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Structural analysis of technological processes with multivariate machining operations

A M Schipachev

Department of transport and storage of oil and gas, Saint Petersburg Mining University, 2, 21st Line, St Petersburg, 199106, Russia

E-mail: schipachev_am@pers.spmi.ru

Abstract. This article addresses the issue of structure optimization for machining technological processes. A technological process typically offers multivariate operations. A choice of one option is an optimization problem. A mathematical solution of it is complicated since a number of optimization criteria can be present. However, a multivariate technological process can be presented as a directed graph. First, all paths of the graph are found and their length that correspond to values of certain optimization criteria are determined. Then the optimal path is selected (that is, the optimal technological process) by finding generalized optimization criteria and comparing them.

1. Introduction

Machining as a technological process is multivariate. Given one design and technical specification, it is possible to create a finished product by utilizing different processing methods, technological modes, equipment and facilities.

Theoretically, no matter what technological process is chosen, it is possible to manufacture an item that meets all requirements. The purpose of optimization calculations is to find out the optimal variant of its machining: in comparison with other options, it should save production time and costs, provide higher energy efficiency, minimize risks and improve other factors included in the analysis. All factors that are important for a researcher constitute optimization criteria.

2. Methods and materials

It is a common practice to represent variants of technological processes in a form of the directed graph: vertices correspond to technological operations, while edges are logical connections that display a sequence of operations. A graph has one root vertex and one end vertex.

For example, figure 1 shows a graph of the machining technological process for some abstract item. Here, multiobjective optimization is considered. The goal is to choose the optimal technological path. To solve this problem, both a systematic approach to decision-making and informal methods, such as common sense, need to be applied. The role of the decision-maker in this process is also significant. Which variant of a technological path can be considered optimal requires analysis. The chosen path can be less favorable in one parameter, but the increased gain in another factor can significantly outweigh it. The formal application that relies purely on mathematical relations is not sufficient in this case.



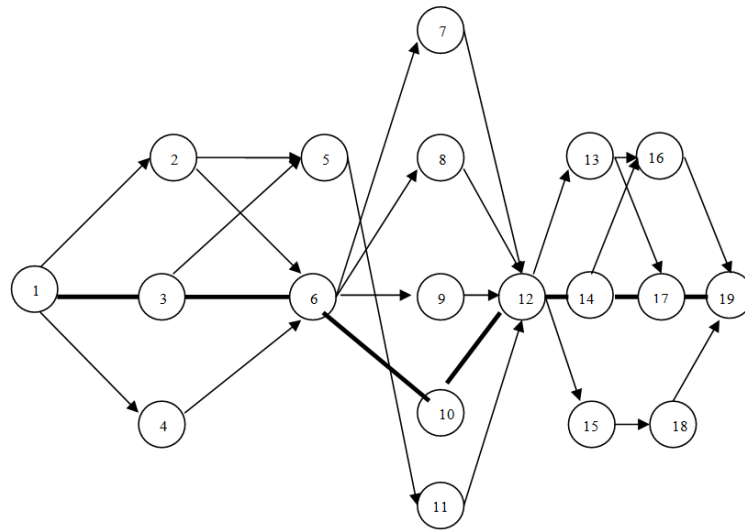


Figure 1. Example of a graph that corresponds to a multivariate technological process.

This research aims to analyze methodological approaches to optimization of technological processes described in studies [1-7], demonstrate their shortcomings to offer more suitable one. It will also show the necessity of informal analysis to get a broader view on the issue.

For a set of all possible graph paths $\{q\}$ that connect a designated vertex with an end one, a notion of j -th path length ($j=1, q$) by k -th criterion of optimization L_{jk} needs to be defined: it is a sum of k -th criterion values ($k=1, t$) for all vertices of the j -th path.

For our example (Figure 1) the number of graph paths is pretty small and it is easy to find them using enumeration. However, most technological processes are very complex, making it difficult to determine all possible paths and their lengths according to the required criteria.

In order to list all paths of the graph, the following software can be used: Amacont (developed by Anferov M. A.) [5] or BMAS (developed by Mitioglov B. A. and Shchipachev A. M.) [3]. BMAS software is easier to use, as it has more user-friendly interface and convenient graph visualization options. It is written in Java programming language.

In resulting list of graph paths, manufacturing costs and handling time are specified for each path. Each path corresponds to a specific processing option.

Consider the example of manufacturing a nut. Its schematic can be found in Figure 2.

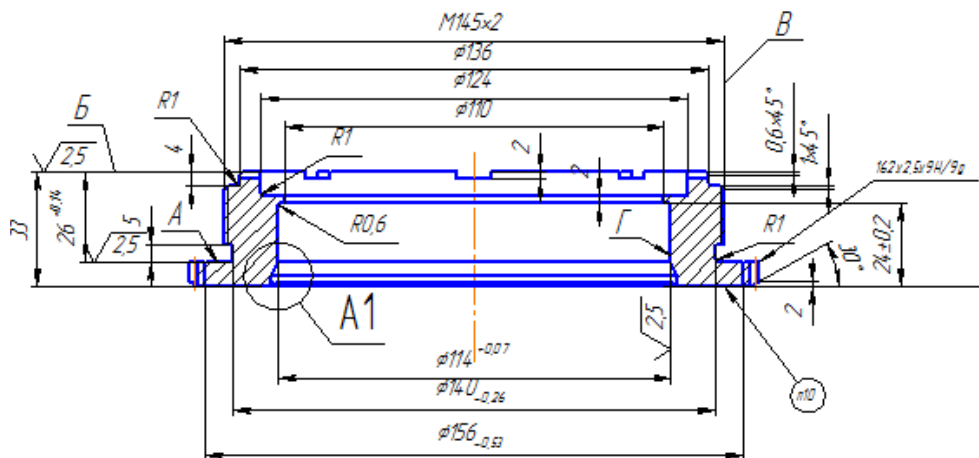


Figure 2. Schematic of a nut (a fragment).

3. Results and discussion

A graph of multivariate technological process for manufacturing a nut is shown in Figure 3.

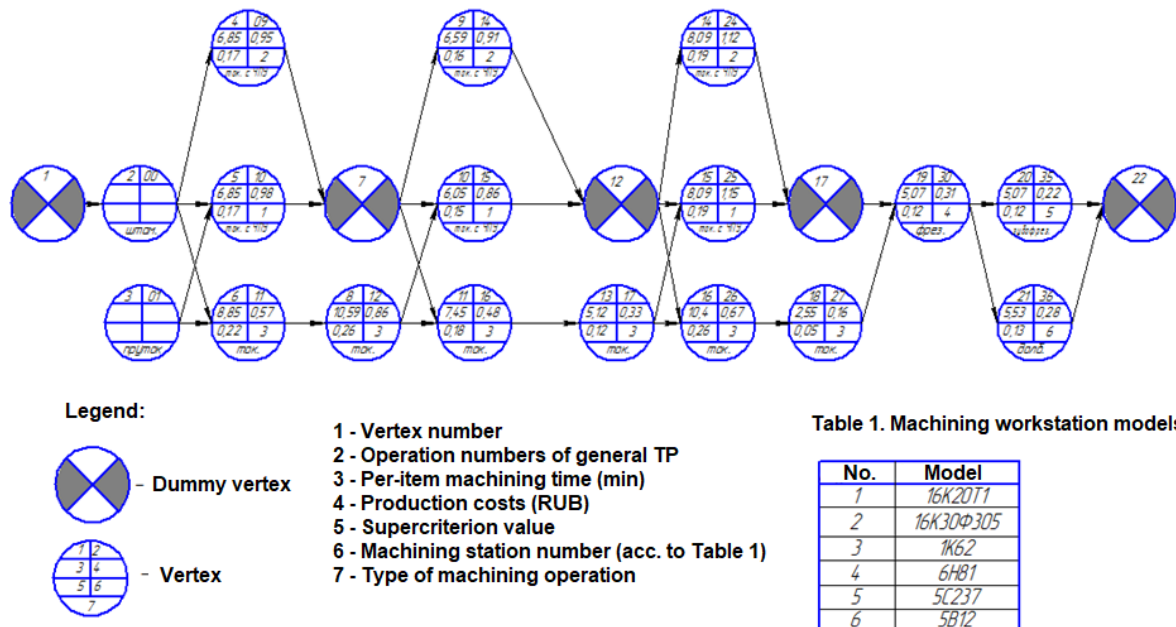


Figure 3. A graph of technological processes for nut machining.

The following values of optimization criteria were calculated: cost of machining C and machining time T per item for each operation. Variants of technological process can be represented graphically, with C and T used as a coordinate grid. Figure 4 shows a diagram with absolute values of the criteria.

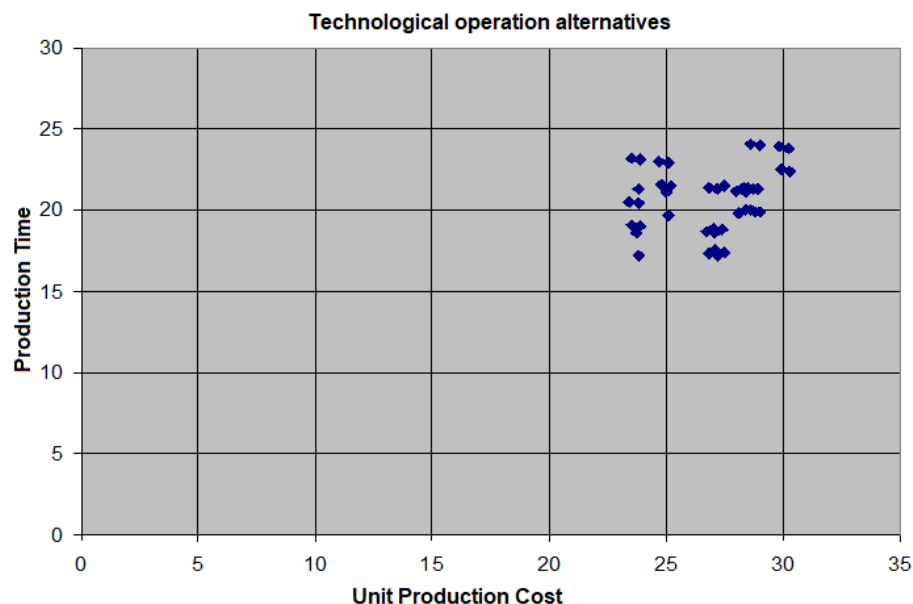


Figure 4. Time vs. item production cost in absolute coordinates.

The result is a cloud of points. However, in order to handle and compare values, we need to present them in a relative form: for each k -th criterion, the lengths of all q paths are calculated in relative form in Figure 5. For a j -th path :

$$L_{jk}^* = \frac{L_{jk} - L_{\min k}}{L_{\max k} - L_{\min k}} \quad (1)$$

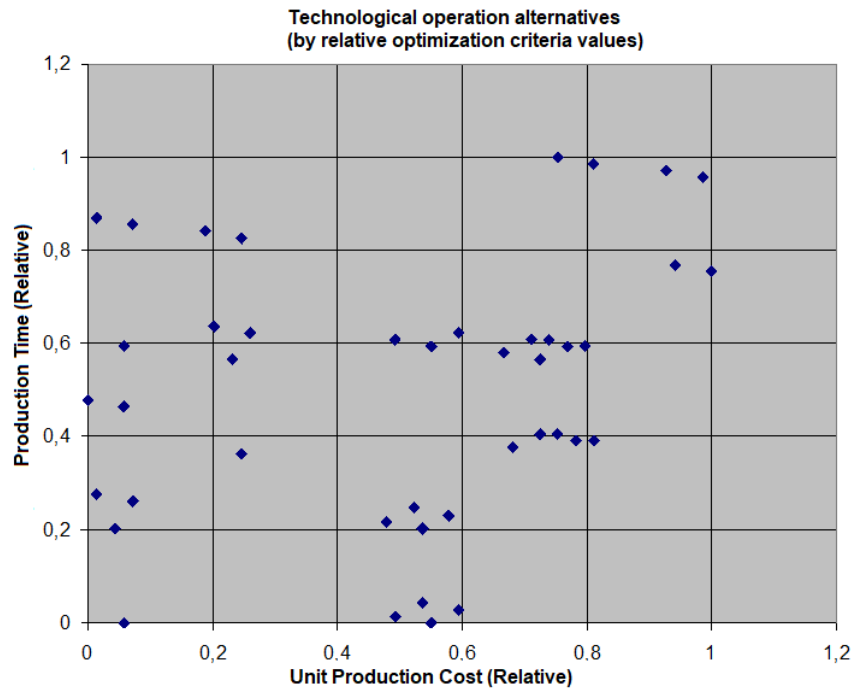


Figure 5. Time vs. item production cost in relative coordinates.

Using relative coordinates is the only correct approach to represent results for the following reasons:

- a) Nondimensional view allows for comparison of criteria that have different dimensions and further criteria minimization
- b) The range of criteria value change in its absolute form can be quite different, while in relative coordinates, if criteria minimization formulas are used, it is uniform. This is indicated in a study by R. L. Keeney and Raiffa [4]. When formula (1) is used, the range of change of all criteria in a relative form is from 0 to 1.

The same range of criteria changes is necessary for correct calculation of the supercriterion (criteria minimization) for every j -th path via the following formula: $L_{sj}^* = \alpha_C L_{Cj}^* + \alpha_T L_{Tj}^*$ – for this particular example. For generic case, the formula is as follows:

$$L_{sj}^* = \sum_{k=1}^m \alpha_k L_{kj}^* \quad (2)$$

Criteria values for operations (vertices), similar to the data input in software, should be strictly in absolute form. The relative form is only calculated via the formula (1). The supercriterion is calculated via the formula (2), i.e. via the path lengths. It is a common practice to minimize values of optimization criteria, i.e. the optimum is the minimum. If some criterion needs to be maximized, an inverse criterion should be used instead: for example, instead of performance efficiency, processing time as its inverse value can be used.

For a case considered in this research, the optimal path can be found based on criteria minimization method or by determining a supercriterion if a task is discrete, via the following formula:

$$L_{s,opt} = \min \{ L_{s,j} \}$$

For two criteria, a graphical interpretation is possible via the following criterion function:

$$L_s^* = \alpha_C L_C^* + \alpha_T L_T^* \rightarrow \min ,$$

After that, find its minimization direction in the diagram and the limit point of intersection with a discrete set that correspond to the optimal solution. It is also possible to apply informal and subjective restrictions (such as availability of appropriate machining equipment, insufficient qualification to perform an operation, etc.).

4. Conclusion

The structural analysis of a technological process considered in this study consists in the following:

- representing multivariate technological process in a form of the directed graph;
- finding optimization criteria for a technological process;
- determining a generalized criterion through the use of appropriate methodological approaches.

It allows for finding the best variant of a technological process when several optimization criteria should be considered.

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