i$: they characterize, correspondingly, the technology of item manufacture, content and characteristic of technological equipment, content and characteristics of production tooling, manufacturing process organization, company’s operating practices, company’s staff composition, material component suppliers, production financing structure.

The evaluation of the set $Q$ should be conducted with the help of the rare event law when the specifications permit a small percent of defective products in a batch of accepted products. That is why in case the number of tests $g$ is large (normally, dozens, hundreds, thousands) and the event probability $h$ in each test is extremely unlikely, and the condition $g \cdot h < 10$ is fulfilled, one should use the approximate Poisson formula to obtain the probability that in $g$ surveys the event will occur exactly $d$ times:

$$P_g(d) = \frac{\lambda^d}{d!} e^{-\lambda}$$  \hspace{1cm} (7)

where $\lambda = g \cdot h$ - average number of event occurrence.

During the calculations by (7) one should use only probably significant or statistically significant events, characterizing a set of impact of internal and external factors on the probability of the attainment of a required value $Y$. The mathematical expectation $Y$ is equal to a sum of products of all possible combinations of $X$ and $Q$ by their probabilities ($P$):

$$m_Y = \sum_{X} \sum_{Q} f(X,Q) \cdot P(X,Q)$$  \hspace{1cm} (8)

The control plans of ready products shall be compared by means of the Monte Carlo method.

3. Method implementation

For the purpose of study and practical illustration of the developed method efficiency it is necessary to have the sets of specific experimental data which could be considered as the realization of some stochastic quality value with a known distribution law. Data processing in compliance with a corresponding statistical algorithm, the authors obtain a possibility to compare a theoretical prediction and practical results.

The results of modeling sampling plans allowed conducting a comparable analysis of the efficiency of the criteria $Y$ under study during the evaluation of the quality of a modular turning tools and face mills applied for machining. According to (2), 60 partial criteria were formed by 10 groups. A number of parameters characterizing the tool (3) was assumed as being equal to 20. A number of external and internal company’s environment parameters (6) varied in the range from 25 during milling to 52 during turning.

Estimate increment of partial quality indicators was assumed to be 1.

For proper evaluation of the quality by the given parameters (1) it is necessary to conduct a large number of experimental studies, accumulate and process of a large statistics on each of the designs of cutting tool structures. DMP modeling using the conditions (7) and (8) allowed forming a representative sample of alternative designs for each cutting tool. The control process consisted in the implementation of the Monte Carlo algorithm. A final decision on the selection of the structure of a modular cutting tool was made on the basis of the results of the quality composite index (5).

For the automation of the developed method the authors applied the software MathCad Prime. The results of mathematical and statistical model showed a good convergence with the results of verification tests of a sample frame of cutting tools.

4. Conclusions

As a result of conducted research a method of sampling for the control and evaluation of the industrial product quality practically tested by the example of tool-making facilities.
The method framework consists of a set of mathematical and statistical methods for forming a total of partial criteria for evaluating the industrial product quality and DMP control.

The industrial approbation of the method showed its efficiency for the solution of production tasks related to the evaluation and control of industrial product quality at various stages of product and manufacturing life cycles. The development of sampling plans allowed for the reduction of design engineering costs by 30% on average due to the decrease of decision-making time and the number of live experiments.

Further method development stipulates for its adaptation for resolving the problems of control and evaluation of the quality of digital technology and production.

References

[1] Kapitanov A 2016 Special characteristics of the multi-product manufacturing. *Procedia Engineering* **150** 832–36
[2] Feofanov A, Kim N, Frolov E and Grishina T 2017 Identification of the technical product characteristics of process scoping studies *MATEC Web of Conferences* **129** 04008
[3] Lukina S, Kosov, M and Tolkacheva I 2019 Predictive modeling of design innovative solutions on tooling configurations at high-tech manufacturing companies *Lecture Notes in Mechanical Engineering* 1885–93
[4] Kapitanov A, Mitrofanov V 2019 General Principles and Design Strategy of Optimal Reconfigurable Manufacturing Systems *Lecture Notes in Mechanical Engineering* 1347–53
[5] Costa D, Martins M, Martins S, Teixeira E, Bastos A, Cunha A, Varela D and Machado J 2020 Performance Evaluation of Different Mechanisms of Production Activity Control in the Context of Industry 4.0 *Lecture Notes in Networks and Systems* **85** 82-103
[6] Bansiyia J and Davis C 2002 A hierarchical model for object-oriented design quality assessment *IEEE Transactions on Software Engineering* 28 4–17
[7] Soualhi A, Hawwari Y, Medjaker K, Clerc G, Hubert R and Guillet F 2018 PHM SURVEY: Implementation of diagnostic methods for monitoring industrial systems *International Journal of Prognostics and Health Management* 9 02111790
[8] Galli T, Chiclana F and Siewe F 2020 Software Product Quality Models, Developments, Trends, and Evaluation *SN Computer Science* 1 154
[9] Aggarwal K, Singh Y, Kaur A and Malhotra R 2007 Investigating effect of design metrics on fault proneness in object-oriented systems Journal of Object Technology 6 127–41
[10] Androu A and Tziakouris M 2007 A quality framework for developing and evaluating original software components Information and Software Technology 49 122–41
[11] Aapaoja A and Haapasalo H 2014 The challenges of standardization of products and processes in construction *The Challenges of Standardization of Products and Processes in Construction* 983–93
[12] Alves T and Tsao C 2007 Lean construction – 2000 to 2006 *Lean construction journal* 3 46-70
[13] Chesalin A, Grodzenskiy S, Nilov M and Agafonov A 2019 Modification of the WaldBoost algorithm to improve the efficiency of solving pattern recognition problems in real-time *Russian Technological Journal* 7 20-9
[14] Malaka R, Auricha J 2013 Software tool for planning and analyzing engineering changes in manufacturing systems *Procedia CIRP* **12** 348–53
[15] Lukina S, Koshunova E and Dorozhkin I 2018 Methods of automated control over composition and structure of metalworking equipment *MATEC Web of Conferences* **224** 01095