Automation of technological preparation of single and small-scale production using simulation modeling

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Abstract. The article describes the model of technological preparation of engineering production. The described model includes three levels: the level of design and analysis of technological processing routes, the applied technological equipment, the level of the methodology for determining the best process option, the level of analysis and control of the production schedule, operational correction of the production schedule to eliminate bottlenecks. Criteria for choosing the best process option and its objective function are described. The practical application of the developed model of technological preparation of production is presented on the example of a ship repair plant. The work was financially supported by the Ministry of Education and Science of the Russian Federation in the framework of the Federal Targeted Program for Research and Development in Priority Areas of Advancement of the Russian Scientific and Technological Complex for 2014-2020 (14.584.21.0022, ID RFMEFI58417X0022).

1. Introduction
Technological preparation of production is an integral stage of the production process for the production of products, which solves the following tasks: analysis of the design of the part and formulation of technological problems; the choice of the method of obtaining the workpiece; development of technological routes for processing parts; selection of technological equipment; design of the structure of technological operations; development of a set of technological documentation.

Currently, a large number of engineering products are produced precisely in the conditions of single and small-scale production, where the highest laboriousness of the stage of technological preparation of production is most noticeable, which leads to a decrease in productivity and an increase in the cost of products. Reducing the complexity of technological preparation of production is possible due to integrated automation and modeling of production processes.

2. Purpose of research
The work aims to develop a simulation model that allows increasing the efficiency of technological preparation of production of enterprises operating in the conditions of single and small-scale production.

3. Materials and Methods
In the process of comparative work, an analysis of methods and models to increase the efficiency of technological preparation of products described in the scientific literature was performed [1–16]. The
described models of technological preparation of production do not address the issues of multivariance of the technological process and theoretical calculation of processing error.

The developed simulation model includes elements of two methods of designing a technological process: a group technological process and a modular technological process.

The following elements of a group technological process are present in the developed model of technological preparation of production: designing a complicated part and designing an enlarged route for processing an intricate part. The following elements of modular technology were included: dividing the part into design and technological elements, designing a module of the technological process of manufacturing an elementary surface. The following mathematical dependencies were applied for describing the proposed model of technological preparation of production: determination of the total processing error for the most accurate sizes, determination of the magnitude of variable costs and the duration of the production cycle. The objective function is defined.

The developed simulation model is a three-level model (Fig. 1). At the first level, design and analysis of feasible process options are carried out, taking into account the production schedule, and the quality of the products is evaluated. Currently, a set of parameters is used to assess the quality of engineering products. These parameters are dimensional accuracy and accuracy of geometric elements and surface layer textures, which are mainly characterized by amplitude roughness parameters [17].

![Design of technological processing routes](image)

![Control of production process](image)

![Operational adjustment of the production schedule](image)

**Figure 1. Levels of simulation modeling**

The design of technological processes and the selection of the best option are divided into nine stages (Fig. 2). The process engineer performs steps 1–4; the implementation of steps 5–9 is carried out in automatic mode.

The selection of the best process option is based on multicriteria analysis according to the following criteria: variable costs, production cycle duration, and processing error for the most accurate size. The formula determines the value of the objective function:

\[
F_{\text{TP}} = \frac{T_i}{T_{\text{min}}} \cdot k_T + \frac{3_{\text{var},i}}{(3_{\text{var}})_{\text{min}}} \cdot k_3 + \sum_{i=1}^{n} \left( \frac{\Delta_\Sigma_i}{(\Delta_\Sigma)_{\text{min}}} \right) \cdot k_\Delta ,
\]

where \(T_i\) – production term of a batch of parts manufactured according to the \(i\)-th process option; \(T_{\text{min}}\) – the minimum production time for a batch of parts; \(3_{\text{var},i}\) – the value of the variable costs of manufacturing a batch of parts according to the \(i\)-th version of the process; \((3_{\text{var}})_{\text{min}}\) – the minimum value of variable costs for manufacturing a batch of parts; \((\Delta_\Sigma)_i\) – the value of the processing error for the most accurate size processed according to the \(i\)-th version of the technological process; \((\Delta_\Sigma)_{\text{min}}\) – the minimum value of the processing error for the most accurate size; \(k_T, k_3, k_\Delta\) – weight coefficients.

At the second level, the production process is monitored: monitoring the operation of each unit of technological equipment, analysis of bottlenecks, monitoring the implementation of the production schedule, modeling alternative process options in the event of a malfunction in the production process, making operational decisions to stabilize the production schedule (based on modeling various management decisions).
The task of the third level is the operational introduction of changes to the production schedule (setting new production tasks), adopted on the basis of modeling various production scenarios.

4. Results
The developed model was used for the technological preparation of production at a ship repair enterprise (St. Petersburg). Sixteen items of parts made of corrosion-resistant steels were analyzed. Corrosion-resistant steels are increasingly used in mechanical engineering [18].

Acceptable options for technological processing routes were developed for each batch of parts, various options for the use of technological equipment (cutting tools) were analyzed, the best process option for each batch of parts was determined based on multicriteria analysis. For the best option, a set of technical documentation is drawn up in an automated mode. In the table. One presents the results of the technological preparation of production on the example of 5 parts.
Table 1. The results of the technological preparation of the production

| № (detail number) | Number of considered options for technological processing routes | Number of alternatives for each cutting tool | Processing error as a percentage of tolerance zone (%) | The duration of the production cycle (hours) | The value of variable costs (thousand rubles) |
|-------------------|-----------------------------------------------------------------|---------------------------------|-------------------------------------------------|---------------------------------|---------------------------------|
| 1                 | 5                                                               | 4                               | 63                                             | 371                                            | 48.2                           |
| 2                 | 8                                                               | 4                               | 51                                             | 328                                            | 63.8                           |
| 3                 | 11                                                              | 4                               | 43                                             | 418                                            | 27.3                           |
| 4                 | 6                                                               | 4                               | 59                                             | 301                                            | 51.4                           |
| 5                 | 9                                                               | 4                               | 49                                             | 308                                            | 71.6                           |

5. Conclusions

The developed model of technological preparation of production makes it possible to design a set of acceptable processing routes, determine rational parameters of cutting conditions on the basis of calculating the processing error, choose the best process option from the set of acceptable options, control and promptly adjust the production schedule based on modeling various production scenarios.

The described model leads to a decrease in labor intensity to no small extent and an increase in the efficiency of technological preparation of production for enterprises operating in the conditions of single and small-scale production.

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References

[1] Troshina A, Ivutin A, Frantsuzova Y V and Trushin N N 2017 The method of planning of rational organization of the process of design and technological preparation for manufacturing Int. Conf. “Quality Management, Transport and Information Security, Information Technologies” (IT&QM&IS) pp 776–9

[2] Leshenko O I 2018 Efficiency increase of the manufacture technological preparation on the basis of CAD/CAM/CNC systems Reporter of the Priaevsky State Technical University Section Technical sciences 36 148–56

[3] Rubleva O 2014 Basic features of production technological preparation on small furniture enterprises Actual directions of scientific researches of the XXI century: theory and practice 2 260–4

[4] Kiselev E S, Nazarov M.V and Mezin N V 2019 To the issues of technological preparation and processing of non-rigid workpieces machine parts Vektor nauki Tol’yattinskogo gosudarstvennogo universiteta 47(1) 21–9 DOI:10.18323/2073-5073-2019-1-21-29

[5] Lutov A G, Ryabov Yu V, Shaydullin R I and Shambasov I I 2017 Intellectual Control of Processes of Technological Preparation of Machine-Building Production Bull. of the South Ural State University. Ser. Computer Technologies, Automatic Control & Radioelectronics 17 117–24

[6] Voronenko V, Sedykh M and Shashin A 2018 Technological preparation science intensive improvement in multiproduct production Science intensive technologies in mechanical engineering 2018 45–8

[7] Baurina S 2013 The process of technological preparation of production in quality management system: characteristics and main stages Economics of the Firm 2(1) 31–5

[8] Rabinskii L N, Ripetskiy A, Zelenov S V and Kuznetsova E 2017 Analysis and monitoring methods of technological preparation of the additive production J. of Industrial Pollution Control 33(1) 1178–83
[9] Svetlik J, Baron P, Dobránsky J and Kočiško M 2014 Implementation of Computer System for Support of Technological Preparation of Production for Technologies of Surface Processing *Applied Mechanics and Mater.* 613 418–25

[10] Burdo G B 2017 Improving the technological preparations for manufacturing production *Rus. Engineer. Res.* 37(1) 49–56

[11] Zhilyaev A S, Kugultinov S D and Efremov S M 2019 Problems of ensuring accuracy in the manufacture of largesized thin-walled parts *IOP Conf. Ser.: Mater. Sci. and Engineer.* 2–6

[12] Nazarevich S A, Urentsev A V, Kurlov V V, Balashov V M and Rozhkov N N 2019 Management of development of basic structures of technological systems of machine-building production *IOP Conf. Ser.: Materials Sci. and Engineer.* 537 042024

[13] Krastyaninov P M and Khusainov R M 2016 Selection of equipment for machining processing of parts using NX and TEAMCENTER programs *IOP Conf. Ser. Mater. Sci. and Engineer.* 134 012041 2–7

[14] Karpaev S A 2019 Improving the process of designing route maps in production *IOP Conf. Ser. Mater. Sci. and Engineer.* 537 042024

[15] Yurchik P F and Ko M K 2015 Use of Graph-Theoretic Models in Technological Preparation of Assembly Plant *Automation and Control in Technical Systems (ACTS)* 1 38–44 DOI: 10.12731/2306-1561-2015-1-5

[16] Abdrakhmanova K 2015 *Computer technologies in the life cycle of the product* DOI: 10.13140/RG.2.1.1720.0241

[17] Zhukov E L, Kozar I I and Kolodyazhniy D Yu 2016 Problems of Ensuring quality of a surface layer when producing components from hard-to-process heat resistant alloys *Acta Metallurgica Slovaca* 22(2) 128–132

[18] Maksarov V V and Keksin A I 2018 Forming conditions of complex-geometry profiles in corrosion-resistant materials *IOP Conf. Ser. Earth and Environmental Sci.* 194(6) 062016