Technique for optimizing the technological process of manufacturing electrical radio products in the context of digital transformation of production

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Abstract. The article discusses the process of optimization of production processes for the manufacture of electronic products in the context of the implementation of the concept of digital transformation of industrial enterprises. One of the elements of digitalization used to improve the effectiveness of electronics manufacturing technology in industry is Design for Manufacturing (DFM) in the MatLab computer mathematics environment. The technological production cycle is illustrated in the form of a graph diagram using the apparatus of Markov chains. The application of the developed methodology, as well as the use of graph theory in the technological process of a modern industrial enterprise, allows achieving the required performance indicators, due to the optimal reflection and fixation in the database of non-stationary influences that cause deviations, which are leveled due to adaptive control actions.

1. Introduction
The implementation of information systems at industrial enterprises is at the heart of the digitalization concept. Intellectualization and automation of most of the processes in industrial enterprises will lead to an increase in the efficiency and quality of manufactured products. Today, in conditions when traditional management methods do not adequately meet the constantly changing market conditions and the external environment as a whole, the direction associated with the development of an adaptive strategy for managing all business processes from document flow to the shipment of finished products seems to be especially relevant.

2. Features of the organization of the management process in the context of digital transformation
Figure 1 illustrates the features of the organization of the process of managing an industrial enterprise in the context of implementing the concept of digitalization.
Digital governance

Figure 1. Features of the organization of management processes in the context of digitalization.

At the same time, special attention should be paid to the development of methods for optimizing the production activities of industrial enterprises in the context of the introduction of digital technologies in order to prevent the widespread dependence on IT technologies, as well as leakage of official and commercial information into the worldwide network [1, 2]. Today, it is necessary to take into account the peculiarities of the domestic industry when developing a management strategy using digitalization techniques.

The application of technological innovations and the requirements of the functional organization are the basic components of the structure of the production line for the manufacture of domestic electrical radio products (ERP). The application of the concept of digitalization in the domestic industry is a single system into which production machines, life support and safety systems, sensors and sensors are integrated, providing the ability to combine various physical objects into a virtual network, in which they can interact with each other without human intervention.

3. Technique for optimizing the technological process of manufacturing electrical radio products in the context of digital transformation of production

Today, it is especially relevant to develop domestic software and hardware systems that make it possible to increase the security of an enterprise’s electronic database from outside interference, as well as to ensure high efficiency of production processes in view of the specific features of the organization.

The technological processes (TP) of ERP production are affected by non-stationary disturbances, which entail deviations in the quality indicators of both the manufacturing processes themselves and the technical characteristics of ERP. The DFM concept is used in the process of defining a set of preventive measures to minimize the level of risk of low-quality products and reduce the impact of unpredictable disturbances on TP. The use of DFM tools allows you to optimally level the deviations of the current qualitative indicators from the specified requirements reflected in the IPC series standards [3].

DFM analysis, the implementation of which, allows to optimize the process of identification and adjustment of the current non-standard values from the directive ones at each stage of the TP of ERP manufacturing and, accordingly, to bring the control process closer to the intellectual due to the timely development of preventive methods and tools using the remote monitoring device, internal and external critical states of processes [4, 5].

The methodology developed by the authors is based on the process of the most complete and adequate to current trends, the formation of a TP manufacturing database for ERP, which contains information
about the main, additional and auxiliary processes, as well as predicted TP fluctuations that occur at various stages of the technological cycle. At the same time, the formed database does not directly affect the occurrence and reduction of the risk impact, but allows to form optimal control actions in order to ensure the performance indicators of the TP.

Figure 2 illustrates the decomposition of the TP for the manufacture of ERI using the apparatus of Markov chains in the MatLab computer modeling environment. The detailing of the TP can be performed before the initial stage, at the same time, the authors are interested in the stages carried out on the automatic assembly line. Adhering to the theory of graphs, each basic stage of the TP for the manufacture of ERI is assigned the value of the probability of achieving the states of effectiveness specified by the technological documentation.

In the conditions of the developed methodology, the probability of transition from the previous state $i$ to the next state $j$ is considered as $P_{ij}$. In the case when the discrepancy between the state vector of the current values and those specified by the regulatory documentation is recorded, the probability of transition to the state of nonconforming products (fail) is reflected as $P_{if}$.

![Figure 2. Probability graphs of TP transition from the development stage to electronics manufacturing.](image)

The probabilities of transition from the previous state of the process to the next are given by the matrix:

$\begin{bmatrix}
0 & P_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{1f} \\
0 & 0 & P_{23} & 0 & 0 & 0 & 0 & 0 & P_{2f} \\
0 & 0 & 0 & P_{34} & 0 & 0 & 0 & 0 & P_{3f} \\
0 & 0 & 0 & 0 & P_{45} & 0 & 0 & 0 & P_{4f} \\
0 & 0 & 0 & 0 & 0 & P_{56} & 0 & 0 & P_{5f} \\
0 & 0 & 0 & 0 & 0 & 0 & P_{67} & 0 & P_{6f} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{78} & P_{7f} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & P_{8f} \\
P_{f1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$

If $P_{i}(\emptyset) = 0$, then there is no transition on the graph ($i = 1,7, f = 1,7$).

Evaluation of the effectiveness of TP for the manufacture of ERP and the compliance of quality indicators (predicted values of yield) through $n$ batches was performed using the Matlab software package. For this, a software package was developed that allows calculating the probabilities of the percentage of the yield of suitable, at the prescribed values, using the probability function (QualityProbability). The specified probability function contains three parameters:

- reqProb – the smallest value of the % yield of suitable;
• nChainUnits – the number of stages of TP for the manufacture of ERP;

• nIterations – the number of repetitions of calculating the % yield of suitable ones during the stages of TP and has the form \( \text{functionAvgProb} = \text{QualityProbability} (\text{reqProb}, \text{nChainUnits}, \text{nIterations}) \).

Table 1 contains information on the values of the probability of transitions for TP, which consists of 8 stages.

**Table 1. Values of transition probabilities for eight links.**

| 1st batch | 10th batch | 50th batch | 100th batch |
|-----------|------------|------------|-------------|
| \( \gg \text{QualityProbability} \) (0.98; 8; 1) | \( \gg \text{QualityProbability} \) (0.98; 8; 10) | \( \gg \text{QualityProbability} \) (0.98; 8; 50) | \( \gg \text{QualityProbability} \) (0.98; 8; 100) |
| ans = 0.9886 | ans = 0.9899 | ans = 0.9902 | ans = 0.9900 |

Figures 3 and 4 illustrate the procedure for calculating the percentage of product yield depending on the batch number of ERP. The calculations carried out indicated an increase in the percentage of output suitable for the production of electronic devices in TP with the expansion of capacities and the organization of mass production: 1 batch - 0.9896 (output of suitable); 5 batch - 0.9992 (yield); 10 batch - 0.9900 (yield); 60 batch - 0.9904, etc. At the same time, throughout the entire technological cycle of ERP manufacturing, an assessment is made and corrective actions are developed to eliminate deviations from the specified values.

**Figure 3.** Influence of the batch number on the probability of yield of suitable ERP.

The peculiarity of the DFM concept application is its versatility for various TP for the manufacture of electronic devices, and the greatest efficiency is achieved in the conditions of systemic production of large batches of serial products of varying complexity and composition.

**Figure 4.** Indicators of the probability of the DFM being suitable for the implementation conditions.
Figure 4 clearly illustrates the process of increasing the percentage of the yield of suitable products depending on the batch production of ERP in the context of the implementation of the DFM concept and in the case of traditional production. The graphs indicate the feasibility of using DFM to optimize the TP for the manufacture of ERP, in view of the achievement of performance indicators and the quality of production processes.

4. Conclusion
The introduction of methods for optimizing technological processes in the context of digital transformation provides industrial organizations manufacturers of electrical and radio products with a set of advantages, such as adaptability of business process management due to the optimal use of the initial data of technological processes, providing correct information to all users of the enterprise management system based on a single digital platform, increasing the efficiency of production activities by reducing the number of rejects and ensuring the reliability of technical systems at all stages of the life cycle.

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