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Simulation-dynamic model of working time costs calculation for performance of operations on CNC machines

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Abstract. This article presents a simulation-dynamic model for determining the time spent on machining operations on machines with a numerical control (CNC). The model is developed on the basis of the system dynamics method using Powersim Studio tools. In the shown model, the calculations of the probabilistic deviation of the actual time of technological operations on CNC machines from the technically sound time norm were carried out on the basis of the Gaussian normal distribution law. The model was used as a tool to study the probabilistic distribution of time for equipment retooling and to perform technological operations on HAAS SL-20 CNC machines. The study allows us to conclude that the constructed simulation dynamic model is quite universal and, on its basis, it is possible to carry out a variety of studies concerning various aspects of the technical substantiation of the time norms for performing machining operations on CNC machines.

1. Introduction

In a market economy, globalization and increased competition, the most important issues for modern domestic engineering enterprises are to increase the competitiveness of the production environment and management processes. Realizing this, many enterprises invest heavily in re-equipping production with new equipment, mainly numerically controlled machines (CNC). A CNC lathe is a computerized system for controlling the manufacturing processes of metal parts. They are based on microprocessors with random access memory, an operating system and microcontrollers. CNC allows you to work with incredible accuracy, despite the fact that its work is almost not related to the human factor. Also, these machines significantly increase ergonomic indicators, reducing the number of injuries at work. The share of equipment of CNC machines in the production of all directions is growing from year to year [1].

Among the main factors that make up the technological process in which CNC machines are involved is the time required to process the part. It is a technical time standard for paying for work, for calculating the cost of a part and a product, and for calculating the required number of machines in a workshop. The technical norm of time should be understood as the time required in certain organizational and technical conditions for processing the product in accordance with the operational capabilities of the machine, in terms of the application of working methods that meet the current level of advanced technology. Consequently, a technically justified rate of time acts as one of the economic levers of the economic mechanism affecting the efficiency and quality of work [1].

But the actual processing time of a part may differ to a greater or lesser extent from a technically justified norm of time, due to the influence of factors such as: irrational organization of the workplace, processing allowances abnormal for this equipment, inappropriate grade and quality of the material, not optimal cutting conditions, etc.

The need to take into account the influence of these factors determines the use of instrumental management methods, such as economic and mathematical modeling (EMM), which increase the efficiency of decisions made on the organization of the production process. One of these modern and widely used approaches today is a simulation and dynamic simulation, system dynamics method [1].

2. Model for determining cost of working time for performance of operations machining CNC machines

The model for determining the time spent on technological operations is presented in figure 1.

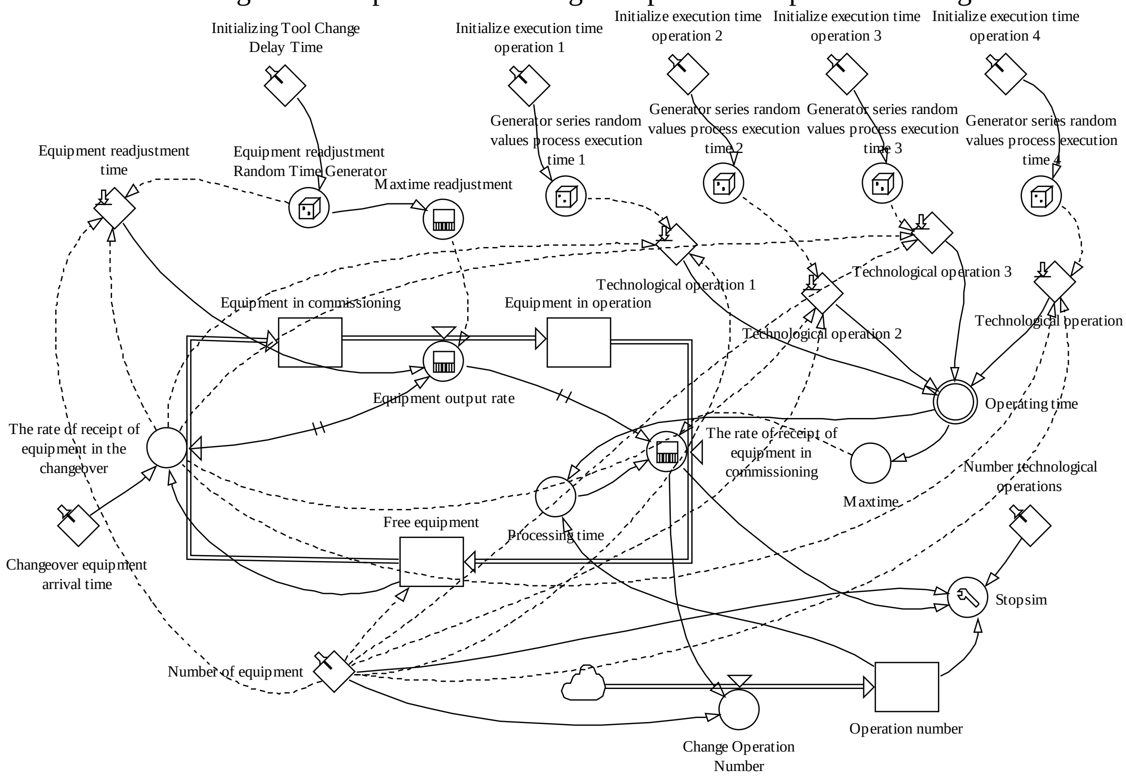

Figure 1. Diagram of flows and levels for determining the costs of working time for performing machining operations on CNC machines.

It includes four levels (drives): free equipment; equipment in commissioning; equipment in operation; operation number. The diagram also shows four streams: rate of receipt of equipment in the changeover; equipment output rate; rate of receipt of equipment in commissioning; change operation number. In addition to the listed flows and levels, auxiliary variables are present in the diagram. The interpretation of the variables shown in the diagram is presented in table 1.

Consider the algorithm for determining the cost of working time to perform machining operations on CNC machines.

Rationing of machining operations on CNC machines is carried out according to the standards of piece time and preparatory-final time. The piece time is divided into the cycle time of the automatic machine operation according to the program and the manual auxiliary time. In turn, the cycle time of automatic operation of the machine according to the program is divided into the main time of automatic operation of the machine according to the program and machine auxiliary time.

Table 1. The variables used in the diagram of flows and levels of determining the time spent on machining operations on CNC machines.

Name	Documentation
Change Operation Number	Process counter
Changeover equipment arrival time	Changeover equipment arrival time
Equipment in commissioning	Conversion Equipment
Equipment in operation	Equipment in operation
Equipment output rate	Equipment Changeover Rate
Equipment readjustment Random Time Generator	Equipment Changeover Random Time Generator
Equipment readjustment time	Equipment readjustment time
Free equipment	Equipment freed up after operation
Generator series random values process execution time 1...n	Generator of a series of random values of the execution time of the technological operation 1 ... n
Initialize execution time operation 1…n	Initialization of the execution time of operation 1 ... n
Initializing Tool Change Delay Time	Initializing Tool Change Delay Time
Maxtime	The maximum processing time
Maxtime readjustment	Maximum equipment retooling time
Number of equipment	Number of equipment
Number technological operations	The number of technological operations
Operating time	Temporary routing
Operation number	Process Operation Index
Processing time	Processing time
Stopsim	Stop the simulation process
Technological operation 1…n	The duration of the technological operation 1 ... n
The rate of receipt of equipment in commissioning	The pace of the technological operation
The rate of receipt of equipment in the changeover	The rate of receipt of equipment in the changeover

Machine-auxiliary time associated with the transition, included in the program and related to the automatic auxiliary work of the machine, provides [2 - 4]:

- Supply of the part or tool from the starting point to the machining zone and retraction.
- Setting the tool to the processing size.
- Automatic tool change.
- Turning on and off the feed.
- Idling during the transition from processing one surface to another.
- Technological pauses provided for a sharp change in the flow direction, when checking the dimensions, for inspecting the tool and reinstalling or re-securing the workpiece [5, 6].

In the developed model, the change in the main time of automatic operation of the machine according to the program and machine auxiliary time is investigated. It is assumed that the deviation of the actual execution time of the technological operation and auxiliary time occurs according to the law of the normal Gaussian distribution [7]. Since the normal distribution is well suited for real phenomena in which:

- There is a strong tendency for data to cluster around the center.
- Positive and negative deviations from the center are equally probable.
- The frequency of deviations decreases rapidly when the deviations from the center become large.

The Gauss formula, which calculates the probability distribution of the values of the main time of automatic operation of the machine according to the program and machine auxiliary time, is presented below:

$$f(x) = \frac{1}{\sigma \times \sqrt{2\pi}} \times e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad (1)$$

where: parameter μ is the mean (average), median and distribution mode, and parameter σ is the standard deviation (σ^2 is the variance) of the distribution.

The simplest case of a normal distribution is the standard normal distribution, a special case when the mathematical expectation is $\mu = 0$ and the standard deviation is $\sigma = 1$. Its probability density is

$$\varphi(x) = \frac{1}{\sqrt{2\pi}} \times e^{-\frac{1}{2}x^2}, \quad (2)$$

About 68% of the values from the normal distribution are located at a distance of no more than one standard deviation σ from the average; about 95% of the values lie at a distance of no more than two standard deviations; and 99.7% of not more than three. This fact is a special case of the 3-sigma rule for normal sampling.

The rule of three sigma (3σ) – almost all values of a normally distributed random variable lie in the interval ($\mu - 3\sigma;\ \mu + 3\sigma$), where $\mu = \mathrm{E} \times \xi$ is the mathematical expectation and the parameter of the normal random variable. More precisely, with approximately probability 0.9973, the value of a normally distributed random variable lies in the indicated interval.

3. Management interface for a model for determining working time costs for performing machining operations on CNC machines

Figure 2 shows the management interface for determining the cost of working time for machining operations on CNC machines. The interface structure consists of two parts: input data input and monitoring of calculation results.

Before the start of the calculation, the following data is entered:

- Time of the operation; amount of equipment in operation.
- Number of technological operations performed (1 ... n).
- Tool change delay time.

In the second part of the interface, the results of the calculation are displayed in graphical form:

- Series of random values for the equipment change-over time.
- Series of random values for the duration of the technological operation (1 ... n).

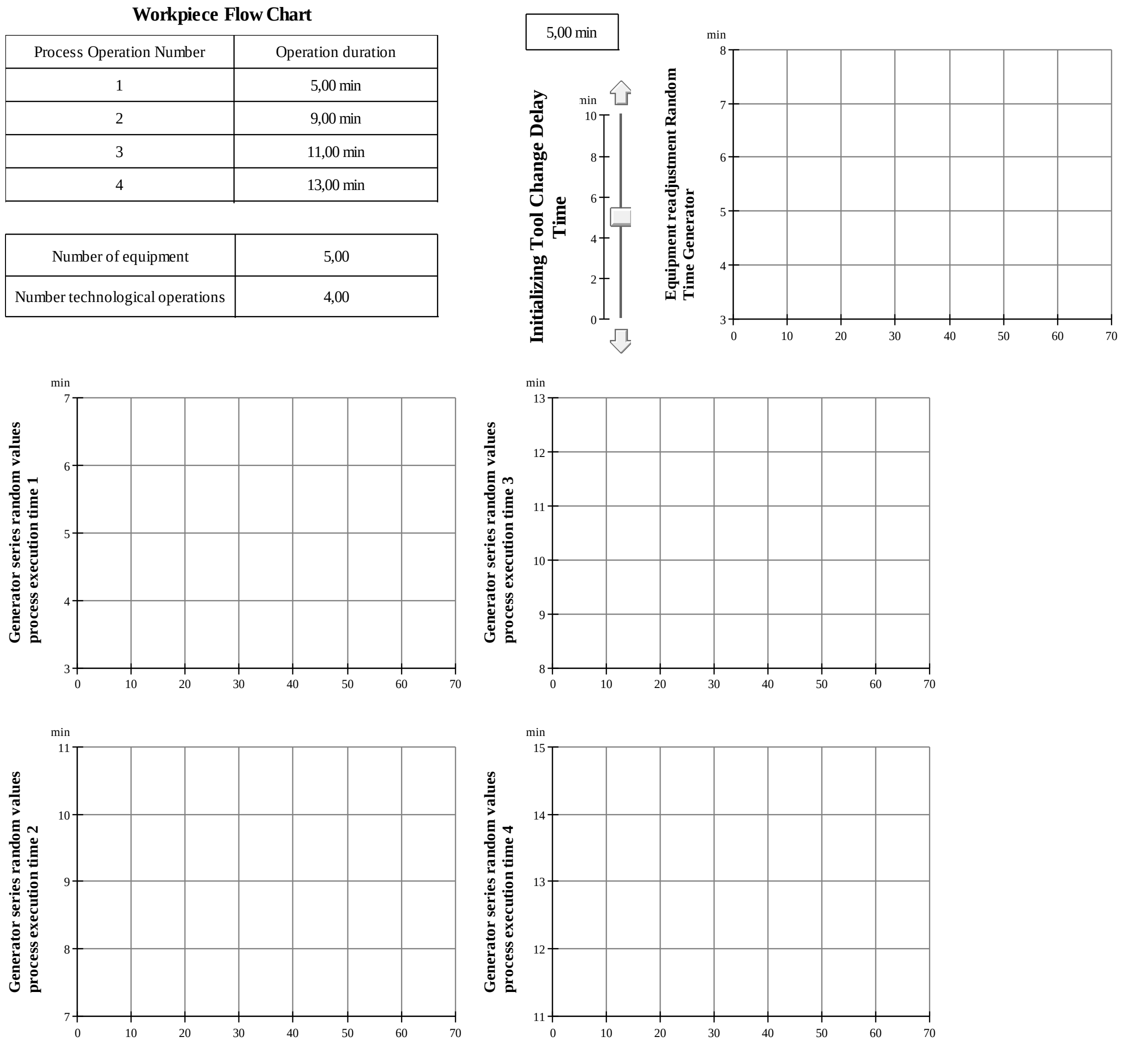

Figure 2. The control panel of the model for determining the cost of working time to perform machining operations on CNC machines.

4. Results

During the experiment, the calculations of the costs of working time for performing machining operations on CNC machines were carried out according to the following initial data:

- Number of machines - 5 pcs. HAAS SL-20 (figure 3).
- Number of technological operations is 4.
- Initial value of the delay time for equipment retooling is 5 minutes.
- Initial value of the process operation time is 5 minutes.
- Initial value of the process operation time is 9 minutes.
- Initial value of the process operation time is 11 minutes.
- Initial value of the process operation time is 13 minutes.

The calculation results are presented in figure 4.

It can be seen from the graphs (figure 4) that about 68% of the values of the equipment retooling time and the time for performing technological operations on CNC machines from the normal distribution are located at a distance of no more than one standard deviation σ from the average; about 95% of the values lie at a distance of no more than two standard deviations; and 99.7% of not more than three. This fact corresponds to a special case of the 3-sigma rule for normal sampling. The total production cycle time was 68 minutes; the standard production cycle time was 62 minutes. The delay time for equipment readjustment from 1 to 4 technological operations was fixed, respectively (9, 6, 4 and 6 minutes), the maximum deviation was 4 sigma. The execution time of technological operations is from 1 to 4 (5, 9, 13 and 12 minutes), the maximum deviation is 1 sigma.

Figure 3. HAAS SL-20. CNC Turning Turret.

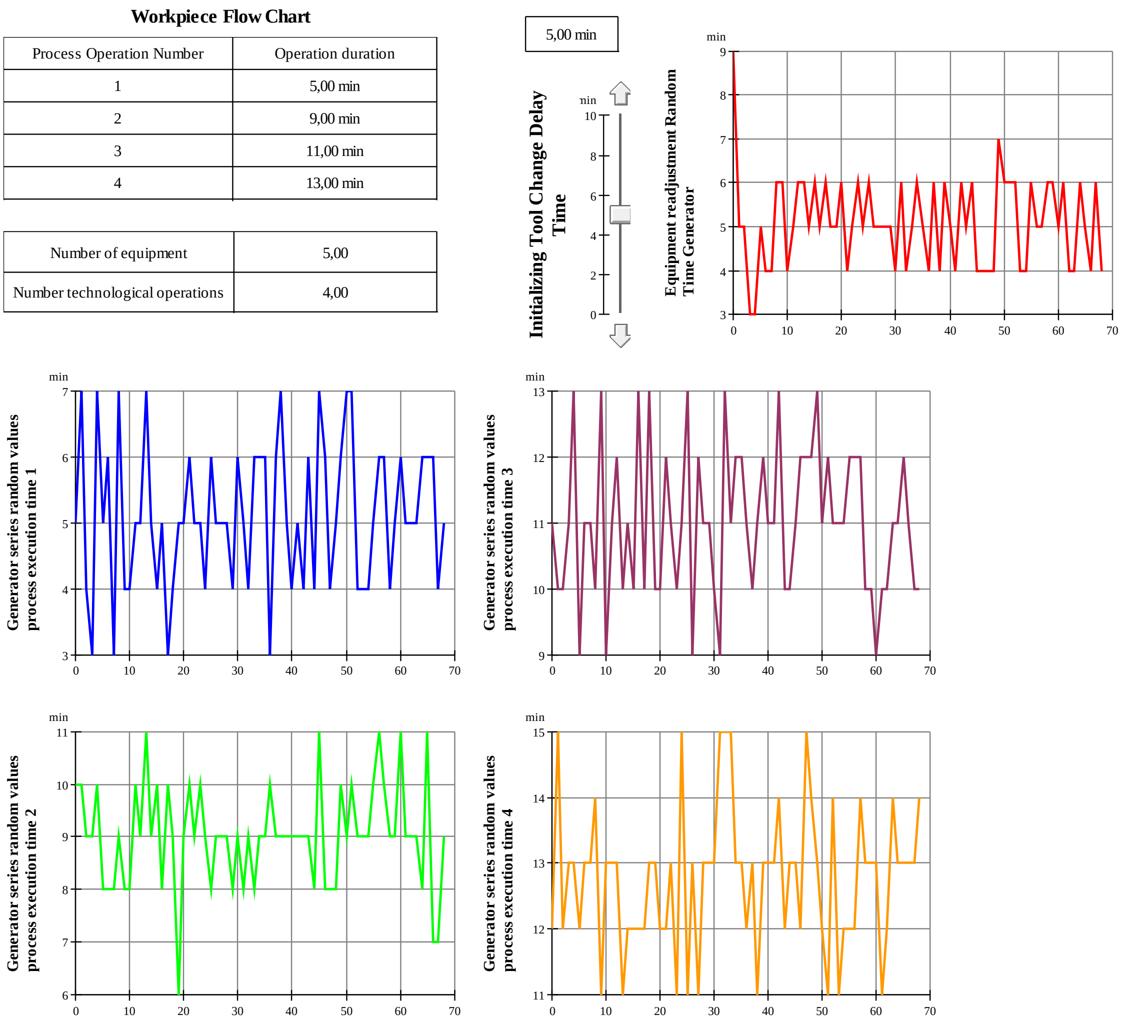

Figure 4. The results of calculating the cost of working time to perform machining operations on CNC machines.

5. Conclusion

As a result, based on the performed calculations, it can be concluded that in this version of the model run, the actual production cycle time exceeded the standard time by 6 minutes due to an increase in the delay time before performing 1, 2 and 4 technological operations and the execution time of 3 technological operations.

It should also be noted that the constructed simulation model for determining the time spent on machining operations on CNC machines can be used to calculate any type of machine tools and technological operations in connection with this, it can be considered universal.

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