**Management and Production Engineering Review**
Volume 11 • Number 4 • December 2020 • pp. 4–12
DOI: 10.24425/mper.2020.136115

# AN INTEGRATED APPROACH FOR IMPROVING TOOL PROVISIONING EFFICIENCY

Yuliia Denysenko[1], Vitalii Ivanov[1], Slawomir Luscinski[2], Viliam Zaloga[1]

[1] *Sumy State University, Ukraine*
[2] *Kielce University of Technology, Poland*

***Corresponding author:***
*Vitalii Ivanov*
*Sumy State University*
*Department of Manufacturing Engineering, Machines and Tools*
*Rymskogo-Korsakova 2, Sumy, 40007, Ukraine*
*phone: +380 542331024*
*e-mail: ivanov@tmvi.sumdu.edu.ua*

Received: 9 April 2020
Accepted: 10 September 2020

Abstract

The specificity of tool provisioning is conditioned using tooling, the quantity of which exceeds the nomenclature of the manufactured goods considerably. Therefore, for modern enterprises, first-priority issues are harmonizing the processes of tool provisioning systems, increasing the level of the reaction of this system to changes, obtaining operational control over the production system, and, thus, improving the efficiency of the production process. In this paper, a mathematical model of decision-making based on determining the optimal strategy for the process flow was proposed to improve the efficiency of the information system for quality management of tool provisioning. It is suggested to use the sustainable development factor of information system for quality management of tool provisioning to make decisions about the path of the tooling process, which considers the requirements of international standards for management systems (ISO 9001, ISO 45001, etc.). This model is based on the application of graph optimization theory, fuzzy logic, and Markov chains. The use of this model is universal and will increase the validity of operational management decisions, increase productivity, reduce resource dependency, and, therefore, reduce the costs of tool provisioning, which directly affects the cost of production and competitiveness of the enterprise as a whole.

Keywords

Tool provisioning, information system, decision making, optimization, sustainable development.

## Introduction

Modern production corresponds to the multiproduct conditions. The production planning under these conditions has certain features, which depend not only on the width of the workpiece and the batch size but also on the production conditions [1, 2]. Tool Provisioning (TP) of a multiproduct machine-building enterprise is a set of interrelated processes. Their purpose is to provide primary production with a quality tool and equipment exactly in time [3]. The quality of TP processes has a significant impact not only on the efficiency of the leading products but also on the competitiveness of the enterprise as a whole [4]. Many components ensure production efficiency, in particular the level of perfection of tooling and technological equipment [5–8], advanced materials and coatings [9, 10], the energy efficiency of implemented processes and their logistical connections [11, 12], the system of quality indicators [13], the level of automation of processes and systems to support the life cycle of products [14–16].

One of the main ways of improving the quality of TP is the introduction of modern information technologies, for example, AutoTAS, TIM LEITZ, eTMS Tadcon, GTMS, etc. The use of the "Tool Management" approach [17–19] is the foundation for effective management. Still, the issue of information systems (hereinafter referred to as IS) is assigned a minor role that does not entirely mirror the significance of the interactions between the management levels. As a rule, the tool (equipment) in these systems act only as a resource for enabling a specific production task; it is not considered as an object of control in the manufacturing process.

In order to effectively manage the TP process, it is essential to develop, implement, and maintain a TP quality management system. The general model of the information management system of TP [20] was developed according to the requirements of ISO 9001: 2015 (Fig. 1a). It integrates tool lifecycle and tooling processes, TP resource management, measurement, analysis, and improvement (both at the tactical and operational levels) in a single information space.

a)

b)

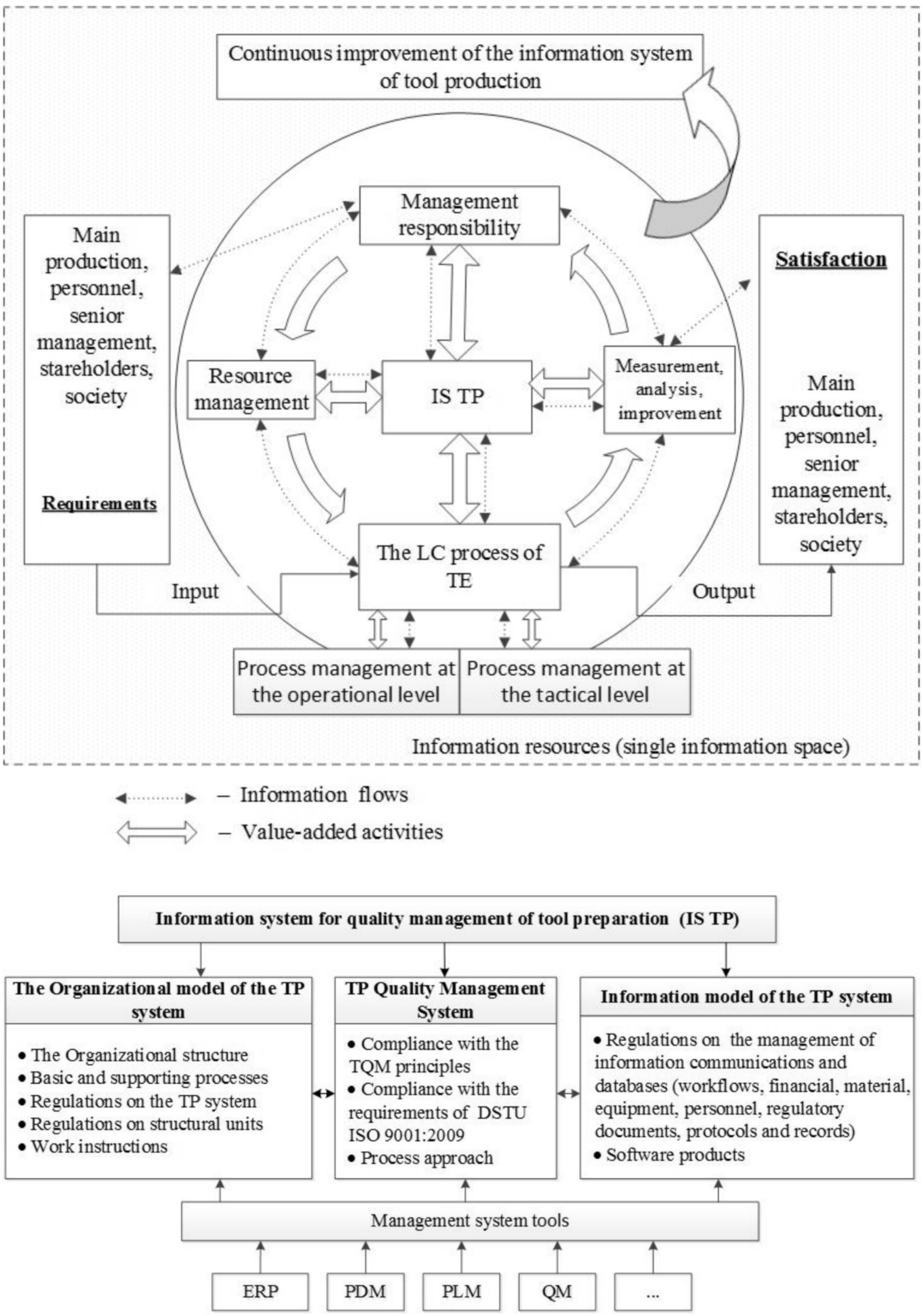


Fig. 1. A general model of the information system of tool provisioning management (a) and conceptual model of the system of TP management in the conditions of application of information technologies (b).

At the same time, the issue of development and implementation of the TP enterprise management system with applying the process approach to increase the efficiency of tooling is relevant for the modern multiproduct industrial enterprises, especially at the machine-building branch [21]. The conceptual model of the information system for quality management of tool provisioning (IS TP) consists of three interdependent models of process-based TP sub-systems: organizational, information, and quality management (Fig. 1b) [20].

In addition to the creation and implementation of management systems for various activities (quality management systems, environmental management systems, etc.), it is essential to develop a system of technical and economic indicators (hereinafter referred to as TEI) specifically for IS TP [20]. The TEI system supports presenting, concretizing, and realizing the life cycle of the tool, equipment and tooling (hereinafter – TE). It provides opportunities to show clearly the real picture and further prospects of IS TP development; evaluate its effectiveness and efficiency; identify the interconnections and interactions of the various factors of technology and economy that affect it; determine the reserves of tool production and equipment; elaborate measures to rationalize the use of maintenance and resources for their production, etc.

The information provided on the TEI system for IS TP is the basis for making strategically important quality decisions. At the same time, this information should have an orderly, comprehensible, and convenient look for the decision-maker. Particularly noteworthy is the selection of the most appropriate method for analyzing and evaluating the TEI system for IS TP due to the specified goal, the type, accuracy, and timeliness of the source information.

Therefore, the paper aims to introduce a mathematical model of making rational decisions, based on the application of the coefficient of its sustainable development, to increase the efficiency of the information system for managing the quality of tool provisioning

## Research methodology

One of the ways to solve the problem of analyzing and evaluating TEI IS TP is to create a mathematical model regarding the decision making on the TP for a machine-building enterprise. The model should be grounded in the system a process and approach with ensuring compliance with the principle of international standards of the 9000 series ISO – "fact-based decision making".

The decision-making process implementation is based on the following recommendations: definition of the goals and objectives for IS TP; consideration of issues related not only to the acquisition of qualitative TE, but also to other IS TP processes; orientation to the requirements of the primary production; determination of all necessary TEI that will provide a rational life cycle of TE; establishment of the target function and decision-making based on the definition of the stable branch of the TE LC.

A mathematical model for determining a rational TP strategy is proposed to meet the above requirements with applying the algorithm presented in Fig. 2. The model is based on the application of graph optimization method and Markov chain theory. It should be mentioned that the developed model allows choosing a rational TP strategy but does not exclude the possibility of making the final decision by the decision-maker.

In unit 1 of the model implementation algorithm, a database needed to build the model is formed, as well as an analysis of the states of IS TP processes. Although modern information systems also allow for the processing of information of large enough volumes quickly, at the same time, in order to reduce the time to make a rational decision, it is necessary to try to reduce the data sets.

The requirement to display a complete outline of IS TP processes can lead to very detailed information, which may not be very valuable. Moreover, it will significantly increase the time of processing, systematizing etc. Most of these systems may not be sufficient, so the IS TP management model must be aggregated. Aggregation refers to the replacement of the process sets a description with a process description that reflects the content of the process set being replaced and includes the essential characteristics of the set.

One of the major advantages of modern information systems is the suppling of a single information space, which greatly facilitates the exchange of information and the collection of necessary data. Also, control systems based on the principles of CALS-technologies allow the creation of relatively large arrays of output data in the shortest possible time. The baseline data for making a rational decision about IS TP processes are as follows: the planned costs of IS TP maintenance and quality management (based on the use of forecasting methods) and complex TEI IS TP (presented in points) [22]; the estimated time of execution of IS TP processes, and also the matrix of transitions of states of IS TP processes.

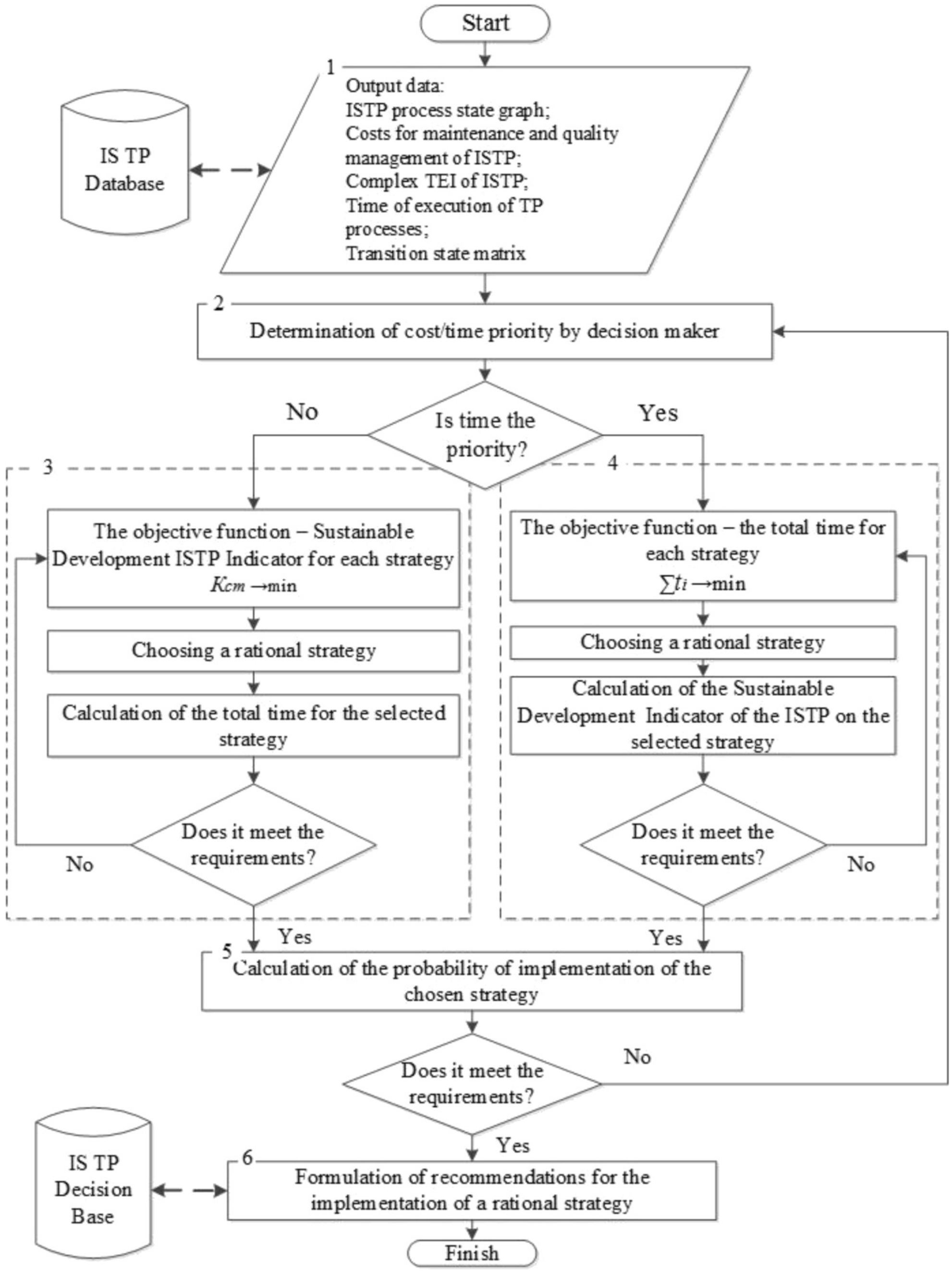


Fig. 2. Algorithm for implementation of a mathematical model for decision making in the information system of quality management of tool production provisioning.

Unit 3 implements the proposed procedure for determining the "cost/time" priority for the configuration of a new or modernization of an existing TE, the use of a combined TE, etc. by the decision-maker.

It was found on the analysis of the activities of domestic and foreign machine-building enterprises that decision-making regarding TP is typically based on the fulfilment of the two most common conditions: 1) the implementation of activities with the lowest costs (the most common condition); 2) the execution time minimization of the set tasks for TP. Following the obtained results, it is proposed to include split of the decision-making process model, regarding the choice of a rational strategy for TP, into two separate units, presented in the form of units 3 and 4 (Fig. 2).

Unit 3 corresponds to the strategy of implementing activities with minimal cost while providing the required level of TEI for IS TP; in other words – implementing the strategy of sustainable development of IS TP. Usually, the process of production planning is well-established in enterprises, so the schedule of providing TE of appropriate workplaces is already known in advance. In this case, the time function in the implementation of the TP is a priority and is restrictive.

In general, sustainable development is a concept of managed development that combines three components: economic, environmental, and social [23, 24]. All three elements must be considered in a balanced manner, so the main task is their coordination. Suggested Optimization Target Function – IS TP Sustainability Function ($K_{st}$):

$$K_{st} = Q \cdot \sum_{j=1}^{m} \sqrt[6]{\left(\frac{B_b}{B_j}\right)^{\gamma_1} \cdot K_{oj}^{\gamma_2} \cdot K_{mj}^{\gamma_3} \cdot K_{qj}^{\gamma_4} \cdot K_{ej}^{\gamma_5} \cdot K_{sj}^{\gamma_6}} \rightarrow \min, \tag{1}$$

where $Q$ is the quality index of the IS TP process; $B_b$ – the baseline cost indicator for IS TP processes; $j$ – IS TP process number; $m$ – the number of IS TP processes; $B_j$ – the cost of process quality; $K_o$, $K_m$, $K_q$, $K_e$, $K_s$ – respectively organizational-technical, production, process quality of IS TP, environmental, and socially integrated TEI calculated for each IS TP lifecycle; $\gamma_1 - \gamma_6$ – weight coefficients of complex TEI, respectively: organizational-technical, production, process quality of IS TP, environmental, and social.

The use of the IS TP Process Quality Score eliminates a path whose process quality does not meet the requirements of the decision-maker. If the quality level of the IS TP process meets the requirements, then $Q_q = 1$, if doesn't, $Q_q = 0$.

Costs for the quality of IS TP processes are determined separately for a particular enterprise, taking into account its technical and economic status and other economic factors. Also, depending on the time at which quality costs are determined, they can be estimated or calculated.

It should also be noted that the cost of the process lifecycle of TE is taken to the corresponding unit of TE, i.e., the planned cost of the quality of the processes IS TP $B$ is calculated by the formula:

$$B = \frac{\sum_{i=1}^{m} (B_{p_i} + B_{y_i})}{K_{\text{TO}}}, \tag{2}$$

where $B_{p_i}$ – planned costs for quality assurance of the IS TP process; $B_{y_i}$ – planned costs for managing the quality of the IS TP process; $m$ – the number of cost articles on the quality of the IS TP process; $K_{\text{TO}}$ – the number of those TE for which the decision-making process regarding the LC process is underway.

It should be noted that due to the implementation of IS TP, there are processes at the tactical level that incur costs with a negative value, and the opposite at the operational level. For example, the process of refinishing a toll or repairing entails additional costs for quality, while increasing the number of refinements increases the value of the tool as it extends the payback period of the costs involved in making or acquiring the TE (tool) by extending its service life. Therefore, for the TP operational level, it is suggested to attribute the cost of TP processes quality to the number of repairs or overhauls, i.e., it is suggested to use relative quality indicators.

It is proposed to determine the coefficients of the weight of complex TEIs using an expert approach for a specific enterprise.

The limiting conditions when performing unit 3 are (a) the possibility of supplying TE for the main production at the determined time:

$$\sum_{j=1}^{n} t_j \leq T, \tag{3}$$

where $t_j$ – the time of performance of the $j$-th process; $T$ – the total time for TE of the main production; (b) fulfillment of the requirements of quality by all coefficients [6]:

$$\sum_{k=1}^{6} \gamma_j = 1. \tag{4}$$

In unit 4, a strategy is implemented to minimize the execution time of tasks set in IS TP. It is explained by the occurrence of a situation when the time for supplying TE to workplaces is limited due to the launch of an unplanned party or neglect of factors that may affect the availability of the necessary TE in the reserve stock. In this case, a strategy is chosen where the rigid timeframes set will not cause the overhead or dramatic deterioration of the TEI of the main production.

When executing this strategy, the purpose of the decision-making function is to optimize the execution time of the relevant TP processes:

$$\sum_{j=1}^{n} t_j = T \rightarrow \min. \tag{5}$$

In this case, the limiting conditions will be as follows:

$$K_{cm} \rightarrow \min \quad \text{and} \quad \sum_{k=1}^{6} \gamma_j = 1. \tag{6}$$

Unit 5 provides a calculation of the probability of implementing the chosen strategy by applying the theory of Markov chains [25] If the value of the calculated probability is less than the level that satisfies the decision-maker, then alternative strategies for the flow of IS TP processes should be considered.

In unit 6, based on the information received from units 3, 4, and 5, the decision-maker chooses the most rational strategy for the development of IS TP processes.

## Results

The proposed algorithm of rational decision-making in IS TP was implemented for the example of the IS TP tactical level processes. As a case, a rational decision was made to provide the cutters with machining details of the Shaft 1.3910-650.10-02. The following options were considered: "to buy 10 tools", "to use 10 tools available", "to make 10 tools", "to upgrade 10 tools" and "to make 10 tools out of stock". The limiting condition was "time". Accordingly, unit 3 of the algorithm of the decision model in IS TP was executed (Fig. 2).

According to the first stage of the proposed algorithm, a graph of the tactical level processes states of the IS TP is constructed (Fig. 3).

According to the graph, the decision "to buy 10 tools" fits the route 1-4-11-14-15-22-23, decision "to use 10 tools available" – route 1-3-15-22-23, "to make 10 tools" – route 1-2-5-8-9-15-22-23, "to upgrade 10 tools" – route 1-2-6-10-13-15-22-23 and "to make 10 tools out of stock" – route 1-2-7-10-13-15-22-23.

The estimation of TEI predicted values in IS TP, the calculation of complex TEI for IS TP, and the coefficient of sustainable development of IS TP processes were performed using Microsoft Excel.

The values of TEI (Fig. 4) and the cost of quality of IS TP processes (Fig. 5) were found using forecasting methods. It should be noted that in Fig. 4 the values of TEI are translated into points according to the rating scales that are proposed to be developed for a particular enterprise by applying the methods of fuzzy logic [8].

As can be seen from Figs 4 and 5, the file has seven attachments, the first (basic) – to calculate the coefficient of sustainable development of IS TP tactical processes, the second – to calculate the cost of quality of IS TP processes, the other five – to calculate complex TEI social, organizational, quality, production, and environmental groups.

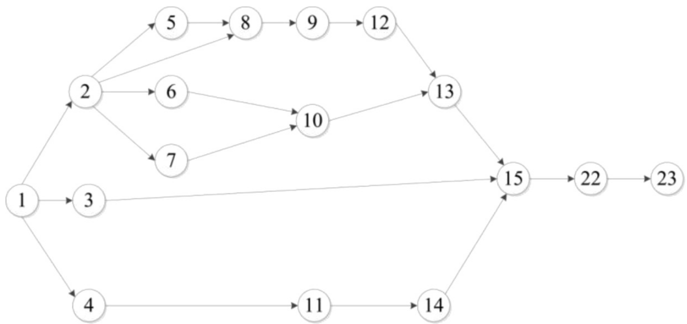


Fig. 3. A graph of the tactical level processes states of the IS TP.

| Social TEI | TEP values for ISTP processes according to state graph, points | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | identification of technological equipment (TE) needs | the decision to manufacture, modernize TE or use prefabricated TE | making a decision on the use of the available TE | making a decision on the purchase of a unified TE | development of a project for manufacturing TE | development of a project for the modernization of TE | development of a project for the preparation of TE | preparation of a TE productionplan | purchase of materials | purchase of components | purchase of TE | TE production |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| The level of regulatory documents in the field of labor | 5 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 |
| The level of staff briefing | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Employment rate of staff | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| level of attestation of personnel working with high risk | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| **Complex indicator** | 4,684556 | 4,603421 | 4,414214 | 4,414214 | 4,414214 | 4,603421 | 4,414214 | 4,414214 | 4,414214 | 4,414214 | 4,414214 | 4,792628 |

KCT | Costs | organizational | production | quality | social | environmental

Fig. 4. Organizing information on TEI values for IS TP tactical processes.

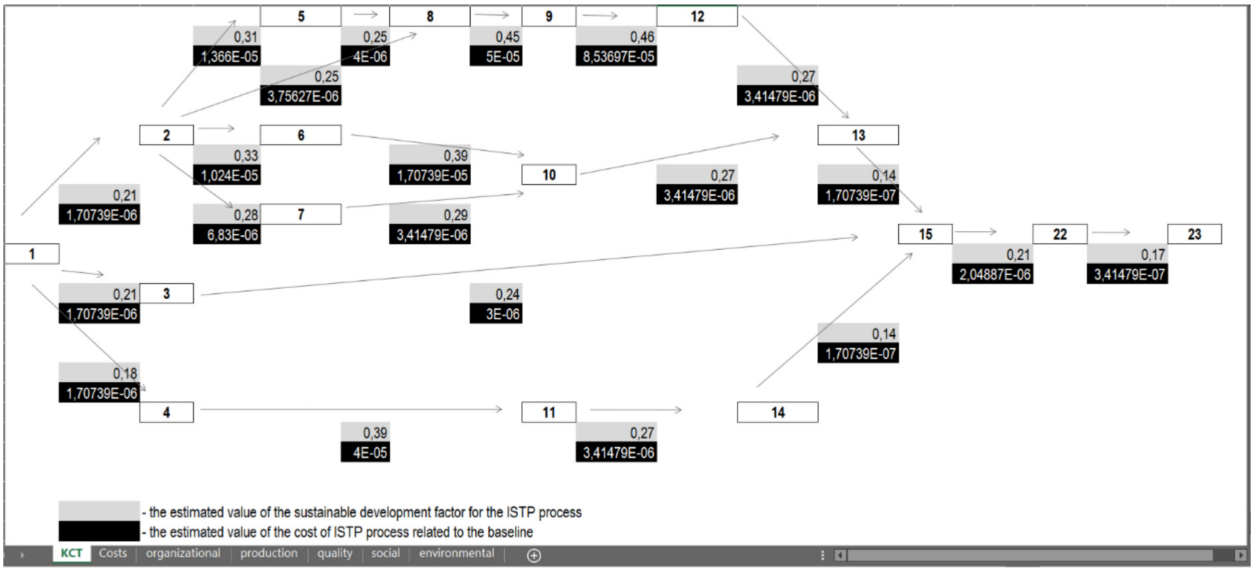


Fig. 5. Sustainability factor calculation for IS TP tactical processes.

The calculations confirmed that for the case study under consideration, the rational solution would be "to use the 10 tools available".

## Conclusions

Under current global market conditions, ensuring the competitiveness of machine-building multi-product manufacturing-oriented enterprises requires the introduction of information technologies to support production processes more efficiently oriented. The traditional provisioning-tool management software considers machine tools only as a resource, without the complex context of their use in flexible manufacturing systems. The presented new approach based on introducing a system of technical and economic indicators TEI to decisions-making on tool-provisioning strategy allows to evaluate TP effectiveness and efficiency; identify the interconnections and interactions of the various factors of technology and economy that affect it; determine the reserves of tool production and equipment; elaborate measures to rationalize the use of TE and resources for its production, etc.

To solve the problem of analyzing and evaluating the TEI system for IS TP, a mathematical model regarding the decision making on the TP of a machine-building enterprise was developed. The model is based on the definition of a rational strategy for the flow of IS TP processes of the engineering company and the use of optimization theories on graphs and Markov chains.

This model significantly simplifies the information dissemination process and increases the validity of operational management decisions; minimizes IS TP costs and increases IS TP efficiency by 13%.

For the first time, it was suggested to use the IS TP Sustainable Development Factor for decision making regarding the rational route of TP processes, which takes into account the requirements of international standards for management systems (ISO 9001, ISO 45001, etc.) and allows to increase the level of validity of the decisions made.

In the future, it is planned to improve the functionality of the software integrated into the enterprise's IS TP, which will allow the use of information from databases in automatic mode.

## References

[1] Trojanowska J., Kolinski A., Galusik D. et al., *A methodology of improvement of manufacturing productivity through increasing operational efficiency of the production process*, Advances in Manufacturing, MANUFACTURING 2017, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 23–32, 2018, doi: 10.1007/978-3-319-68619-6_3.

[2] Rewers P., Trojanowska J., Diakun J. et al., *A study of priority rules for a levelled production plan*, Advances in Manufacturing, MANUFACTURING 2017, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 111–120, 2018, doi: 10.1007/978-3-319-68619-6_11.

[3] Martynov A., Chernodubova E., *Information and analytical tools management of innovative expenses of the enterprise*, Scientific Notes of Taurida National VI. Vernadsky University, Series: Economy and Management, 30, 69, 4, 82–86, 2019, doi: 10.32838/2523-4803/69-4-15.

[4] Xu J.Y., Wang G.C., Liu G., *Study on whole life cycle management of cutting tool*, Advanced Materials Research, 455–456, 234–239, 2012, doi: 10.4028/www.scientific.net/amr.455-456.234.

[5] Kotliar A., Gasanov M., Basova Y., Panamariova O., Gubskyi S., *Ensuring the reliability and performance criterias of crankshafts*, Diagnostyka, 20, 1, 23–32, 2019, doi: 10.29354/diag/99605.

[6] Krol, O., Sokolov, V., *Development of models and research into tooling for machining centers*, Eastern-European Journal of Enterprise Technologies, 3, 1(93), 12–22, 2018, doi: 10.15587/1729-4061.2018.131778.

[7] Sokolov V., Krol O., Stepanova O., *Automatic control system for electrohydraulic drive of production equipment*, 2018 International Russian Automation Conference, RusAuto-Con 2018, IEEE, 2018, 8501609, doi: 10.1109/RUSAUTOCON.2018.8501609.

[8] Voloshina A., Panchenko A., Boltyansky O., Titova O., *Improvement of manufacture workability for distribution systems of planetary hydraulic machines*, Advances in Design, Simulation and Manufacturing II, DSMIE-2019, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 732–741, 2020, doi: 10.1007/978-3-030-22365-6_73.

[9] Kostyuk G., *Prediction of the microhardness characteristics, the removable material volume for the durability period, cutting tools durability and processing productivity depending on the grain size of the coating or cutting tool base material*, Advances in Manufacturing II, Vol. 4, MANUFACTURING 2019, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 300–316, 2019, doi: 10.1007/978-3-030-16943-5_27.

[10] Kostyuk G., Nechyporuk M., Kostyk K., *Determination of technological parameters for obtaining nanostructures under pulse laser radiation on steel of drone engine parts*. 10th International Conference on Dependable Systems, Services and Technologies, DESSERT 2019, IEEE, 18865252, 2019, doi: 10.1109/DESSERT.2019.8770053.

[11] Kiyko S., Druzhinin E., Prokhorov O., Ivanov V., Haidabrus B., Grabis J., *Logistics control of the resources flow in energy-saving projects: case study for metallurgical industry*, Acta logistica, 7, 1, 49–60, 2020, doi: 10.22306/al.v7i1.159.

[12] Behúnová A., Knapčíková L., Behún M., *Logistics of controlling implementation in conditions of manufacturing enterprise*, Acta logistica, 7, 1, 23–29, 2020, doi: 10.22306/al.v7i1.154.

[13] Tonkonogyi V., Sidelnykova T., Dašić P., Yakimov A., Bovnegra L., *Improving the performance properties of abrasive tools at the stage of their operation*, New Technologies, Development and Application II, NT 2019, Lecture Notes in Networks and Systems, vol. 76, pp. 136–145, Springer, Cham, doi: 10.1007/978-3-030-18072-0_15.

[14] Kuric I., Kandera M., Klarák J., Ivanov V., Więcek D. *Visual product inspection based on deep learning methods*, Advanced Manufacturing Processes, InterPartner-2019, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 148–156, 2020, doi: 10.1007/978-3-030-40724-7_15.

[15] Saniuk S., Saniuk A., Caganova D., *Cyber industry networks as an environment of the Industry 4.0 implementation*, Wireless Networks, in press, 2019, doi: 10.1007/s11276-019-02079-3.

[16] Denysenko Y., Dynnyk O., Yashyna T., Malovana N., Zaloga V., *Implementation of CALS-technologies in quality management of product life cycle processes*, Advances in Design, Simulation and Manufacturing, DSMIE-2018, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 3–12, 2019, doi: 10.1007/978-3-319-93587-4_1.

[17] Skowron A. *Tool lifecycle management in industrial practice*, Management Systems in Production Engineering, 18, 2, 69–75, 2015, doi: 10.12914/MSPE-04-02-2015.

[18] Enterprise Tool Management Software, http://www.tadcon.com/eTMS%20solution.htm.

[19] Chemborisov N., Khisamutdinov R., Akhmetzyanov D., *Tool management systems*, Russian Engineering Research, 30, 94–96, 2010, doi: 10.3103/S1068798X10010211.

[20] Zaloga V., Denysenko Y., *Improvement of technical and economic indicators of tool preparation of machine-building production by improvement of the regulation base*, New stages of development of modern science in Ukraine and EU countries: monograph, 3rd ed. Riga: Baltija Publishing, 2019, pp. 116–142 (in Ukrainian).

[21] Ivanov V., *Process-oriented approach to fixture design*, Advances in Design, Simulation and Manufacturing, DSMIE-2018, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 42–50, 2019, doi: 10.1007/978-3-319-93587-4_5.

[22] Dynnyk O., Denysenko Y., Zaloga V., Ivchenko O., Yashyna T., *Information support for the quality management system assessment of engineering*

*enterprises*, Advances in Design, Simulation and Manufacturing II, DSMIE-2019, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 65–74, 2020, doi: 10.1007/978-3-030-22365-6_7.

[23] Streimikiene D., Mikalauskiene A., Ciegis R., *Chapter 1. Sustainable development and organizational sustainability*, Sustainable Development, Leadership, and Innovations, book, 1st ed., Boca Raton: Taylor & Francis Group, 2019, doi: 10.1201/9781003003397-1.

[24] Dimitrakopoulos G., Uden L., Varlamis I., *Chapter 13 – ITS and sustainability*, The future of intelligent transport systems, Elsevier, 2020, pp. 145–156, doi: 10.1016/B978-0-12-818281-9.00013-9.

[25] Hamdy A. Taha, *Operations Research: An Introduction*, 10th ed., University of Arkansas, 2017.