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Digital production management methods of radio-electronic industry

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Abstract. During the past decade the methods of Industry 4.0 became widely spread in many areas. Radio electronic industry is not an exception in this process. Nowadays methods of digital manufacturing are gaining the particular significance in this industry. These methods propose elaboration of models of products and processes and their further simulation-based optimization. In this paper an analytical model has been developed for detailing the manufacturing process of electronic products. The model allows to determine the technical level of the projects in radio electronic industry with respect to production cycle stages: manufacturing, assembly, testing. The significant part of this model is coefficients that imply the complex assessment of projects parameters: laboriousness, material consumption, capital and quality. These indicators could be employed in the process of simulation-based optimization of products and technological processes.

1. Introduction

The electronic industry is an innovative and dynamic industry. Increasing product complexity as well as its miniaturization justifies the necessity of technological processes modeling. Production modeling is required not only to ensure product quality and to reduce the production cycle, but also to calculate planned expenses and determine economic viability of production.

During the introduction of technological innovations into the production process, it is necessary to highlight the following urgent tasks that are solved by using the elements of Industry 4.0:

- Analyses of current customer requirements, development and rapid implementation of them in production;
- Improvement of the electronics performance, particular its reliability and durability;
- Compatibility with local GPS systems;
- Increase of products yield;
- Quick machine and technological processes changeover;
- Cost reduction by decrease of production labor intensity;
- Enhancement in processes and products quality.

Within the process of creating the production models in the radio-electronic industry the most important problem is to create uniform methods, means and procedures for maintaining the technological processes quality. During the last 5 years, quite a lot of researches have appeared on how to use Digital, Smart, and Virtual Fabrics. In the electronic industry, these methods can be associated with the stages of the product life cycle as follows (figure 1).

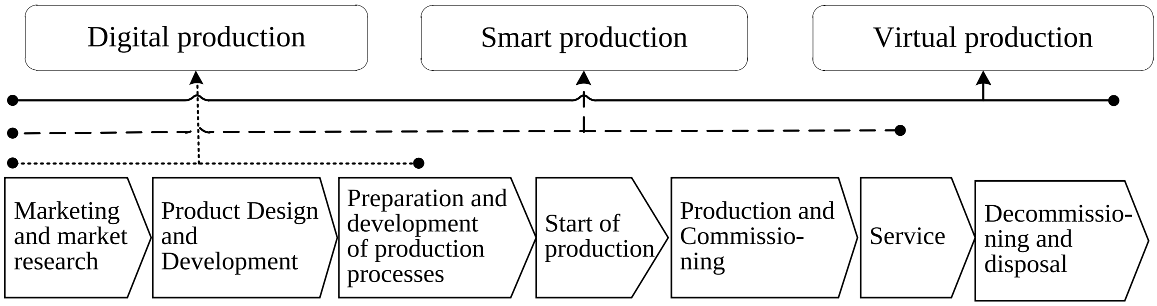

Figure 1. Digital, Smart and Virtual Fabrics and product life cycle in electronic industry.

Mutual implementation of emerging methods of Digital, Smart and Virtual Fabrics should contribute to the company competitiveness. A key element of the Digital factory is a creation of simulation models set that describes the technological processes stage by stage from the design and manufacturing of the product to the testing process. The use of a simulation model is most appropriate from the stage «design and product development» to the stage «installation and commissioning».

To ensure the maximum approximation of simulation model to actual production, the following input parameters should be entered [1-3]:

- Product configuration parameters that affect the process characteristics and are described by ordinary mathematical relationships (for example, the overall part size (dimensions);
- Production process stages and their characteristics with a detailed description of each process stage: time standards, labor intensity and measures of other types of resources;
- Detailed description of internal supply chain from the point of entrance control, movement in the production area, storage and shipment to the consumer. Also it is essential to enter the indication of alternative traffic patterns in order to minimize operating risks;
- Probabilistic parameters of the whole enterprise as a part of external supply chain: capacity, cost level, flexibility, interchangeability, reliability and other information that necessary for implementing the methods of Virtual factory.

One of the main elements of the Industry 4.0 concept is big data and distributed registries. When designing technological processes using simulation modeling in production it is crucial to collect and analyze big data in conjunction with distributed registries. There are two types of databases that serve the process of simulation models elaboration.

The first type should include databases contained comprehensive information about the produced products, including detailed description of material and labor costs, technological processes and other resources. Such databases are the main sources of input parameters that are the basis for the simulation models elaboration. Such databases are especially expedient when fuzzy logic apparatus is implemented in technological processes management. The use of artificial intelligence in the nearest future will help technicians to develop simulation models and adapt them to actual production by making the necessary adjustments [4-6].

The second type of database contains information about the results of experiments in simulation models implementation. The purpose of such databases is to systematize and analyze obtained data. The main aim is to provide the decision-makers with information about different aspects of creation and implementation of new technological innovations in the production process including the elements of the "Industry 4.0" concept. Contemporary enterprises are paying more attention to design processes as initial and most important stage of the product life cycle. In this context the less significance is usually given to issues of technological processes adjustment. However, stage-by-stage simulating process makes it possible to predict emerging risks, evaluate the preliminary efficiency of manufacturing system, and pay the necessary attention to quality insurance issues.

2. The implementation of the digital life cycle model for electronics products

The manufacturing process in radio-electronic industry can be represented in the form of three main stages (levels) [7].

The first stage is a technological process (figure 2). The process is depicted in the form of a graph, in which the P_0 (product) vertex determines the product blank from which the finished device is produced (P_n vertex).

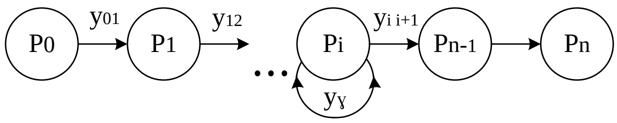

Figure 2. Model of the manufacturing process of electronics (model of the first level).

To determine the coefficient of the model technical level and calculate the cost of the product, the following notation was introduced:

x - technological operations performed in the manufacturing process,
M - (materials) materials consumption
L - (labor intensity) laboriousness,
F (fondintensity) capital ratio,
a_L - the ratio of additional deductions for labor,
a_f - the ratio of additional costs for the of production equipment maintenance,
PP - (Payback period) payback period for production costs [8].

The coefficient $x_ɣ$, depicted at stage P_i, characterizes the connections with the main workpiece of the necessary parts.

The value indicators of the product components are determined by the following equations.

$$M = \sum_{i-1}^{n} x_ɣ \quad (1)$$

$$L = \sum_{n-1} P_i \quad , at\ i = \overline{1, n} \quad (2)$$

$$F = \sum_{\substack{i=0 \\ j=1}}^{\substack{n-1 \\ n}} x_{ij} \quad (3)$$

The perfection degree of the production technical base, organizational and technological methods can be determined in terms of laboriousness, material consumption and quality of finished parts. Taken together, these metrics may be consolidated into one complex coefficient of technical level (CTL) of the project. This coefficient is determined by the expression:

$$CTL_1 = 1 - \frac{x_{ij}}{(P_0 - a_L * P_i - a_f * x_{ij}) * PP} \quad (4)$$

The second stage of production is the assembly of the finish product (figure 3).

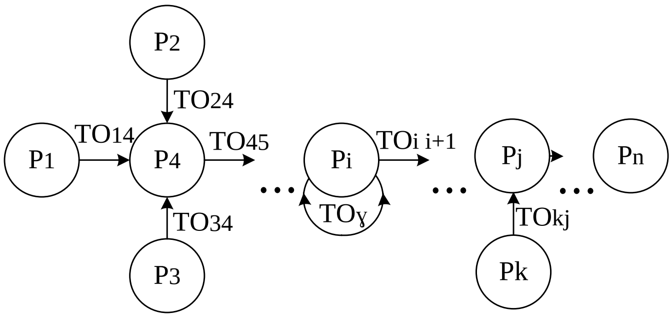

Figure 3. Model of electronics assembly process (model of the second level).

The vertices P of the graph shown in figure 3 determine the intermediate state of the assembled product. The connecting lines TO (technological operation) describe the technological process at this stage of assembly. The arc TO_γ characterizes the contribution of additional materials (solders, seals, alloys, mastics) to the system of elements in assembly [9,10].

The specific values of the technical level of the second level model can be defined as a specific technological transition by the formula:

$$CTL_2 = 1 - \frac{\sum TO_{ij}}{(TO_{ij} + a_L * P_i - a_f * \sum TO_{ij}) * PP} \quad (5)$$

So for the whole node:

$$CTL_2 = 1 - \frac{\sum TO_{ij}}{(\sum TO_{ij} + a_L * \sum P_i - a_f * \sum TO_{ij}) * PP} \quad (6)$$

The final stage of the product manufacturing process is the commissioning and testing of the finished product (figure 4). After this phase quality, performance and reliability of finished products will be assessed by the customers. The technological process of assembly includes a number of sequential operations for installation, creation of various types of compounds, control, adjustment and testing [4].

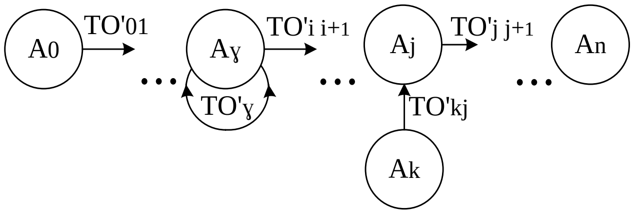

Figure 4. Model of the process of adjustment and testing of electronics (model of the third level).

During the process of adjustment, it is possible to attach materials or necessary elements (A_k) to adjust the product, as well as to perform additional necessary technological operations (TO_γ) for the correct operation of the completed device.

The coefficient of the technical level of a single operation can be determined by the formula:

$$CTL_3 = 1 - \frac{\sum TO_{ij}}{(TO_\gamma + a_L * B_i - a_f * \sum TO'_{ij}) * PP} \quad (7)$$

For the model of the third level as a whole:

$$CTL_3 = 1 - \frac{\sum TO'_{ij}}{(\sum TO'_\gamma + a_L * \sum B_i - a_f * \sum TO'_{ij}) * PP} \quad (8)$$

The finished product can be characterized by indicators determined from the analysis of the remaining elements of the graph and by prompt detection of defects.

The technical level of the entire manufacturing project is expressed by the formula:

$$CTL = 1 - \frac{\Delta F}{(\Delta M + a_L * \Delta L - a_f * \Delta F) * PP} \quad (9)$$

where

$$\Delta M = \sum P_0^i + \sum_{i=1}^{n} \sum x_{\text{Y}} + \sum_{i=1}^{n} \sum TO_{\text{Y}} + \sum_{i=1}^{n} \sum TO'_{\text{Y}} \quad (10)$$

$$\Delta L = \sum P_i + \sum_{i=1}^{n} \sum P_i + \sum_{i=1}^{n} \sum TO_{\text{Y}} + \sum_{i=1}^{n} \sum A_i \quad (11)$$

$$\Delta F = \sum_{\substack{i=0 \\ j=1}}^{\substack{n=1 \\ n}} x_{ij} + \sum_{\substack{i=0 \\ j=1}}^{\substack{n-1 \\ n}} TO_{ij} + \sum_{\substack{i=0 \\ j=1}}^{\substack{n-1 \\ n}} TO_{\text{Y}} \quad (12)$$

The second summation in the calculation of the coefficients ΔM, ΔL and ΔF is made by the number of product parts, separate assembly processes and technological operations of commissioning and testing, which appear in the first stage of the production process, carried out during manufacturing the device.

3. Conclusion

A model has been elaborated for evaluating the production process during the manufacturing of electronic products. It allows to determine the coefficient of the product technical level, that is based on the ratio of additional costs for maintaining production equipment, additional labor and material expenses. It may be applied for calculation of labor, material and capital intensity of the manufacturing process on each stage of the production cycle.

Modeling of the production stages allows to reveal not only the structure of the product, consisting of the individual elements, but also to show the topology of the technological process.

The graph theory in mathematical modeling permits to provide the elaboration of high level for modelled objects with aim to reflect the complex interrelation between process stages and product components. The coefficients of technical level introduced in this paper could be applied in the process of simulation models elaboration. It will help to estimate the preliminary effectiveness of manufacturing projects in radio-electronic industry.

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