

# Data Processing of Digital Productions under Conditions of Uncertainty using System Information Models

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## Abstract

The problem that arises in data processing tasks under conditions of uncertainty is the problem of building an adequate information model of the studied subject area, as well as the formation of effective models and procedures for finding optimal or close to their solutions. The methods of building information models that allow the reliable description of design objects and the processes that take place in them are determined by the nature of the tasks being solved. Therefore, the formation and selection of one or other information model can be carried out only after setting a specific task, while even for the same task it is possible to use different types of models. The work analyzes the subject area and the main provisions of system and information modeling. Examples of data processing of digital machine-building production under conditions of uncertainty with the use of system and information models are presented. Performing digital production data processing on the basis of a system-informational approach allows for expanding the possibilities of implementing digital production tasks.

## Keywords <sup>1</sup>

Digital production, system-information model, conditions of uncertainty, system information, information norm, information measure

## 1. Introduction

The basis of the development of modern mechanical engineering in the world is the computerization and integration of all production processes and production management from the beginning of development to the delivery of finished products to the consumer. In the era of digital transformation, it is important to take advantage of the competitive advantages of an integrated digital manufacturing system, which includes tools for numerical modeling, 3D visualization, analytics, and collaboration, etc. [1, 2]. The implementation of the concept of digital production makes it possible to reduce the number of errors in real production due to their detection and elimination at the early stages of preparation in a virtual environment. As a result of reducing errors in the actual production process, production costs and production preparation time are reduced. Since errors in technology and production organization are detected and eliminated at the design stage, it allows production to be launched in a shorter time. Developed simulation models of production systems in the conditions of actual production become simulators for its improvement, verification of the introduction of new management approaches without stopping production, and production planning tools.

Integration in production systems or complexes is implemented (within the concept of international standards ISO series 9004) regardless of the category and type of production activity and the sector of the national economy, as well as the level and scale of integration (starting from a lower level of integration of operations) from one workplace and ending with integration at the highest, international level [3]. Based on the ideology that meets the specified international standards, we should first of all talk about integration with the aim of improving activities to ensure all stages of the product life cycle, which is the basis of the modern theory of quality management.

The complex of «digital production» solutions belongs to the class of MPM systems (Manufacturing

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Process Management). Digital manufacturing is a key point of integration of a PLM solution (Product Lifecycle Management) with various factory applications and equipment, which opens the way for the exchange of product information between design and production departments. One of the main component technologies of PLM is the forecasting and optimization of complex manufacturing technological processes. This category includes tools that allow you to transfer data from design systems to production systems, develop, model, and visualize production systems and processes, plan and evaluate the quality of various technological processes. This allows simultaneous design and technological preparation of production and work in other directions, which are based on the need for joint development of products and processes.

The proposed concept of digital production data processing under conditions of uncertainty using system information models of processes and systems at the stages of the product life cycle allows to create of specialized computer systems and develop methods and models for solving problem-oriented tasks set within the framework of integration with PLM information technology «digital production». It allows you to predict and optimize manufacturing processes in a controlled environment and create flexible instructions capable of displaying part information, as well as machining and tooling instructions. Therefore, it is worth paying attention to the fact that such a concept is implemented at the enterprise, even if it requires investments and the need for changes.

## **2. Analysis of the subject area and formulation of the problem**

The concept of «Industry 4.0» of production involves the integration of modern information technologies and communication networks with production equipment and means of automation for the organization of value creation in the life cycle of products. Integration is used to obtain and process reliable information on the state characteristics of the production system to ensure prompt and timely resolution of control and management tasks in digital production. This path of development is an indisputable condition for Ukrainian enterprises to reach a higher level of competitiveness in the global saturated market.

The main limitations of the known methods and information technologies currently used for solving problems that are difficult to formalize are due to the mathematical form of information presentation and insufficient efficiency in solving the problems of learning, setting and adapting to the problem area, processing of measured values of incomplete and inaccurate source information, data interpretation and accumulation of experts' knowledge, uniform presentation of information coming from different sources, etc. These limitations can be eliminated by taking into account the use of system-information models (SIM) to formalize the measured values of system information and promising soft computing methods for their processing [4, 5].

The system-information approach (SIA) to processes and systems as a scientific direction in information theory was summarized in the paper [6]. The amount of a priori and a posteriori information possessed by the system, as well as information about the process, is subject to measurement from the standpoint of the SIA. According to the theoretical principles of SIA, the mathematical model of an informative parameter of a process or system can be presented at two levels: the first, as an element  $\Delta x$  (sensitivity threshold) of the set of possible states  $X$ , which has a stochastic nature; and the second, as a deterministic value of the  $X/\Delta x$  ratio, which characterizes the final value of the number of possible states of the system. Thus, the content of such a model of an informative parameter of a process or system is a collection (unity) of the content of stochastic and deterministic parts, which determine the numerical value of possible states of the process or system relative to the threshold of their sensitivity and the probability of transition from one state to another.

The greatest scientific interest and important practical importance is the development of information models of the subject area under conditions of uncertainty, which is characterized by incompleteness, unreliability, the uncertainty of the source information, diversity, and complexity of influence on the process of solving various factors, etc. Depending on the degree of uncertainty, the information processing task can be divided into the following [7, 8]:

- 1) tasks for which an objective assessment of decision results or a comparative assessment of at least two decisions is possible;
- 2) tasks for which an objective assessment is impossible, which is replaced by expert assessments

of specialists in the studied subject area.

The first type of task belongs to poorly structured and difficult-to-formalize problems, which are characterized by the presence of both quantitative and qualitative dependencies between the elements of the studied systems, and qualitative dependencies tend to dominate. These tasks can be structured as system information based on the theory of SIA.

The second type of task refers to unstructured (not formalized), the feature of which is only a qualitative description of systems, while there are no quantitative dependencies between system elements, which determines the need to use expert assessments.

The problem that arises in data processing tasks under conditions of uncertainty is the problem of building an adequate information model of the studied subject area, as well as the formation of effective models and procedures for finding optimal or close to their solutions. The methods of building information models, which allow for reliable describe design objects and the processes that take place in them, are determined by the nature of the tasks to be solved. Therefore, the formation and selection of one or other information model can be carried out only after setting a specific task, while even for the same task it is possible to use different types of models.

The process of finding solutions to a difficult formalized task can be represented by two methods.

The first consists of the following stages [9, 10]:

- 1) extraction (acquisition), representation, and structuring of knowledge about the problem industry;
- 2) construction of adequate mathematical models of the subject area;
- 3) forecast of possible solutions (search for solutions);
- 4) analysis and evaluation of the effectiveness of proposed solutions;
- 5) decision selection.

The second consists of the formalization of the problem on the basis of system-information models, since system information combines quantitative and qualitative characteristics of objects in the informational description of the elements of the studied systems:

- 1) building adequate system and information models of the subject area;
- 2) analysis and assessment of the information process model;
- 3) determination of the main indicators of information objects.

When building systems and information models, the key issue is the determination of the threshold of sensitivity as a feature of the subject area.

The information system is characterized by the presence of internal and external connections, which may have an energy or physical nature. A distinctive feature of the information system is that the structure of energy and material connections is a carrier of information about the properties of objects in the external world and the internal environment of the system. These connections with significant structural features are informational connections when solving tasks under conditions of uncertainty.

The conducted analysis of information flows showed the relevance of developing data processing methods for digital production under conditions of uncertainty based on a SIA. This will allow the expansion of the class of production tasks of digital manufacturing in the PLM system. The purpose of the work is the development and research of data processing methods of digital production at the stages of the product life cycle using system information models of processes and systems.

### **3. Data processing of digital products based on a system-Informational approach**

#### **3.1. Analysis of the main provisions of information-system modeling**

The basis of classical information theory is the results of solving a number of problems at the syntactic level. It is based on the concept of «amount of information», which is a measure of the frequency of use of signs, which in no way reflects either the meaning or the importance of the messages being transmitted. According to the system-information approach, the exchange of information between two objects occurs as a result of a deterministic or stochastic information process [11], and the amount of system information of an object's feature is formalized as

$$I = \log_2 \frac{X}{\Delta x}, \quad I = \log_2 \frac{\mu_x}{K u_x}, \quad (1)$$

where:  $X$  – the value of the feature of the object;  $\Delta x$  – the sensitivity threshold;  $u_x$  – standard uncertainty;  $\mu_x$  – the mathematical expectation of  $X$ ;  $K$  – coverage factor.

The amount of information on a deterministic and stochastic parameter is formalized by

$$\Delta x = T I_x = 2k u_x = 2U_x, \quad I_{\text{nap}} = \log_2 \frac{X}{T I_x}, \quad I = \log_2 \frac{\mu_x}{2k u_x},$$

where:  $T I_x$  – parameter accuracy tolerance  $X$ .

The system-information model of a deterministic or stochastic information process is formalized as

$$\begin{aligned} \log_2 \frac{X}{T I_x} &= \log_2 \frac{Y}{T I_y}, \\ \log_2 \frac{\mu_x}{2U_x} &= \log_2 \frac{\mu_y}{2U_y}. \end{aligned} \quad (2)$$

If system information is transmitted with an error, in the equations of the information process (2), the equal sign (=) is replaced by an approximation sign ( $\approx$ ).

System information is characterized by the numerical value of a quantity, quality, and value. The amount of system information is calculated as the logarithm of the ratio of the feature value to the sensitivity threshold according to (1). The quality of the system information of the receiver belongs to the result of the information process and characterizes the amount of possible loss of information, or excess when transmitting optimal values of the amount of system information. The less possible loss or excess in the received information, the higher the quality of the received system information, which is calculated on the basis of a priori information:

$$\sum_{i=1}^n I(x_i) = \sum_{i=1}^n \frac{X_i}{\Delta x_i}, \quad (3)$$

$$I_{\text{qual}}(y_j) = \frac{\sum_{i=1}^n I(x_i)}{\sum_{j=1}^m \left(1 + \left| \Delta y_j - U_{y_j} \right| \right)},$$

where:  $\Delta y$  – sensitivity threshold,  $U_y$  – extended uncertainty.

The value of system information refers to information processes and is characterized by the efficiency of using optimal values of qualitative system information of the receiver:

$$\begin{aligned} \sum_{j=1}^m I(y_j) &= \sum_{j=1}^m \frac{Y_j}{\Delta y_j}, \quad \sum_{i=1}^n I(x_i) = \sum_{i=1}^n \frac{X_i}{\Delta x_i}, \\ \sum_{i=1}^n \frac{X_i}{\Delta x_i} &= \sum_{j=1}^m \frac{Y_j}{\Delta y_j}, \end{aligned} \quad (4)$$

$$I_{\text{val}}(y_j) = \frac{\sum_{i=1}^n I(x_i) \times \sum_{j=1}^m \left(1 - \left| \Delta y_j - U_{y_j} \right| \right)}{\sum_{j=1}^m I(y_j)},$$

where:  $\Delta y$  – sensitivity threshold,  $U_y$  – extended uncertainty.

The informational object of the research of the system-informational approach is the system – a set of  $X$  elements that are in informational relations with each other and form certain integrity and unity. The system information possessed by the elements of the  $X$  set is characterized by the interval between the upper  $X_{\text{max}}$  and lower  $X_{\text{min}}$  limits of its manifestation, as well as the sensitivity threshold  $\Delta x = x -$

$X_{min}/n$ , where  $x = n \Delta x + X_{min}$ ,  $\Delta x = x - X_{min}/n$ , is a discrete variable value in the  $X_{max} - X_{min}$  interval,  $\Delta x$  is the sensitivity threshold.

The system information of the object is characterized by the information measure  $|I(X)|$ , which is a function of the absolute value of the qualitative and/or quantitative proportion of the ratio:

$$|I(X)| = f\left(\frac{X_{max} - X_{min}}{\Delta x}\right), \quad (5)$$

and the information norm, which is equal to the value of the ratio of the general value of the feature to its discrete variable value:

$$\|(X)\| = f\left(\frac{X_{max} - X_{min}}{x}\right) = f\left(\frac{X_{max} - X_{min}}{n\Delta x + X_{min}}\right), \quad (6)$$

where:  $x = n \Delta x + X_{min}$ .

The amount of system information of the first kind is calculated on the basis of the information measure:

$$\log_2 |I(X)| = \log_2\left(\frac{X_{max} - X_{min}}{\Delta x}\right), \quad (7)$$

where:  $\Delta x = X_{min} / k$ ;  $k = 1 \dots m$ ;  $m \neq 0, \infty$ ;  $X_{min} \neq 0$ .

The amount of system information of the second kind is calculated on the basis of the information norm:

$$\log_2 \|(X)\| = \log_2\left(\frac{X_{max} - X_{min}}{x}\right) = \log_2\left(\frac{X_{max} - X_{min}}{n\Delta x + X_{min}}\right), \quad (8)$$

where:  $x = n \Delta x + X_{min}$ .

The presented approach to the definition of the concept of «system information» differs from the generally accepted one, where information is usually taken to be the numerical values of the data  $X_{max}$ ,  $X_{min}$ ,  $\Delta x$ ,  $x$ , and not their proportional relations. These values may coincide with the type of system information, which depends on the value of the function  $\Delta x = f(I_{ET}, TI, U, I_{PL}, \dots)$  – the sensitivity threshold, where  $I_{ET}$  is the standard unit of the physical quantity (PQ),  $TI$  – the parameter accuracy tolerance,  $U$  is the extended uncertainty of the measured characteristic,  $I_{PL}$  is the Planck unit, etc., and reflects the information of the first kind. The type of information formalized by the system-information model depends on the sensitivity threshold function used.

Example: if the sensitivity threshold  $\Delta x = f(I_{ET})$  is a function of  $I_{ET}$  of the etalon PQ unit, then the SIM data characterize the numerical value of the system information of the physical quantity  $I(PQ)$ ; if  $\Delta x = f(TI)$ , the SIM data characterize the system information of the accuracy of the parameter, which is functionally related to the complexity of the technological process during its manufacture; if  $\Delta x = f(U)$  – SIM data characterize the system information of indicators of the stochastic nature of PQ and the law of distribution; if  $\Delta x = f(I_{PL})$  – SIM data characterize the informational connection between PQ regardless of physical laws.

System information is the value of the proportion of the ratio, which indicates the knowledge of the place of the variable feature in its overall possible value, it does not depend on the unit of measurement of the feature and is a dimensionless number [7]. Numerical data of system-information models are the quantity, quality, value of system information of parameters of processes and systems, and information measure and norm, which are subject to processing under conditions of uncertainty. System information is counted in units of information bit, the numerical value of which indicates the number of steps required to find the value of the sign in the information system of the digital double (ISDD).

### 3.2. Data processing of digital production at the stages of the product life cycle using system-information models

The integration of production processes at the stages of the product life cycle, necessary for the production of products (from manufacturing to delivery of finished products to the consumer and their subsequent disposal) into a single production system based on the information system of a digital double (ISDD) is a complete cycle of modern production.

In the first stage, the research and design departments of the system-information model (SIM) of the experimental product are encrypted and the ISDD is entered. SIM and their dynamic characteristics [7] are reflected in the ISDD through the quantity, quality, and value of system information parameters, as information features of the product. The divisions of researchers, designers, technologists, and management of the digital double develop the product SIM structure, technological manufacturing processes, mathematics, algorithms, software, and technical support of the ISDD in the PLM system.

In the second stage, the SIM data of the product and the technological process are used by the technological system for the manufacture of the product, and data processing ensures production, preparation, management of the technological process, and information flows of the ISDD on a real-time scale. Information flows are meant for the determination of the quantity, quality, and value of system information of production parameters and the consistency of information transfer between objects in the ISDD. The data structure of system information of object parameters consists of intensity (object feature), extent (space), and duration (time) and is an integrated SIM:

$$\begin{aligned} \text{IM} &= \sum \text{I}_{\text{par}} = f(\text{I}_{\text{int}}, \text{I}_{\text{ext}}, \text{I}_{\text{dur}}), \\ \sum \text{I}_{\text{par}} &= \log_2 \frac{\text{Par}}{\text{TI}_{\text{par}}} + \log_2 \frac{\text{T}_0}{\Delta\text{T}_0} + \log_2 \frac{\text{R}^n}{\Delta\text{R}^n}, \\ \log_2 \frac{\text{R}^n}{\Delta\text{R}^n} &= \log_2 \frac{\text{X}}{\Delta\text{X}} + \log_2 \frac{\text{Y}}{\Delta\text{Y}} + \log_2 \frac{\text{Z}}{\Delta\text{Z}}, \end{aligned} \quad (9)$$

where: Par - an object parameter; TI<sub>par</sub> – accuracy tolerance of the parameter; T<sub>0</sub> - the parameter detection time; ΔT – time sensitivity; R<sup>n</sup> - the location of the parameter detection space; ΔR<sup>n</sup> – spatial sensitivity; X, Y, Z - space coordinates; ΔX, ΔY, ΔZ – sensitivity of space coordinates.

The SIM data of digital production processes and systems at the stages of the product life cycle consists of:

1) SIM data at the design stage: the amount of system information about the dimensions of the product, informational coordination of dimensions, dimensional chains, and tolerances in the KD; the amount of system information about the quality of the surface layer;

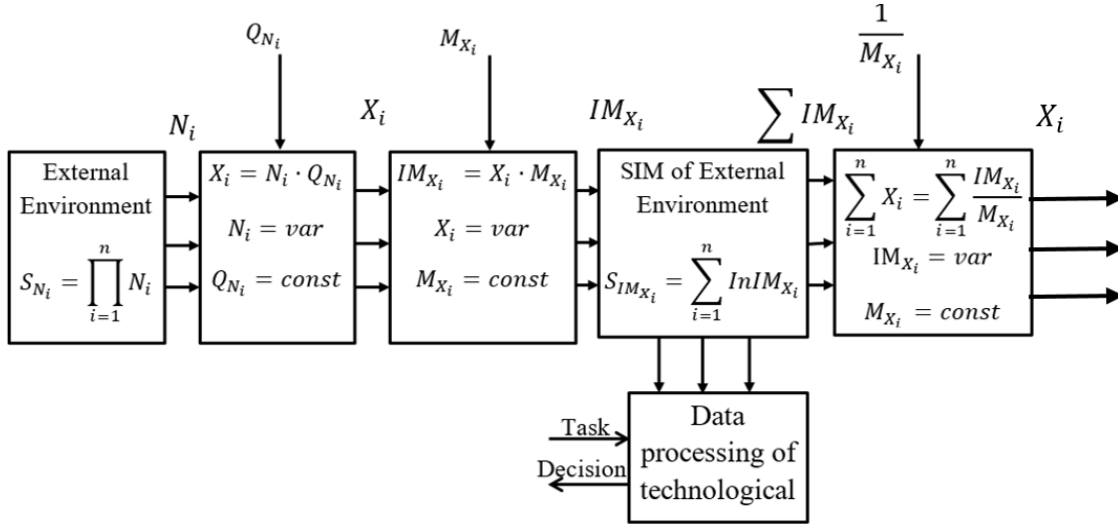
2) SIM data at the stage of technological preparation of production: the amount of system information about the accuracy of mechanical processing, information coordination of the parameters of the accuracy of mechanical processing; determination of the amount of system information of cutting modes; information coordination of parameters of cutting modes; determination of the amount of system information about technological operations; information coordination of technological operations; determination of the amount of system information about technological processes; information coordination of parameters of technological processes;

3) SIM data at the production stage: the amount of system information, equipment settings, control measurement processing; information coordination of parameter management methods in accordance with the quality and value of system information about the parameters of the product and technological process.

The integral SIM of the product, which is formed on the basis of ISDD, is present at all stages of life cycle control. This is determined by the specifics of data processing of the system and information models of the external environment, shown in Fig. 1.

In Fig. 1 the following designations are given: S<sub>Ni</sub> - a feature of the external environment (EE), Ni - a numerical value of the feature, Q<sub>Ni</sub> - a PQ unit, X<sub>i</sub> - a reproduced PQ, M<sub>X<sub>i</sub></sub> - a unit measure of the communication capacity of the PQ, IM<sub>X<sub>i</sub></sub> - measure indicator of the communication capacity of the PQ, SIM - system and information model.

The practical use of SIM consists in the development of data processing algorithms using the properties of «Planck units» and their uncertainties, which can be considered stationary due to the stationarity of the fundamental physical constants and the agreed values of their absolute errors (agreed on by KODATA in 2002) [12]. To solve the task, we will introduce the concept of logarithmic unit measure (LUM) of PQ communication capacity, and logarithmic indicator (LI) of PQ communication capacity, which are structural components of SIM.



**Figure 1:** Structural scheme of data processing of technological process using system-information models

The unit measure (UM) of the communication capacity of PQ is a scalar quantity that is the only measure of various forms of communication of objects and is defined as

$$\mathbf{UM}(\mathbf{x}) = \frac{1}{\Delta \mathbf{x}}.$$

The logarithmic unit measure (LUM) of the communication capacity of PQ is defined as

$$\mathbf{LUM}(\mathbf{x}) = \log_2 \frac{1}{\Delta \mathbf{x}}.$$

The logarithmic indicator (LI) of the communication capacity of the PQ is a measure of the numerical value of the PQ and is defined as

$$\mathbf{LI}(x_i) = \log_2 \left( x_i \times \frac{1}{\Delta x_i} \right).$$

The given logarithmic indicator of PQ is an equivalent measure of the reflection of one PQ through the second PQ using the proportionality factor K and is defined as

$$\mathbf{GLI}(x_{ij}) = \log_2 \left( X_i \times \frac{1}{\Delta x_i} \times k \right), \quad k = \frac{\Delta x_i}{\Delta x_j}.$$

There may be several sources (transmitters) of system information, which may be interdependent or independent of each other.

With N independent sources (transmitters) of system information, the receiver's system information is equal to the sum of system information from the sources, and their information measures are multiplied:

$$\begin{aligned} \mathbf{I}(Y_j) &= \sum_{i=1}^N \mathbf{I}(X_i), \\ \frac{Y_{j\max} - Y_{j\min}}{\Delta y_j} &= \frac{\prod_{i=1}^N (X_{i\max} - X_{i\min})}{\prod_{i=1}^N \Delta x_i}, \\ \log_2 \frac{Y_{j\max} - Y_{j\min}}{\Delta y_j} &= \sum_{i=1}^N \log_2 \frac{(X_{i\max} - X_{i\min})}{\Delta x_i}. \end{aligned} \quad (10)$$

With N interdependent sources (transmitters) of system information at the receiver, the system information is defined as

$$\log_2 \frac{X_{j \max} - X_{j \min}}{\Delta x_j} = \sum_{i=1}^N \log_2 \frac{(X_{i \max} - X_{i \min})}{(\Delta x_i + \Delta x'_i)},$$

$$\Delta x'_i = \frac{(X_{i \max} - X_{i \min}) \prod_{i=1}^N \Delta x_{N-i}}{\prod_{i=1}^N (X_{N-i \max} - X_{N-i \min})}. \quad (11)$$

The SIMs are divided into four types: absolute, relative, equivalent, and mixed. Each of these types of SIM is divided into types depending on the sensitivity threshold function, which is an element of the model. SIM data are divided into informational, physical, parametric, stochastic, etc. depending on the subject area of modeling. In digital manufacturing SIMs, parameter sensitivity thresholds are used, which are a function of uncertainty or accuracy tolerance. When processing information under conditions of uncertainty in the solution of a number of production tasks, it is advisable to represent the parameter accuracy tolerance through Planck units  $\Delta x = TI = k \times IPL$ . This approach allows the model of relationships between parameters without loss or excessive exchange of system information corresponding to their optimal value.

Tasks that are solved with the use of SIM data of processes and systems of digital products on the basis of ISDD include:

1. Forecasting. Forecast of technical and economic indicators (KPI) and the number of necessary resources for launching a new product into production in the early stages of the life cycle based on the parameters of the design documentation (DD) of the new and old product.

2. Optimization of new production. Optimization of resource costs for the technological preparation of production based on the parameters of the design documentation (DD) and the technological system (TS) of the existing production.

3. Production preparation. Development of technological processes of product processing and selection of management methods and parameters based on the parameters of the design documentation (DD) of the new product and existing technological processes (TP) of production.

4. Control and management of production processes. Control of product processing mode parameters and optimization of process equipment control parameters in real-time on the basis of product parameters and technological process (TP) of production.

5. Control of technical and economic indicators (KPI) in real-time and optimization of corrective management of the TP of production. Analysis of controlled parameters of finished products, identification of technological reserves of production.

### 3.3. Examples of the use of system-information models in the processing of parts by the turning method under conditions of uncertainty

The development of methods for the practical use of system-information models in mechanical engineering at the engineering level is an urgent scientific task. Machining by turning consists of two interrelated processes: the process of processing the cut allowance and the process of shaping. That is, the processed stock system information is displayed on the shaping system information. Shaping is the formation of the required shape of a part, determined by the geometric nature and mutual arrangement of its bounding surfaces, as well as dimensions, tolerances, and roughness. The basis of shaping is the mutual display of the properties of the system machine - part - tool, and the display is the basis for the transfer of information.

The main turning works include:

- turning and boring of cylindrical surfaces for passage and stop;
- turning of grooves, shaped turning of end surfaces;
- removal of chamfers;
- multi-cutting turning to process of details such as stepped shafts, discs, and flanges;
- turning of external and internal turns with transverse and longitudinal feed;
- turning of end grooves with axial feed and with axial and radial feeds;
- turning off end surfaces and cutting off parts, etc.



Integral SIMs formalize the information relationship of turning parameters and have the following form:

1) the main time for the operation:

$$\ln \frac{T_0}{U_{T_0}} = \ln \frac{L}{U_L} + \ln \frac{i}{\Delta i} - \ln \frac{S_0}{U_{S_0}} - \ln \frac{n}{\Delta n}, \quad (12)$$

where:  $T_0$  – the main time for the operation, min;  $U_{T_0} \leq \Delta T_0$  – time accuracy tolerance for the operation, min;  $L$  – part size, mm;  $U_L \leq \Delta L$  – size tolerance, mm;  $i$  – the number of passes of the tool;  $S_0$  – feed per spindle rotation, mm/rev;  $U_{S_0} \leq \Delta S_0$  – feed accuracy tolerance per spindle revolution, mm/rev;  $n$  – spindle rotation frequency, rpm;  $\Delta n$  – the accuracy of the spindle rotation frequency, rpm;  $U$  – expanded uncertainty;

2) cutting speed:

$$\ln \frac{V}{U_V} = \ln \frac{C_V}{U_{C_V}} + \ln \frac{K_V}{U_{K_V}} - \ln \frac{T}{U_T} - x_0 \ln \frac{t}{U_t} - y \ln \frac{S_0}{U_{S_0}}, \quad (13)$$

where:  $V$  – cutting speed, m/min;  $U_V \leq \Delta V$  – cutting speed accuracy tolerance, m/min;  $C_V$  – coefficient;  $K_V$  – coefficient;  $t$  – cutting depth, mm;  $U_t \leq \Delta t$  – tolerance of the accuracy of the determination of the cutting depth, mm;  $K_V, x_0, y, m$  – coefficients;  $T$  – the period of stability of the cutter,  $U_T \leq \Delta T$  – tolerance period of stability of the cutter  $S_0$  – feed per spindle rotation, mm/rev;  $U_{S_0} \leq \Delta S_0$  – feed accuracy tolerance per spindle revolution, mm/rev,  $U$  – expanded uncertainty;

3) spindle rotation frequency:

$$\ln \frac{n}{\Delta n} = \ln 1000 + \ln \frac{V}{\Delta V} - \ln \pi - \ln \frac{D}{\Delta D}, \quad (14)$$

where:  $D$  – the diameter of the treated surface;  $U_{AD} \leq \Delta D$  – accuracy of the diameter of the machined surface (size tolerance),  $V$  – cutting speed,  $U_{AV} \leq \Delta V$  – cutting speed accuracy tolerance,  $n$  – spindle rotation frequency, rpm;  $\Delta n$  – the accuracy of the spindle rotation frequency,  $U$  – expanded uncertainty;

4) components of the cutting force along x, y, z coordinates:

$$\begin{aligned} \ln \frac{P_{x,y,z}}{U_{P_{x,y,z}}} &= \ln 9,81 + \ln \frac{C_{P_{x,y,z}}}{U_{C_{P_{x,y,z}}}} + \\ &+ x_P \ln \frac{t}{U_t} + y_P \ln \frac{S_0}{U_{S_0}} + n_P \ln \frac{V}{U_V} + \ln \frac{K_P}{U_{K_P}}, \end{aligned} \quad (15)$$

where:  $P_{x,y,z}$  – components of the cutting forces along the coordinates x, y, z;  $U_{P_{x,y,z}} \leq \Delta P_{x,y,z}$  – accuracy tolerance of cutting force components;  $n_P, y_P, K_P, C_{P_{x,y,z}}$  – coefficients,  $t$  – cutting depth, mm;  $U_t \leq \Delta t$  – accuracy tolerance for determining the depth of cutting,  $S_0$  – feed per spindle revolution, mm/rev;  $U_{S_0} \leq \Delta S_0$  – feed accuracy tolerance per spindle revolution, mm/rev,  $V$  – cutting speed,  $U_V \leq \Delta V$  – cutting speed accuracy tolerance,  $U$  – expanded uncertainty;

5) cutting power:

$$\ln \frac{N}{U_N} = \log_2 \frac{P_z}{U_{P_z}} + \log_2 \frac{V}{U_V} - \log_2 1020 - \log_2 60, \quad (16)$$

where:  $N$  – power,  $U_N \leq \Delta N$  – power accuracy tolerance,  $P_z$  – cutting force along z coordinates;  $U_{P_z} \leq \Delta P_z$  – accuracy tolerance of the cutting force component;  $V$  – cutting speed,  $U_V \leq \Delta V$  – cutting speed accuracy tolerance,  $U$  – expanded uncertainty.

The model of relationships between information on the size of a part and information on cutting parameters is as follows:

$$\begin{aligned} \ln \frac{L}{U_L} &= \ln \frac{T_0}{U_{T_0}} + \ln 1000 + \ln \frac{C_V}{U_{C_V}} + \ln \frac{K_V}{U_{K_V}} - \ln \pi - \\ &- \ln \frac{D}{U_D} - m \ln \frac{T}{U_T} - x_S \ln \frac{t}{U_t} - (y_S - 1) \ln \frac{S_0}{U_{S_0}}. \end{aligned} \quad (17)$$

In equation (17), the values of the quantities  $D, t$  are given by the design and technological documentation; coefficients  $C_V, K_V, \pi, x_V, y_V, m$  depending on the characteristics are selected according to the directory; values of quantities  $T$  and  $S_0$  are assigned in accordance with the values set by  $L, D, t, x_V, y_V, m, C_V, K_V$ ; values  $\Delta L, \Delta T_0, \Delta D, \Delta T, \Delta S_0$  are set according to parameter size tolerances. Thus, from equation information on the basic time per operation is determined, which is related to the basic parameters of turning.

The presented SIM of parameters of turning processing is the information base of the ISDD in the production PLM system. Data processing of the integrated model of turning parameters of the part is used to obtain additional information during communication.

Let's consider examples of data processing during the turning of a part using the turning method based on the SIM model (12).

1. Data processing when forecasting  $T_0$  of the main turning time of the partition: the sensitivity threshold of the parameters  $\Delta x = 1ET$  is a function of the PQ reference unit:

$$\begin{aligned} \ln T_0 &= \ln L + \ln i - \ln S_0 - \ln n, \\ T_0 &= e^{(\ln L + \ln i - \ln S_0 - \ln n)}. \end{aligned} \quad (18)$$

2. Data processing when calculating the extended uncertainty of the main turning time of the partition: sensitivity threshold  $U_{x \leq} (\Delta T_0, \Delta L, \Delta S_0, \Delta i, \Delta n)$  taking into account the interrelated parameters:

$$\begin{aligned} \ln \frac{T_0}{U_{T_0}} &= \ln \frac{L}{\Delta L + \Delta L'} + \ln \frac{i}{\Delta i + \Delta i'} - \ln \frac{S_0}{\Delta S_0 + \Delta S_0'} - \ln \frac{n}{\Delta n + \Delta n'}, \\ \Delta L' &= \frac{L \times \Delta i \times \Delta S_0 \times \Delta n}{i \times S_0 \times n}, \quad \Delta i' = \frac{\Delta L \times i \times \Delta S_0 \times \Delta n}{L \times S_0 \times n}, \\ \Delta S_0' &= \frac{\Delta L \times \Delta i \times S_0 \times \Delta n}{i \times L \times n}, \quad \Delta n' = \frac{\Delta L \times \Delta i \times \Delta S_0 \times n}{i \times S_0 \times L}, \\ U_{T_0} &= \frac{T_0 \times k}{e^{\left( \ln \frac{L}{\Delta L + \Delta L'} + \ln \frac{i}{\Delta i + \Delta i'} - \ln \frac{S_0}{\Delta S_0 + \Delta S_0'} - \ln \frac{n}{\Delta n + \Delta n'} \right)}}, \\ k &= \frac{\Delta L + \Delta i + \Delta S_0 + \Delta n}{\Delta L \times \Delta i \times \Delta S_0 \times \Delta n}, \end{aligned} \quad (19)$$

where:  $U = Ku_c$  – expanded uncertainty;  $u_c(L, i, S_0, n)$  – standard uncertainty;  $g = 2\sqrt{3}$ ;  $g$  - the unit of the smallest digit of parameters  $L, i, S_0, n$ ;  $K = 2$ .

3. Data processing when calculating the equivalent of energy from the data of the turning parameters of the part. The sensitivity threshold is a function of the Planck unit  $\Delta x = f(1PL)$  and is used in production optimization tasks. Tasks, as an example, can consist in determining the ratio of costs of funds in the processing of machine parts to the energy equivalent of the processing parameters. This approach allows you to assess the efficiency of production units and, if necessary, take measures to optimize production:

$$\begin{aligned} \ln \frac{T_0}{\Delta T_0} &= \ln \frac{L}{\Delta L} + \ln \frac{i}{\Delta i} - \ln \frac{S_0}{\Delta S_0} - \ln \frac{n}{\Delta n}, \\ \Delta T_0 &= aT_{PL}, \quad \Delta L = bL_{PL}, \quad \Delta S_0 = cS_{0PL}, \\ \ln \frac{T_0}{aT_{PL}} &= \ln \frac{L}{bL_{PL}} + \ln \frac{i}{\Delta i} - \ln \frac{S_0}{cS_{0PL}} - \ln \frac{n}{\Delta n}, \\ \ln \frac{T_0}{1T_{PL}} &= \ln \frac{1}{a} - \ln \frac{1}{b} - \ln \frac{1}{c} + \ln \frac{L}{1L_{PL}} + \ln \frac{i}{\Delta i} - \ln \frac{S_0}{1S_{0PL}} - \ln \frac{n}{\Delta n}, \\ \ln \frac{E}{1E_{PL}} &= K_{T_0}^E \ln \frac{T_0}{1T_{PL}}, \\ E_{eq}(T_0) &= 1E_{PL} \times e^{K_{T_0}^E \left( \ln \frac{1}{a} - \ln \frac{1}{b} - \ln \frac{1}{c} + \ln \frac{L}{1L_{PL}} + \ln \frac{i}{\Delta i} - \ln \frac{S_0}{1S_{0PL}} - \ln \frac{n}{\Delta n} \right)}, \end{aligned} \quad (20)$$

where:  $E_{eq}(T_0)$  is the energy equivalent to the main part processing time,  $K_{T_0}^E$  is the energy-to-time matching factor.

Consider an example of determining the characteristics of system information for processing products by fine turning. One of the key indicators of turning is the main processing time. System-information models for predicting the main turning time have the form:

$$T_0 = e^{\sum I_{sh} - \sum I_{pi}(W)} = \frac{e^{\sum I_{sh}}}{e^{\sum I_{pi}(W)}}, \quad (21)$$

$$I_{sh} = \left( \ln \frac{L}{R_z} + x_v \ln t + \ln \frac{D}{T_d} \right), \quad (22)$$

$$\sum I_{pi}(W) = \left( \ln 1000 + \ln C_v + \ln K_v + (1 - y_v) S_0 - \ln \pi - m \ln T + \ln \frac{1}{T_d} + \ln \frac{1}{R_z} \right), \quad (23)$$

where:  $I_{pi}(W)$  – the intensity of transformation of system information by shaping (processing intensity),  $I_{sh}$  – the amount of shaping information.

The amount of intensity system information  $I_{pi}(W)$  depends on the feed  $S_0$ , surface roughness  $R_z$ , dimensional accuracy  $T_d$ , coefficients  $C_v$ , and  $K_v$  and is determined from the graphs depending on the shaping parameters

$$\sum_{i=1}^n I_{pi}(W_i) = I_{pi}(W_L) + I_{pi}(W_t) + I_{pi}(W_D) + I_{pi}(W_{R_z}) + I_{pi}(W_{T_d}). \quad (24)$$

The amount of system shaping information depends on the parameters  $L$ ,  $t$ ,  $D$ ,  $R_z$ ,  $T_d$ .

In our example, on a screw-cutting lathe, the end of the sleeve is cut with a diameter of  $D = [\text{mm}]$  is cut to a diameter of  $d = [\text{mm}]$ . Machining allowance (per side)  $t = [\text{mm}]$ . Roughness parameters of the machined surface  $R_z = [\mu\text{m}]$ . Workpiece material with hardness  $[\text{HB}]$ . Surface to be machined without casting skin. The system machine-fixture-tool-workpiece is rigid. Determine the main processing time for finishing turning.

Given: Machine - 16K20, Cutter - T15K6,  $D = 66 \text{ mm}$ ,  $d = 63 \text{ mm}$ ,  $l = 300 \text{ mm}$ ,  $R_z = 0.02 \text{ mm}$ ,  $t = 3 \text{ mm}$ ,  $T_d = 0.017 \text{ mm}$ , workpiece steel 40X,  $\sigma = 720 \text{ MPa}$ .

1. Determine the amount of system-shaping information:

$$I_{sh} = \ln \frac{L}{R_z} + \ln t + \ln \frac{D}{T_d} = \ln \frac{300}{0,02} + \ln 3 + \ln \frac{66}{0,017} = 18.968 \text{ nit}.$$

2. Determine the intensity of the transformation of system information by turning:

$$\begin{aligned} \sum_{i=1}^n I_{pi}(W_i) &= I_{pi}(W_L) + I_{pi}(W_t) + I_{pi}(W_D) + I_{pi}(W_{R_z}) + I_{pi}(W_{T_d}) = \\ &= 10 + 6,2 + 1,1 + 1,4 + 0,6 = 19,3 \frac{\text{nit}}{\text{min}}. \end{aligned}$$

3. Determine the main processing time for fine turning:

$$T_0 = e^{\sum I_{sh} - \sum I_{pi}(W)} = 2,71^{(18,96 - 19,3)} = 0,71 \text{ min}.$$

It can be seen from the example that the solution of technological problems in the methods of processing products using system-information models significantly reduces both resource computer costs and the time to solve them, which is important for digital industries.

The presented SIMs of the parameters of the technological process of turning to make it possible to provide various types of information when solving production tasks during their processing in digital production. This approach to data processing of digital productions refers to SIM models of various methods of machining by cutting. In the given examples of data processing of machining parameters by the method of turning into digital production, the SIM model of the main machining time (12) is used. Data processing of one model makes it possible to obtain information of three or more types: information on the relationship of parameters to the PE standard; information on the relationship of interrelated parameters to extended uncertainty; information on the ratio of parameters of the energy equivalent. Data processing of digital productions based on system information models significantly expands the possibilities of solving production tasks under conditions of uncertainty.

## 4. Conclusions

The paper examines the solution to problems arising in data processing tasks under conditions of uncertainty, namely the construction of an adequate information model of the studied subject area, as well as the formation of effective models and procedures for finding optimal or close to their solutions. An analysis of information flows was carried out, which indicated the relevance of developing data processing methods for digital production under conditions of uncertainty based on a system-information approach. To find solutions to difficult formalized tasks, which include the task of data processing of digital production in conditions of uncertainty, the use of a system-informational approach is justified. The use of approaches to data processing of digital production in conditions of uncertainty based on system information models allows for solving problems that expand the possibilities of digital production.

The presented integral system-informational models of turning mechanical processing are based on empirical formulas from handbooks on mechanical engineering technology. In material production, the parameters of mechanical processing by cutting specified in the technological process are confirmed on the basis of control, and previous operations on specific technological equipment. In digital twins, the values of the parameters of the technological process of cutting processing relate to the uncertainty of external factors. Data processing of parameters of mechanical processing methods based on system information models allows obtaining quantitative, qualitative, and cost values of various types of system information of twenty-four external factors, which affect the accuracy of parameters of mechanical processing.

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