Analysis of the principles and methods of construction control systems of technological process. Basic terms and definitions

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ANALYSIS OF THE PRINCIPLES AND METHODS OF CONSTRUCTION CONTROL SYSTEMS OF TECHNOLOGICAL PROCESS. BASIC TERMS AND DEFINITIONS.

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Annotation

The article analyzes the production and management systems, types of detail, considered the structure of production. The characteristics of the process, classified by type of production, calendar and planned ahead of the curve, the control of execution of production plans, control system and so on. The definitions of the technological process, process step, the object of labor, means of labor, property and parameters of the product, the type of production, organization methods, PDE-model production lines, in-line production management systems, statistical models of production systems.

Keywords: process, process operation, the subject of labor, means of labor, properties and parameters of the product, the type of production, methods of organization, PDE-model production lines, production management system, statistical models of manufacturing systems

Introduction

Manufacturing is a complex process of transformation of raw materials and semi-manufactured goods into finished products [1-4]. The technological process - part of the production processes sa containing targeted actions to change and (or) the definition of the state of the object of labor (GOST 3.1109.82), [5]. The technological process - part of the production process, comprising the targeted

actions to changing and (or) the definition of the state of the object of labor (GOST 3.1109.82), [5]. The main elements of the process are labor, means of labor and objects of labor. The technological process can be attributed to the product, its part or methods of processing, forming and assembly (GOST 3.1109.82), [5]. Manufacturing products with desired properties is provided by means of work - equipment, tools, appliances, industrial buildings, by which a person works on the subject of work. The subject of labor - something that human activity is directed to the production process, namely, raw materials, semi-finished products, parts and unfinished products (billets) [5]. The collection of objects of labor and means constitute the means of production. Each product is characterized by the properties. Product properties - an objective feature that appears when you create it. [6] Symptom quantitatively characterizing the properties of the product or condition called the parameters of the product [6]. The difference between the highest and lowest limit values of the parameters of the product sets the tolerance on the parameter. As the transformation into finished products items of work are separate, clearly distinguishable in time and space processing step that allows them to be regarded as objects of planning and management. Sequential changes in conditions or the subjects of labor occurs during the transition from one technological process to another. Technological operation - is a finished part of the process running on one workplace (GOST 3.1109.82) [5], is divided into elements: transition, auxiliary, fastening, work and support the course, receiving, commissioning [5]. Description of technological processes differ in the degree of detail. Standard route are (short description of all operations in the route map in the sequence of their execution without transitions and technological regimes) and operating (full description of all operations in the sequence of their execution indicating transitions and technological conditions) a description of the technological process [5]. The subject of labor, to be produced, is a product [7]. Products in the technological process according to GOST 2.101.68 depending on the availability and use are divided into parts, complexes, sets, assembly units [7]. Products, located in the intermediate stages of processing, forms a work in progress [8]

necessary for the elimination of asynchronous performance technology units within the department and between departments directly [9]. Working [10], a minimum or an insurance reserve characterize work in progress [10, 11].

The production structure of the enterprise. Analysis of the types of production and management systems.

Running technological processes are concentrated in the departments that make up the industrial structure of the enterprise. In industry, there are three types of industrial structure of companies - technology, subject and object-technology. The main production unit of the enterprise is shop-detached part of the enterprise, containing the finished process or logically completed part [12]. The organization, planning and control of the production process iare a set of methods for the use of labor, means and objects of labor. During the development of the relations of production developed principles of effective organization of the process - the specialization of sites and jobs; synchronize the rhythm of technological operations; Parallel execution of technological operations; continuous process; reduction in backlog interoperable. One measure of the level of the technological process is the cycle time - time interval from the beginning to the end of the manufacturing process manufacturing products [13,14]. By type of production is understood as a set of organizational, technical and socio-economic characteristics of the construction of the production process due to repeatable and continuous processing of the object of labor, technology, manufacturing, technological and organizational structure of production, and the kind of movement of objects of labor (Table 1.1).

Table 1.Characteristics of the process

Characteristics	Type of production		
	Single	Serial	Mass
Determining the type of	production of small series. Repeatability	product range is stable, repeated; the	specialization in the production of a

production	issue irregular.		number of transacti-ons is much higher than the number of jobs	stable for a long period of time the product range
System of control	made-to-order	Comple te	group	in the rate of release
Initial data for production planning	start and end dates mile-stones	Tehnol. routes machining specifying the operations performed, the equipment and work norms		
		securing parts operations for machine tools		the rate of release and backlogs in-comeplete products
		monthly production target for the details of each item		quarterly, monthly, ten-day plan
The main mac-roeconomic indicators production	production cycle, loading equipment for the periods		size batches and frequency of their production	tempo (rhythm cycle)
	calendar and scheduled timing			
	the density of the works for the production cycle		interoperable	
The main mic-ro indicators production	production cycle		the average standard of inter-operation time of a workpiece	
	the rate of consumption of raw materials in separate operations			
	the percentage of materials development at the stage of execution of works		Replacement rate of technological operations	
The tasks of operational management	monitoring the implementation of production plans			
	Monitoring of Implementation of replacement jobs		control and operational groundwork regulation implementation of the plans	

	control equipment production	motion control components along the process route

There are a massive, serial and single types of production, determines the coecient of consolidation of operations at the workplace (GOST 3.1121.84) [15]. Mass production is characterized by a type of highly specialized departments and sections on output, limited and stable over a long period of time range of products. The main objective of planning is to ensure the movement of workpieces for operations at a given temp. A significant part of the calendar and the planned regulations for the type of mass production is sustainable and just laid the basis for the planned regulations of the production lines. Planning is based on the calculation of the rate of release and details of the calculation of backlog interoperable standards. When you type the serial production of the nomenclature of manufactured products less stable, but still regularly repeated in the issuance program, the number performed in detail shops operations far exceeds the number of jobs that defines the manufacture of bulk [16].

The main task of planning for mass production, ensuring periodicity of manufacturing of products in accordance with the scheduled task. Increasing seriality achieved unification of parts and typed processes. Calendar-planned regulations are a lot size of products with the expenditure of a single set-up times and the frequency of their manufacture; the length of production cycles and calendar, ahead of the planned; payment backlog. Determining the size of the party is the normative basis for the regulation of periodicity changeovers. The parallel production of different types of products that complement each other in the structure of labor input, provides a full load of equipment. To reduce cycle time using a parallel-sequential movement of parts that specifies the parallel execution of technological operations. A single type of production is characterized by the production of goods units or small series [12,16]. Repeatability issue absent or irregular. Production planning problem is to manufacture products on time and uniform loading of production sites for a given production cycle. The

distinguishing feature of a single type of production is a strong link calendar and planning standards with planning technical preparation of production. The products together with original features are standard in the growth of the proportion of the reserve which is laid to improve production efficiency. It increases the technical level of unit production run parts group having a structural and technological similarities that allows you to organize their joint application. Each type of production can be organized in different ways. The main ones are in-line, single party and methods of organization of production. The most effective line method. When a large range of products and frequent changeovers effective party and group methods. To organize the production method of the party is very important factor in uniform working sections on schedule, reducing the range and increasing the value of parties. When the group method of machining process developed by the group and the group made a snap. The set of methods, tools and principles of the process form the system of planning and management. The tasks of operational planning and management is to ensure rhythmic, uniform operation of the enterprise with the plan (Table 1.2).

Table 2. Systems operational production management

<table>
<tr><td rowspan="2">Planning and accounting units</td><td colspan="5">Types of production</td></tr>
<tr><td>Single</td><td>Small-serial</td><td>Serial</td><td>Largeserial</td><td>Mass</td></tr>
<tr><td></td><td colspan="5">System planning and management</td></tr>
<tr><td rowspan="3">Party of details</td><td colspan="5" rowspan="3"></td></tr>
<tr><td colspan="4">warehouse</td></tr>
<tr><td colspan="4">Standards groundwork</td></tr>
<tr><td rowspan="2">Detail</td><td colspan="3" rowspan="2"></td><td colspan="2">maturity interplant innings</td></tr>
<tr><td>On the beat</td></tr>
<tr><td>Order product</td><td colspan="2">by orders</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>Set to the node</td><td colspan="2">Complete-node</td></tr>
</table>

Node set	network planning		
Cyclic set	Complete-group		
Kits		machines complete	
Day complete			continuous
Conditional kit			operational planning

The choice of planning and accounting units (Table 1.2) and periods of planning and management is dependent on the choice of the control system. Differential methods of construction of systems of planning and councils-ment type used in mass production. Enlarged methods are used in the unit by Mr. and small-scale production. From the main control systems stand out in detail the system of management and planning used in mass production provides for the issuance of the shoping in the detailed program production and loading jobs. To the system's detailed operational control is touched on the control system, which supports standard level of interplant storage backlog and are used in established nomenclature. The system of continuous operational control makes it possible to link the work of technological units with continuous output and identify the structure of the work in progress [8]. Control systems in large-scale production, and constructed for a specified period and start the release of batches of parts. System planning and management of tact flow is used for operational process control and automated continuous-flow lines, it is based on the definition of cycles of operations, strictly associated with tact line. In serial production used a complete system, providing the planning process to deliver the product in the package details.

Cycle parts manufacturing, supplied, installed by leading parts. Enlarged planning system is custom-system. Features common system of operational planning and production management are presented in Table 2. Warehouse planning and control system is used for planning, unifies bathrooms parts in series production with short cycle times and broad applicability. Custom scheduling system used in single and small batch production, covers the entire manufacturing

process of the order, including technical training. Complete-node is used in the production unit. This applies multiple supply parts to assemble a number of rounds, which leads to a reduction in the time details. Disadvantages of the system are expressed in the synchronous operation of the organization difficult, since the kits include parts with different routes. Parking complete control system is used in series production with sustained release of the product range, provides a simple method of calculating the targets, but has the disadvantage - the release of parts of the same is planned ahead, which entails details. Version of the machine, the complete system is the system of continuous control. Planning and accounting unit is a conditional package, which consists of units and details in an amount equal to the average daily consumption. Considered planning and management system using the corresponding model-driven production processes. The emergence of a new class of PDE-models requires the construction of new and improvement of existing systems of production planning and control.

Formalizing the process step.

The essence of the formalization process is dismembering it to the elementary operations [17, s.235], which correspond to the planning and management of the elements of a manufacturing process. The most important basic operations of the process are the processing operations, or parts [5], [17, p.236]. Processing parts, assembly, quality control and packaging products are elementary operations. The complexity process operation described by a set of formalized parts of the operation. Co-operation is a simple aggregate of a formal operation in the case where the pre-ditional information that could be obtained in a more detailed description about the process, is not significant. The separation process operations performed in many ways [5]. Due to the ambiguity problem of choosing the optimal variant of the submission process as a set of operations.

Performing operations on the object of labor is associated with a change in its properties. Changing the properties of the object of labor is shown clearly when properties are described numerical characteristics. Performing operations on the object of labor is associated with a continuous change of its parameters [6]. When

constructing a mathematical model of system operations selected parameters describing the state (properties) products and equipment [18,19]. In this case, the operation regarded as a stochastic process of resource transfer to the object of labor that determines the continuous changing parameters values of products resulting from the interaction with the hardware. Matematic model of the process as a set of formal operations constitutes a pre-sequence of stochastic processes resource transfer to the object of labor [3]. As the production process modeling experience [1-5] in the construction of mathematical apparatus are limited to a small number of set of abstract operations corresponding to a major class of formalized operations [5.17].

To construct a mathematical model of operations required to choose values of the system-defined parameters of state of fissionable objects of labor [17, p.237], [3]. One of the essential parameters of the object of labor is the initial processing time of the processing time and times j-th object to labor m-th processing operation [20]. Moment of receipt $t_{j,m-1}$ of the j-th object of labor to equipment to perform the m-th operation may be deterministic or random. In the first case it is strictly determined by the laws of the individual synchronization operations in the process, in the second case - stochastic volatility $t_{j,m}$. For deterministic sequences as formalized scheme used dependence is defined $t_{j,m}$ in terms of known quantities $t_{(j-1),m}$ or $t_{j,(m-1)}$. In the simplest case $t_{j,m}$ is given by one of the relations [17,20]:

$$t_{j,m}=t_{(j-1)m}+\Delta\tau_m, \qquad t_{j,m}=t_{j,m-1}+\Delta\tau_m; \qquad (1)$$

where $\Delta\tau_m$ is the effective technological labor object processing time for my operation [21]. For random sequences $t_{j,m}$ are known two types of formalization. The first is based on the random increments variables $\Delta\tau_m$ with $t_{j,m}$ given distribution laws, the second - on the description of the sequence $t_{j,m}$ as a random stream of homogeneous events, similar to the flow of applications queuing theory [17,20]. The stream of homogeneous events is simply realized by the circuit

representation of values when accounting random variation does not changing the meaning of the inequalities

$$t_{j,m} \geq t_{(j-1)m}. \qquad (2)$$

Inequality (2) corresponds to the motion of the object of labor on free flow line when the following sequence of objects of labor within the considered time interval is not violated, decreases or impairment is insignificant. If the order of the objects of labor is essential, the use of homogeneous flow of events becomes Difficult. In this case it is convenient to use for the distribution laws of random deviations $\Delta\tau_m$ [17]. In addition to the receipt, the subject of work is characterized by a certain set of audio output governmental characteristics described by continuous parameters $q_{j,k}$, as well as qualitative characteristics described by discrete parameters [6]. In general, continuous and discrete parameters of the object of labor are random variables.

Simulation of processing operations.

Under the formal operation of the processing equipment is understood as the result of exposure to the subject of work in order to transfer resources, at which the value changes at least one of the parameters of the object of labor. By processing transactions include transactions associated with changes in the labor dimensions of the subject, its position in space, telling him additional parameters. Presentation of the process sequence of operations is not uniquely. The complex, facilitating the implementation of the processing operation is generalized-gap of the unit of equipment [20], regardless of the actual structure and purpose. processing operation is performed a certain generalized piece of equipment. For the mathematical description of the processing steps necessary to establish the relationship between the parameters is determined impact equipment on the subject of work in the course of treatment, which may be represented by the relation:

$$\Phi_m\left(t,q_{j,1},q_{j,2},\ldots..q_{j,k},..q_{j,N},\beta_{m,1},\beta_{m,2},\ldots,\beta_{m,i},\ldots,\beta_{m,I}\right)=\Phi^0{}_m,\ i=1..I,\qquad m=1..M. \qquad (3)$$

Random parameters can be the objects of labor $q_{j,k}$ and hardware options $\beta_{m,i}$. Regardless of the nature of the occurrence of disturbances applied the simplest formalization of the process

$$\Phi_m\left(t, q_{j,1}, q_{j,2}, \ldots, q_{j,k}, \ldots q_{j,N}, \beta_{m,1}, \beta_{m,2}, \ldots, \beta_{m,i}, \ldots, \beta_{m,i}, \beta_{m,I}\right) = \Phi^0{}_m + \delta\Phi_m, \quad (4)$$

where $\delta\Phi_m$ deviations are random values Φ_m from a random value $\Phi^0{}_m$. Relationships (3) or (4) do not exhaust the mathematical description of the processing operation. It should be added depending on defining equipment operations. In addition to (1) use the value of: $t^p{}_{j,m}$ - the time of receipt of the j-th objects of labor to the machine, $\Delta\tau^g{}_m$ - the time spent on preparing the equipment to perform the following operation [21]

$$t^p{}_{j,m} = t^k{}_{j-1,m} + \Delta\tau^g{}_m \quad (5)$$

The operation may begin at any time, if the necessary conditions: the equipment is ready for use and it arrived the next object of labor [17]. Downtime associated with the peculiarities of the production cycle, including in $\Delta\tau^g{}_m$ [21]. There are examples of processes [17,20], which are characterized by centralized management of production cycles. In the simplest case this type can specify the flow line mode, when the processing of work items rigidly synchronized with the mode of assembly of products on the conveyor. For such production processes are used on the assumption that the processing operation is started only at time points spaced apart by the length of stroke value $\Delta\tau_{max} = \max\{\Delta\tau_1, \Delta\tau_2, \ldots, \Delta\tau_m, \ldots, \Delta\tau_M\}$. Time to prepare the equipment for operation $\Delta\tau^g{}_m$ after the end of treatment of the subject of the previous labor typically is a random variable with a given distribution law. The most important characteristic is its processing operation duration $\Delta\tau_m$ [21], which depends on the properties of the equipment, and the properties of the work items. When the equipment has a hard time with work, and random fluctuations in the value insignificant, it $\Delta\tau_m$ is non-random fixed value determined by the parameters of the equipment. Many studies [17,22] $\Delta\tau_m$ presented a random variable, the probability characteristics of which depend on the parameters of the

equipment. Quite often describe a random variable $\Delta\tau_m$ with an accuracy of two points [21]. Average value $\Delta\tau_m$ depends on the parameters of the objects of labor and equipment characteristics. Resolved transaction processing description can be used in the formalization of a broad class of processes.

Modeling of operations of product assembly. [23]

Unlike processing operations term operation involves several pieces of working [23]. Among them, the leading product is different (assemblage) and the driven semi-finished products (parts, which are attached to the node). For many production processes range of the object of labor as the lead is to a large extent arbitrary. Under the operation of product assembly pony toils operation on the set of the objects of labor, as a result of which changes the value of at least one of the parameters of the subject of labor leading by acceding to the slave, and the corresponding slave labor goods cease to exist. A significant parameter that determines the modes of interaction of equipment over time is the duration of treatment $\Delta\tau_m$. Characteristics associated with the interaction of the process elements in time can be described by a formalized in constructing circuits in the same manner as for processing operations.

Simulation control operation.

processing and assembly operations are the main technological operations, part foundation of the production process. Formally, they are reduced to the transformation of para-meters of objects of labor with the help of the form (3) ratios. In contrast, the control operation by themselves do not change the parameters of the objects of labor, have no effect on their physical properties, and directly related to the processing and assembly are not. As a result, management operations generated information necessary for coordinated work of individual elements. The control problem is to configure the equipment to a mode corresponding to the parameters of the incoming pas object of labor. As examples of the control operations can be called a regulation cycle of the production process, distribution of the objects of labor between the parallel processors, defining sign of stopping or

resuming supply of work items to the equipment, depending on the length of the queue, as well as activities related to the supervision of the progress of production and product quality. To control operations include operations effort control, temperature or other basic parameters, specific to a particular operation. It is believed that there is a set of equipment, called a control unit that provides performance management operations. In general, in the simulation object control processes involving people meet and some of the principal challenges that require further research [24]. As a result, the control operation is extracted information about the required changes in process conditions for this complex manufacturing equipment with parameters $\beta_{m,i}$. This information is presented in the form of amendments $\Delta\beta_{m,i}$ to the parameters of the equipment $\beta_{m,i}$:

$$\Delta\beta_{m,i} = \Delta\beta_{m,i}\left(t, q_{j,1}, q_{j,2}, ..., q_{j,k}, ...q_{j,N}, \beta_{m,1}, \beta_{m,2}, ..., \beta_{m,i}, ..., \beta_{m,i}, \beta_{m,I}\right). \quad (6)$$

Also relations (6) is necessary to describe the passage of time control signals. An important factor is the binding management operations for the duration of technological act associated with the operation. It may be that the control operation is completed before the start of the operation, and starts after the receipt of the corresponding object of labor. This scheme has advantages $\Delta\beta_{m,i}$ as have the greatest influence on the parameters before entering labor. If the control task is to maintain a stable parameter values $q_{j,k}$ or modes of stable operation of the equipment, it is convenient to assume that the control operation is started after the operation. Do not exclude the possibility of simultaneous execution of the operation and management of the operation, the ratio (6) turns into the equation for the self-regulation $\beta_{m,i}$.

The formalization of violations of state regulatory process technology parameters.

Scheme formalization of operations are based on assumptions about the normalized state parameters of the production process [5-7]. Under normalized condition of process parameters refers to cases where all the controlled process parameters are within the permissible range [6,7]. However, the actual production

processes, accompanied phenomena are capable to bring the process parameters exceed the limits. Violations mated state parameters object of labor, associated with the disorder synchronization mode, the failure of hardware components, repairs and periodic up and adjustment activities. Intervals that determine the synchronization operations are often random variables. There have been instances in the equipment employed education pre-objects with a labor queue, as well as instances of downtime due to lack of work items . If enrolling the subject of work-shy catches equipment to perform operations on the previous object of labor or are in the stage of preparation for implementation of the operation, the object of labor expects to start operations normalized during the production process is not disturbed; semi-finished product may be expected during the operation time interval $\Delta\tau^{pr}_{m}$. If $t^{n}_{j,m} \le t^{p}_{j,m} + \Delta\tau^{pr}_{m}$ the technological process is normalized. Otherwise, at time $t > t^{p}_{j,m} + \Delta\tau^{pr}_{m}$ object of labor is eliminated from the process. When hot working parts as a result of waiting the temperature can drop to such an extent that the operation would be non-feasible. There is a breakdown of the production process because of the long wait, incoming object of labor is excluded from the process (go to the marriage). Excluded subject of work may not be suitable for further use, or be able to restore is stored near the machine and enters the processing when the machine is easy. Timeout, in general, a random variable with a given law of distribution. Of the various cases parameters of manufacturing processes downtime due to delays in receiving the objects of labor. The normalized during the process in this case cannot be violated. Getting the wrong object of labor in the operation is a random event, completely characterized by a probability of bras on, which depends on the parameters of the object of labor, and on the parameters of the equipment. Probably emergence of marriage is considered as a function of the characteristics of the equipment describe his condition as a function of the time interval has elapsed since the last adjustment. As the distance from the moment of setting up the machine output quality deteriorates. The expediency of different-regarded marriage as a result of the output of some product parameters exceed pre-limits of. At failure of the equipment unit processes the subject of work

can be bra-forged with a certain probability. If the equipment failure the subject of work proved to be fit, you need to keep track of his movements on the technological route. In this treatment the subject of labor continues normalized. There may be situations when the treatment stops working object and continues after the commissioning of the equipment. In this treatment the subject of labor must begin again. When equipment failure should be borne in mind two important cases. In the first case, the failure of the unit is out of order and equipment. In another case of failure of the unit or element of the equipment does not fail completely, but the quality of his work is reduced, creases the likelihood of marriage, reduced the time between successive commissioning of equipment, increasing product deviations of parameters after the operation of their required knowledge. One of the major issues of formalization of production processes is the problem of the definition of pro-fault or equipment failure. The repair time is a random mask with a known distribution law [6.25]. In the study of managed production process have to deal with different kinds of impairments - gradual rows of equipment failure. The consequence of wear and tear there is a noticeable increase in the proportion of forged products. The fact of increasing the proportion of marriages according to the time that has elapsed since the next adjustment of the equipment can be described in terms of probability of occurrence of marriage. Consider effects of wear and tear are common. Special measures taken for the elimination of the last Business Plan depreciation of equipment, which are reduced to periodic interruptions of the production process at the scheduled preventive work for the replacement or repair of worn components. Setup time is considered to be a random variable with a given Zuko Mr. distribution. For a formal description of the laws relating to the commissioning of equipments, used the appropriate types of queuing systems.

Conclusion

Analytical methods for the design of control systems, industrial production lines are based on the construction of states in the phase space trajectories of objects rub-yes. The foundation for building effective models of object-

technology-driven production processes that describe the motion of objects on the working party from the technological production line which are the foundation of conservation laws that characterize resource transfer process on the subject of work. Development of a detailed description of the subject-Technology managed production process, based on the stochastic mechanism ne-transference of technology resources on the subject of work as a result of the impact of the equipment in the technological complements you-operation requires the introduction of parameters characterizing the state of the object of labor in the phase technological space. For the introduction of the parameters necessary to determine the formalization of the process, as well as its constituent parts-technology-cal operations. This description should be based on the already known definitions, allowing you to use the existing methodology of process models for the design of control systems with the use of PDE-models (1-4). Held in an article and a brief overview of analys basic definitions used to describe the process, allows us to formulate the basic terms of the known Standard to be used for the projection of such management systems.

References

1. Pihnastyi O. M. O novom klasse dinamicheskih modelej potochnyh linij proizvodstvennyh sistem / O. M. Pihnastyi // Nauchnye vedomosti Belgorodskogo gosudarstvennogo universiteta. Belgorod: BGU. - 2014. - № 31/1. - S. 147-157 (in Russian)

2. Pihnastyi O.M. Obzor modelej upravljaemyh proizvodstvennyh processov potochnoj linii proizvodstvennyh sistem / O. M. Pihnastyi // Nauchnye vedomosti Belgorodskogo gosudarstvennogo universiteta. Belgorod: BGU. - 2015. - № 354/1. S.15 (in Russian)

3. Pihnastyi O.M. Statisticheskaja teorija proizvodstvennyh sistem / O.M.Pihnastyi. - Harkiv: HNU, 2007. - 388 s. (in Russian)

4. Pihnastyi O.M. Analiz modelej perehodnyh upravljaemyh proizvodstvennyh processov / O.M.Pihnastyi // Nauchnye vedomosti

Belgorodskogo gosudarstvennogo universiteta. Belgorod: BGU. - 2015. - № 35/1. - S. 133-144 (in Russian)

5.GOST 3.1109.82. Terminy i opredelenija osnovnyh ponjatij. – M.: Gosstandart Rossii, 2003. –15 s. (in Russian)

6. GOST 15467.79. Upravlenie kachestvom produkcii. Osnovnye ponjatija. Terminy i opredelenija. – M.: Gosstandart Rossii, 2001. – 25 s. (in Russian)

7. GOST 2.101.68. Vidy izdelij. – M.: Gosstandart Rossii, 1995. – 3 s. (in Russian)

8. Pihnastyi O.M. Zadacha optimal'nogo operativnogo upravlenija makroparametrami proizvodstvennoj sistemy s massovym vypuskom produkcii / O.M.Pihnastyi // Dopovidi Nacional'noï akademiï nauk Ukraïni. – Kiïv: Vidavnichij dim "Akademperiodika". – 2006. – №5 – S. 79 – 85. (in Russian)

9. Pihnastyi O.M. Statisticheskaja model' upravlenija tehnologicheskim processom / O.M. Pihnastyi // Sistemnij analiz ta informacijni tehnologiï: Tezi dopovidej 14-ï Mizhnarodnoï naukovo-praktichnoï konfe-renciï, (SAIT2012), (Kiïv, 24 kvitnja 2012). - Kiïv: NTU "KPI". - 2012. – S. 105 – 106. (in Russian)

10. GOST 3.1109.82. Terminy i opredelenija osnovnyh ponjatij. – M.: Gosstandart Rossii, 2003. –15 s. (in Russian)

11. Demuckij V.P. Stohasticheskoe opisanie jekonomiko-proizvodstvennyh sistem s massovym vypuskom produkcii / V.P.Demuckij, V.S.Pihnastaja, O.M.Pihnastyi // Dopovidi Nacional'noï akademiï nauk Ukraïni. – Kiïv: Vidavnichij dim "Akademperiodika". – 2005. – N7. – S. 66 – 71. (in Russian)

12. Razumov I.M. Organizacija i planirovanie mashinostroitel'nogo proiz-vodstva / I.M.Razumov, L. Ja. Shuhgalter – M.: Mashinostroenie, 1974. – 592 s. (in Russian)

13. GOST 14.004-83. Tehnologicheskaja podgotovka proizvodstva. Terminy i opredelenija osnovnyh ponjatij. – M.: Gosstandart Rossii, 2007. – 4 s. (in Russian)

14. Pihnastyi O.M. Raschet proizvodstvennogo cikla s primeneniem statisticheskoj teorii proizvodstvenno-tehnicheskih sistem / O.M.Pihnastyi,

V.D.Hodusov // Dopovidi Nacional'noï akademiï nauk Ukraïni. – Kiev: Vidavnichij dim "Akademperiodika". – 2009. – №12. – S. 38 – 44. (in Russian)

15. GOST 3.1121.84. Obshhie trebovanija k komplektnosti i oformleniju na tipovye i gruppovye tehnologicheskie processy (operacii). – M.: Gosstandart Rossii, 2005. –48 s. (in Russian)

16. Letenko V.A. Organizacija, planirovanie i upravlenie mashinostroitel'nym predprijatiem / V.A.Letenko, B.N.Rodionov.– M.: Vysshaja shkola, 1979.–Ch.2. –232 s. (in Russian)

17. Buslenko N. P. Modelirovanie slozhnyh sistem / N. P. Buslenko. – M.: Nauka, 1978. – 356 s. (in Russian)

18.Armbruster D. Kinetic and fluid model hierarchies for supply chains. / D. Armbruster, D. Marthaler, C. Ringhofer // SIAM Multiscale Model Simul.– 2004. – №1. – P. 43 – 61.

19. Azarenkov N. A. O zakone vozrastanija jentropii tehnologicheskogo processa. / N. A. Azarenkov, O.M.Pihnastyi, V.D.Hodusov // Dopovidi Nacional'noï akademiï nauk Ukraïni. - Kiïv: Vidavnichij dim "Akademperiodika". – 2012. – N5 – S. 32–37. (in Russian)

20. Shkurba V. V. Planirovanie diskretnogo proizvodstva v uslovijah ASU / V.V.Shkurba, V.A. Boldyreva, A.A.V'jun i dr. / pod red. V. M. Glushkova. – K.: Tehnika, 1975. – 296 s. (in Russian)

21.Lefeber E. Modeling, Validation and Control of Manufacturing Systems / E.Lefeber, R.A.Berg, J.E. Rooda // – Proceeding of the 2004 American Control Conference. –Massa- chusetts. – 2004. – P. 4583 – 4588.

22. Pihnastyi O.M. Inzhenerno-proizvodstvennaja funkcija predprijatija s serijnym ili massovym vypuskom produkcii / O.M.Pihnastyi // Voprosy proektirovanija i proizvodstva konstrukcij letatel'nyh apparatov. – Har'kov: NAKU. – 2005. – № 42(3). – S. 111 – 117. (in Russian)

23.Zhang Liang. System-theoretic properties of Production Lines: A dissertation submitted the degree of Doctor of Philosophy / Zhang Liang. – Michigan, 2009. – 289 p.

24. Pervozvanskij A.A. Matematicheskie metody v upravlenii proizvodstvom / A. A. Pervozvanskij. – M.: Nauka, 1975. – 616 s. (in Russian)

25. GOST 50779.10-2000(ISO 3534.1-93). Statisticheskie metody. Verojatnost' i osnovy statistiki. Terminy i opredelenija.– M.: Gosstandart Rossii, 2000. – 38 s. (in Russian)