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# DEVELOPMENT OF THE TEMPORAL KNOWLEDGE REPRESENTATION MODEL FOR COMPUTER SUPPORT OF CONSUMER GOODD PRODUCTION PROCESSES AT MULTI-NOMENCLATURE MACHINE-BUILDING ENTERPRISE

*Викладено підхід до створення темпоральної моделі знань (ТМЗ) для побудови на її основі інтелектуального ядра системи підтримки прийняття рішень щодо організації виробництва товарів народного споживання на багатономенклатурному машинобудівному підприємстві. Відмінною рисою створюваної моделі знань є можливість врахування часових залежностей, які мають місце у виробничих процесах. Вказана особливість ТМЗ надасть змогу ефективного вирішення низки задач, що пов'язані, насамперед, із забезпеченням ритмічності виробничих процесів.*

**Ключові слова:** *машинобудівне підприємство, товари народного споживання, система підтримки прийняття рішень, модель знань, темпоральна логіка.*

## 1. Introduction

The current state in the branch of Ukrainian engineering industry necessitates the introduction of new types of automated control systems (ACS) at enterprises. These systems will provide an opportunity to increase the efficiency of the enterprise as a whole and provide support for making managerial decisions based on reliable information obtained from all levels of the production hierarchy.

Today, the main automation tools in industrial enterprises, in particular machine building, are ERP/MRP systems, which implement tasks related to effective sales management, procurement, finance, accounting and personnel. The implementation of only such systems does not solve the tasks of managing complex production processes. For this, it is also necessary to use MES-class systems that take into account the technological specifics of the enterprise and are specially developed for each specific industry.

Existing MES systems are focused on integration with SCADA-systems installed at the lower level of production. However, the characteristic features of the multi-nomenclature machine-building enterprise (MME), in which along with the flagship products, the share of consumer goods (CG) is large, in terms of the number of titles and the size of lots, make it difficult to implement MES systems in such enterprises [1].

Until now, MES systems have not been developed that take into account the specific features of the production of CGs at the MMEs, the effective organization of which would significantly improve the efficiency of the enterprise as a whole. In the engineering industry, it is very difficult to use SCADA systems through a wide range of CGs and a fairly frequent change in the size of batches of products. This characteristic for the production of CGs at the MMEs line creates a number of problems in automation, primarily because of the lack of up-to-date information on the current state of production, makes it difficult to make decisions when organizing the CG production at the enterprise as a whole.

The process of organizing CGs at the MMEs is characterized by a rather high level of uncertainty. This circumstance is due to insufficient information on the current state of production, so the production process can't be effectively implemented on the basis of traditional, analytical methods of information processing used in existing automated control systems.

Using the methods of artificial intelligence, in particular, the technology of dynamic expert systems (DES), can significantly improve the adequacy of production decisions due to the fact that the formation of decisions takes into account the current state of production facilities.

Modern shells for DES creation, such as G2, RTworks, are oriented to the collection of current data using a network of SCADA systems deployed on production, the use of which is too difficult for the manufacture of CGs at the MMEs, due to its peculiarities. At the same time, modern DESs, which are based primarily on productive models of knowledge representation, do not adequately reflect the time factor, which comes to the fore in solving the tasks of organizing the CG production. Representation of time dependencies will allow to predict the development of CG production processes clearly, which will improve the quality of decisions taken to effectively eliminate the consequences of deviations from the plan if they arise.

Thus, it can be concluded that the scientific task, which consists in developing a model for presenting knowledge of the current state of CGs at the MMEs, taking into account the time dependences that occur when implementing these production processes, is relevant. The solution of this problem will allow to significantly increase the efficiency of decision-making processes in the environment of the corresponding MES systems at the MMEs.

## 2. The object of research and its technological audit

*The object of research* is the processes associated with the organization of the CGs production at the MME. These processes are considered in the aspect of automating the CGs production by creating a special model of knowledge about the current state of production processes. In addition, the object of research is the technology of using this model in the future when developing software and tools for decision support in the form of DES, for organizing production processes at MMEs.

In modern conditions, when the Ukrainian industry as a result of de-industrialization lost a significant part of production capacity, as well as intervention on the Ukrainian market of goods from East Asian countries, the CGs production in the territory of Ukraine has become quite problematic. At the same time, there are industrial enterprises, in particular machine building, where the production of flagship products has remained. This circumstance determines the importance of the organization in such enterprises along with the flagship production and CGs, by as fully as possible loading productive capacities. The solution of this problem requires the creation of qualitatively new methodological and software tools with the help of which effective coordination in space and time of all production processes at the MMEs would become possible.

One of the main problems of complex automation of combined processes of production of main products and CGs at the MMEs is an improvement of the formal apparatus for modeling time dependencies. The existing nomenclature of pseudophysical logics includes so-called temporal logics, but the formal theory of time, constructed with the use of these tools, but does not adequately reflect exactly the mechanism of combining production processes in time.

## 3. The aim and objectives of research

*The aim of research* is the creation of a special model of knowledge, which is able to adequately represent the time dependencies in the CGs production at the MMEs. This model can be used in the intellectual core of the decision support system, which will become an integral part of the corresponding MES system in the enterprise.

To achieve this aim, it is necessary to solve the following tasks:

1. To conduct an analysis of the suitability of existing MES systems, as well as models, methods and information technologies of automated control for the effective organization of CGs production at the MMEs, taking into account time dependencies.

2. To improve the methodological toolkit for presenting time dependencies for constructing the temporal model and the method of its application in the formation of decisions on the organization of CGs production at the MMEs.

## 4. Research of existing solutions of the problem

Effective management of enterprises of the machine-building industry is possible only taking into account the features of modern production. To such features, first of all, one should include dynamism, multiple amounts of subjects, topological distribution of production units, hierarchy of the management structure, the presence of a significant number of functional subsystems and connections between them [1].

According to the Ukrainian classification, machine-building enterprises are divided into enterprises with a single, serial, mass and mixed output [1]. One of the ways to increase the efficiency and profitability of an industrial enterprise is automation of its activities, including automation of production processes management.

At the present stage of automation of industrial enterprises, ERP systems are widely used, as enterprise resource planning systems that solve the tasks of effective sales management, purchases, finance, accounting, personnel. However, the use of only ERP systems can’t solve the task of managing complex production [2], for this it is necessary to implement MES systems of operational planning, optimization and production management, taking into account the technological specifics of the enterprise and specially developed for a particular industry. MES systems allow to provide the coordinated interaction of shops, departments, the sites equipped with the automated control systems of the enterprise (ACSE).

The most promising tasks of the MES system are tracking downtime and loss of production on individual units, as well as calculating the efficiency factor of equipment use. In this case, mechanisms are used to automatically generate events (downtime of production equipment) and to compare these events with possible causes of their occurrence. Determination of efficiency parameters is carried out by comparing and analyzing differences in the production performance of equipment on different lines. Evaluation of the current load of production makes it possible, if necessary, to quickly distribute the load within the available production capacities.

MES system allows to centrally monitor the state of the production line, monitor the production process and in real time to identify restrictions that hinder its effectiveness. To detect these limitations, the OEE (Overall Equipment Effectiveness) indicator is used, which combines the production aspects of efficiency, output and quality [2, 3].

The least widespread, at present, MES systems have at machine-building enterprises that produce a relatively large range of products, but in small series, despite the complex processes of organization of production and management. Typical features of production at such enterprises are the many thousands of items and assembly units, a large number of changes, the production of small series, quite frequent modifications. These features make it difficult to implement MES systems, in particular, if a significant part of the production at such an enterprise is made up of consumer goods. At the same time, the most important and complex tasks of organization of production are:

– analysis of the causes of deviations from the planned course of production;
– elimination of interruptions in the course of the production process;
– adoption of operational measures to prevent and eliminate deviations from planned targets;
– maintenance of the coordinated work of shops by coordination of their current activity. These problems can be classified as difficult to formalize [4, 5], since

they have the following features: ambiguity, incompleteness and inconsistency of the initial data; greater dimensionality of decision space, dynamism of updating data and knowledge. To effectively solve such problems it is advisable to use artificial intelligence methods, including in the form of software tools based on the technology of expert systems [6].

Characteristic features of the modern production facility, in particular the multi-nomenclature machine-building enterprise, is the relatively high dynamics of its functioning, which provides for a dynamic change in the data and knowledge about the management object necessary for making an adequate management decision. Each such shift occurs in time, whether it is the process of assembling the product, performing procurement operations, moving finished assemblies and units across the enterprise. To monitor and manage the process of CGs production at MMEs, it is necessary to accurately monitor and present processes and events in time, and also to predict the development of processes that significantly affect the management object.

Time is one of the fundamental concepts of the world around us. Any change in it occurs over a period of time, any activity is realized in time. Many concepts like transformation change, action, cause, effect and relationship between them can be described in terms of time. Some properties of time are intuitively clear, while others are on the contrary ambiguous [6–9]. An important concept related to the natural understanding of time is the notion of scale, it allows organizing separate «pieces» of time – moments or intervals – tempors. To represent time, there are two ways of scaling. The first reflects the order of events on the scale «past – present – future», and the second – on the scale of the «earlier – later» type. Each event on the scale «past – present – future» in the process of evolution seems to move along it. If at some initial moment it is located in the future, then, changing or approaching, it will arise in the modern, and then go to the past, staying there forever. If it is not realized in the present, it disappears from the scale. On the scales of the second type, the events are arranged in a constant order. It's like a «has already happened» scale is frozen. The main properties of time – direction, linearity, continuity, unlimited, homogeneity [6].

The specified properties of time do not have universality, therefore, if necessary, it is expedient to construct temporary pseudophysical logics, in which there is a different set of initial axioms, and based on the necessary time domain descriptions for the domain description. The analysis of directions in the field of knowledge engineering has made it possible to single out a number of problems for which the use of the time factor is the key [8].

To such problems belong [7]:

– Diagnostics. Identification of the current state of the management object on the basis of the characteristics that influence decision–making by the decision maker (decision maker).
– Monitoring. Monitoring of the state of the control object on a time scale close to the real one, with notification of decision maker about the emergence of critical situations.
– Help. Description of the state of the control object at some point in time has already passed, and which is the cause of the current state of the control object.
– Forecasting. Determination the state of the control object in the future, at a time point given by decision maker.
– Rules of variation. The construction of a set of rules that regulate changes in the causal laws of the considered subject domain.

When organizing the CGs production, an important task is prediction of the state of the parts and assemblies that make up the product, and the finished product as a whole. To describe the relationship between the causes and their consequences, it is necessary to present the relevant temporal relationships in an explicit form. Proceeding from this, it is necessary to allocate the following components of knowledge about the subject area [10, 11]:

– cause-effect relationships about events and the values of parameters in the modeled domain;
– time dependencies describing the mutual position of the causes, their consequences and the duration of the processes occurring during the control of the production facility, or properties that the control object element has.

For predicting the consequences of the current (or some given) situation and responding to inquiries about the future state of production facilities, the forecast model can be used, explicitly takes into account the time dependencies. In this case, requests can be both about the time of occurrence of some events, and about the fact of the presence of circumstances at a certain point in time. Thus, on the basis of the analysis of the subject area, the specifics of solving the problems of organizing CGs production at the MMEs, it is important to develop a temporal model, that is, one that adequately represents the production processes in time.

## 5. Methods of research

To build a model of knowledge with allowance for temporal dependencies, discrete mathematics methods, in particular set theory and mathematical logic, as well as tools that are known in knowledge engineering are used.

The process of building a temporal knowledge model begins with a description of the subject area (SA), then the following steps must be performed [9]:

1. To select the basic time primitives specific to SA and set the basic relationships between them.

2. To enter the necessary elementary functions for converting primitives and relations.

3. To set the time structure using axioms, which determine the basic properties of time and the properties of the basic relationships, depending on the subject area.

4. To describe how temporary constraints are represented.

5. To select the method of connection of logical assertions with time.

6. To describe the formal theory of time-dependent statements.

At the first stage of the knowledge model synthesis, taking into account temporal dependencies, the moments and/or time intervals can be used as the base primitives. If necessary, time constants are used to denote the moments of time and intervals (seconds, minutes, hours, days, dates, time of day, etc.), and also noticed the «duration» corresponding to the distance between the moments of time.

The second stage: some of the functions are built on the basis of the basic relationships and is their functional version, the functions allow for the transformation between temporary primitives.

At the third stage of the model synthesis, it is necessary, when specifying several primitives of time, to specify the relationship between them in the form of the corresponding axioms, taking into account the properties (discreteness/continuity) of SA time characteristics.

The fourth stage is connected with the justification of the choice of the method of representing time dependencies, namely, the method of scaling.

The fifth stage of the knowledge model synthesis, taking into account temporal dependencies, involves the use of approaches that have good expressiveness.

At the last, sixth stage, it is necessary to define the basic time statement, and also define their properties using a set of axioms.

## 6. Research results

Let's consider the conditional scenario, according to which the organization of CGs production is carried out at the level of workshops of a typical MME. Let's assume that information about the current state of tasks that are planned for implementation is updated on the basis of data coming from the dispatching offices (DO) of the production departments. According to the work schedule at the beginning of each shift, the status of production tasks is checked to determine the facts of deviations and the magnitude of the delay in the tasks.

Let's denote the set of all planned tasks as $Z$. In this case there exists a mapping $ZP$: $Z \to P$, which determines the correspondence of the state of production tasks to the elements of the temporal model. The status of the task $z_i \in Z$ is *Status*. This attribute determines belonging $z_i$ to $\Phi^n$, $\Phi^w$ or $\Phi^r$. Timeliness of issue and delivery of tasks is characterized by *timeliness*. This characteristic determines the belonging the task $z_i$ to $\bar{W}$ or $\tilde{W}$, where $\bar{W}$ – the set of tasks issued or completed without deviating from the plan, but $\tilde{W}$ – the set of tasks, execution time or issuance that were delayed due to the influence of external or parametric disturbances on production as a management object. At the same time $\bar{W} \cap \tilde{W} = \varnothing$ and $ZW : Z \to (\bar{W} \cup \tilde{W})$.

Production tasks are divided into component and collecting $Z = \left\{ Z^k \cup Z^a \right\}$, while:

$$Z^k \cap Z^a = \varnothing,$$

where $Z^k$ – the task of components manufacturing; $Z^a$ – collecting tasks. There are bijective mapping $Z^k \to B$ and $Z^a \to ((P \setminus B) \setminus R)$.

To activate the temporal model, a lot of events that arise as a result of DO operation are displayed by the elements of the set of all events:

$$E^a = \left\{ E^{pa} \cup E^d \right\},$$

where $E^{pa}$ – the events of the actual or planned start/completion of the production task, while $E^{pa} \to E$; $E^d$ – the events related to checking the status of the task at the beginning of each shift. Events from the set $E^a$ change the signs of tasks at times from the set:

$$T = \left\{ T^p \cup T^f \right\}, \quad T^p \cap T^f = \varnothing,$$

where $T^p$ – the set of time points of checks at the beginning of each shift that took place from the beginning of the launch of the product into production; $T^f$ – a lot of time checks at the beginning of each shift, which will take place until the end of collection of the entire product.

The first stage of the method is implemented in parallel, asynchronously and cyclically in the monitoring networks at the beginning of each working shift in production links. This makes it possible, in the process of supporting decision-making on the implementation of working technology, to take into account the current state of the production of collecting units.

The second stage of the method, in case of delay, makes it possible to form a solution that is a finite set and can be represented by appropriate rules in the knowledge base.

Proceeding from the foregoing, it is expedient to use a two-stage procedure for outputting knowledge to form solutions for organizing CGs production at MMEs [10, 11]. The initial situation is defined as follows:

$$\forall z_i \in \bar{W} \wedge \forall z_i \in \Phi^n, \quad \exists Z^p : Z^k \to Z^a.$$

1. In case of events $e_j^a \in E^{pa}$ that are related to the change in the actual state of the production task, where $j \in \{begin, complete\}$, *begin* – the beginning of the task, *complete* – the completion of the task:

– if $e^a_{begin_{z_i}}$ – the composition of the sets $\Phi^n$ and $\Phi^w$ is changed and by:

$$\Phi_k^n = \Phi_{k-1}^n - \phi_{z_i}^{A^n} \wedge \Phi_k^w = \Phi_{k-1}^w + \phi_{z_i}^{A^n},$$

where $K$ – the next change at the beginning of which the check is performed;

– if $e^a_{complete_{z_i}}$ – the composition of the sets $\Phi^w$ and $\Phi^r$ changes and by:

$$\Phi_k^w = \Phi_{k-1}^w - \phi_{z_i}^{A^w} \wedge \Phi_k^r = \Phi_{k-1}^r + \phi_{z_i}^{A^w},$$

where $K$ – the next production change;

– if for any task does not occur any of these events – go to step 2.

2. In the case of $e_j^{pl} \in E^{pa}$ planned task state measurements, where $j \in \{begin, complete\}$, *begin* – the beginning of the task, *complete* – the completion of the task:

– if $e^{pl}_{begin_{z_i}}$ for $\forall z_i \left| z_i \in \bar{W} \wedge z_i \in \Phi^n \wedge t^{pl}_{begin_{z_i}} \in T^p \wedge t^{\phi}_{begin_{z_i}} \in T^f \right.$ – the composition of the sets $\bar{W}$ and $\tilde{W}$ is changed and by:

$$\bar{W}_k = \bar{W}_{k-1} - \omega_{z_i}^{\bar{W}} \wedge \tilde{W}_k = \tilde{W}_{k-1} + \omega_{z_i}^{\bar{W}};$$

– if $e^{pl}_{complete_{z_i}}$ for $\forall z_i \left| z_i \in \bar{W} \wedge \forall z_i \in \Phi^w \wedge t^{pl}_{complete_{z_i}} \in T^p \wedge \right.$ $\wedge t^a_{complete_{z_i}} \in T^f$ – the composition of the sets $\bar{W}$ and $\tilde{W}$ is changed and by:

$$\bar{W}_k = \bar{W}_{k-1} - \omega_{z_i}^{\bar{W}} \wedge \tilde{W}_k = \tilde{W}_{k-1} + \omega_{z_i}^{\bar{W}};$$

– if $e^{pl}_{complete_{z_i}}$ for $\forall z_i \left| z_i \in \tilde{W} \wedge z_i \in \Phi^r \wedge (t^a_{complete_{z_i}} \le t^{pl}_{complete_{z_i}}) \right.$ – the composition of the sets is changed and by: the composition of the sets $\bar{W}$ and $\tilde{W}$ is changed and by:

$$\bar{W}_k = \bar{W}_{k-1} - \omega_{z_i}^{\bar{W}} \wedge \tilde{W}_k = \tilde{W}_{k-1} + \omega_{z_i}^{\bar{W}};$$

– if for any task none of these events occur, go to step 3.

3. In case of initiating events $e^{ch}_{K_j} \in E^d$, the task execution check, where $K$ – the set of indexes $K$={φφ, ωω, *bb*}, φφ – check of the task status, ωω – check of the task timeliness, *bb* – check of the delay in issuing the task:

– if $e^{ch}_{aa_{z_i}}$ for $\forall z_i \left| z_i \in \Phi^w \wedge t^{pl}_{complete_{z_i}} \in T^f \wedge t^{a}_{complete_{z_i}} \in T^f \wedge t_{check_{z_i}} \right.$ – calculate the current duration of the job:

$$dur^w_{z_i} = t_{check_{z_i}} - t^{\phi}_{begin_{z_i}};$$

– if $e^{ch}_{\omega\omega_{z_i}}$ for $\forall z_i \left| z_i \in \Phi^w \wedge z_i \in \tilde{W} \wedge t_{check_{z_i}} \right.$ – calculate the current duration of the task delay:

$$dur^r_{z_i} = t_{check_{z_i}} - t^{pl}_{complete_{z_i}};$$

– if $e^{ch}_{bb_{z_i}}$ for $\forall z_i \left| z_i \in \Phi^r \wedge z_i \in \tilde{W} \wedge (t^{pl}_{complete_{z_i}} \le t^{a}_{complete_{z_i}}) \right.$ – the composition of the sets $\bar{W}$ and $\tilde{W}$ is changed and by:

$$\bar{W}_k = \bar{W}_{k-1} - \omega^{\bar{W}}_{z_i} \wedge \tilde{W}_k = \tilde{W}_{k-1} + \omega^{\bar{W}}_{z_i};$$

– if none of these events occurs for any task, go to step 4.

4. For any production task $z_i \in Z^a$ that is performed in the shop, check the delays $dur^r_{z_i}$ of the particular tasks that are included in its composition, determine the delay $dur_{\max} = \max\limits_i \left(dur^r_{z_i}\right)$ and establish the fact that $dur_{\max}$ is the delay of the entire production task.

5. Definition of the consumer shop $z_i \in Z$ for the task by analyzing the routing technological process and transfer of the delay $dur_{\max}$ of task $z_i$ to the consumer shop. At this stage, information is transmitted about the deviation, from the monitoring network to the decision support system.

6. Determination of the presence of a critical situation by comparing the length of delay $dur_{\max}$ of the $z_i \in Z$ task with the critical delays of tasks, which are included in the current production task.

7. Forming of technological recommendations, in the environment of decision support system, about measures for overcoming the critical situation.

8. The implementation of the method will be completed if the current status of all production tasks is «handed over», that is, the collection of this product by the CG nomenclature is completed.

The conclusion on knowledge during the realization of the described above method is carried out on the basis of the temporal model of knowledge, which is a set of statements about the temporal dependence between the individual stages of the production process. Depending on the event (which is activated by the dispatcher of the main production workshop or automatically by the system), the corresponding rule is activated.

The events that are generated by the system and are activated by the DO:

– PnMI (*Start_Execution (tasks*), *t*) – upon the issue of the assignment.

– PnMI (*Completion_Execution (tasks*), *t*) – upon the issue of the assignment.

Events that form and activate the system:

– PnMI (*Planned_ start_execution (task), t*) – according to the plan.

– PnMI (*Planned_completion_execution(task*), *t*) – according to the plan.

– PnMI *(Check_ delay(z), t*) – daily.

– PnMI (*Check_Status(z), t)* – daily.

1. At the moment of occurrence of the *Start_Execution (tasks*) the status parameter of the Status task changes to «in_Execution»:

∀$z_i$∈*task*, ∃*i,j*∈*Interval*, ∃*t*∈*Time*
*PnMI (Start_execution(*$z_i$*), t)*∧
∧*VnI (Status(*$z_i$*, unissued), i)*∧
∧*end(i)=t*⇒*VnI (Status(*$z_i$*, in_Exexution), j)*∧
∧*meets(i, j)*.

2. At the moment of occurrence of the event «*Completion_Execution (tasks*)» the task parameter Status changes to «handed over»:

∀*zi*∈*task*, ∃*i,j*∈*Interval*, ∃*t*∈*Time*
*PnMI (Completion_Execution(zi), t)*∧
∧*VnI (Status(zi, in_execution), i)* ∧
∧*end(i)=t*⇒*VnI (Status(zi, handed over), j)*∧
∧*meets(i, j)*.

3. At the moment of occurrence of the event «*Planned_ start_execution (task*)» and the task parameter Status changes on «unissued», the task parameter *timeliness* changes to «delay»:

∀*zi*∈*task*, ∃*i,j,k*∈*Interval*, ∃*t*∈*Time*
*PnMI (Planned_ start_execution(task) (zi), t)*∧
∧*VnI (Status(zi, unissued),i)*∧
∧*VnI (Timeliness(zi, timely),j)*∧
∧*end(j)=t*⇒*VnI (Timeliness(zi, delays),k)*∧
∧*meets(j,k)*.

4. At the time of the occurrence of the «p *Planned_ completion_execution (task*)», the task parameter *Timeliness* changes to «*delay*»:

∀*zi*∈*task*, ∃*i,j,k*∈*Interval*, ∃*t*∈*Time*
*PnMI (Planned_completion_execution, (zi), t)*∧
∧*VnI (Status(zi, in_execution), i)*∧
∧*VnI (Timeliness(zi, timely),j)*∧*end(j)=t*⇒
⇒*VnI (Timeliness(zi, delay),k)*∧*meets(j,k)*.

5. At the moment of occurrence of the event «*Planned_ completion_execution (task*)» the task parameter *Status* «handed over» and previously defined delay, the task parameter Timeliness changes to «timely»:

∀*zi*∈*task*, ∃*i,j,k*∈*Interval*, ∃*t*∈*Time*
*PnMI (Planned_ completion_execution, (zi), t)*∧
∧*VnI (Status(zi,handed over),i)*∧
∧*VnI (Timeliness(zi, delay),j)*∧*(begin(i)=t*∨
∨*begin(i)<t)*∧*end(j)=t*⇒*VnI (Timeliness (zi, timely),k)*∧
∧*meets(j,k)*.

6. Formation of the «delayed output» event:

∀*z*∈*task* ∃*i,j,k*∈*Interval*
*VnI (Timeliness (z, delay),i)*∧
∧*VnI (Status(z,unissued), j)*⇒
⇒*PnMI (Delayed output(z), k)*∧*equal(i, k)*.

7. Calculation of the delay in the output of the task:

$\forall z \in task,\ \exists i,j,k \in Interval,\ \exists t \in Time$
$PnMI\ (Check\_delay(z),\ t) \wedge VnI\ ((z,\ delay),\ i) \wedge$
$\wedge VnI\ (status(z,\ in\_execution),\ j) \wedge Timeliness = end(i) \Rightarrow$
$\Rightarrow VnI\ (Timeliness\ (z,\ delay),\ k) \wedge$
$\wedge Delay(z,\ d) \wedge d = duration(k) \wedge start(k,\ i).$

8. Check of the task status

$\forall z \in task,\ \exists i,j,k \in Interval,\ \exists t \in Time$
$PnMI\ (Check\_status(z),\ t) \wedge$
$\wedge VnI\ (Status(z,\ in\_execution),\ i) \wedge t = end(i) \Rightarrow$
$\Rightarrow start(j,i) \wedge VnI\ (Status(z),\ j).$

The rule that forms the facts about the expected delay in the production task:

$\exists P1,P2 \in z,\ \exists durmax \in Duration$
$Contain(P1,\ P2) \wedge Delay\ P2,\ durmax) \Rightarrow$
$\Rightarrow Expected\_delay\ (P1,\ durmax).$

The rule that forms the facts about the critical delay in the production task:

$\forall P \in z,\ \exists d \in Duration$
$Delay(P,\ d) \wedge Critical\_delay(P,\ l) \in (d = l \vee d < l) \Rightarrow$
$\Rightarrow Critical\_situation(P,\ d).$

## 7. SWOT analysis of research results

*Strengths.* The developed temporal model of knowledge will provide timely detection of deviations from the production plan, and also allow to take into account the current state of production facilities in the process of supporting the adoption of managerial decisions on the organization of production of consumer goods. The overall effect of the implementation of the developed model of knowledge will be achieved by reducing the incidence of disruptions in the production program, preserving the professional knowledge of experienced MME specialists in the production of consumer goods. In addition, the use of the temporal knowledge model as part of the intellectual core of the decision support system will ensure the reduction of the MME costs in the organization of production of consumer goods.

*Weaknesses.* The main weakness of the developed temporal model, as well as of any other means of knowledge engineering, is the need to involve a cognitive engineer at all stages of its life cycle.

*Opportunities.* Introduction of the results of this research will allow to receive additional profit to the enterprise due to the increase in the volume of production of consumer goods without expansion of production.

*Threats.* MME costs for the implementation of the research results will be comparable to the annual costs of automation of production.

## 8. Conclusions

1. The analysis of the existing models of knowledge in the aspect of representing the time dependencies that occur during the operation of the CGs production at MMEs is carried out. The first-order logic is selected as the basis for time extension. This choice is due to the fact that out of the five most common knowledge models, only frame and logic allow the time factor to be clearly represented, however, for the frame models, effective mechanisms of inference have not yet been developed. For the time dependency representation model, a dictionary, semantics, and syntax are specified for a formal logical system. These components of the formal logical system are: basic temporary primitives, relations between temporal primitives, the system of axioms, describing the structure of time, the method of concretization, as a means for linking logical assertions. The formal basis of the constructed temporal model of knowledge is the many-sorted calculus of predicates. This model, when applied as part of a dynamic expert system with a knowledge-based production type, can be interpreted as follows: the predicates of antecedents and the consequent of the corresponding rules will be the essence of many-sorted logic.

2. The methodological toolkit that exists within the framework of mathematical logic has been improved, in the aspect of increasing the adequacy of the models for representing time dependencies between individual fragments of manufacturing processes at the MME. The result of the improvement is the temporal model in the form of many-sorted t predicate calculus. This model, being built into the knowledge base of the decision support system, will adequately reflect the asynchrony and parallelism that is inherent in the production processes of CGs at MME.

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## РАЗРАБОТКА ТЕМПОРАЛЬНОЙ МОДЕЛИ ЗНАНИЙ ДЛЯ КОМПЬЮТЕРНОЙ ПОДДЕРЖКИ ПРОЦЕССОВ ПРОИЗВОДСТВА ТОВАРОВ НАРОДНОГО ПОТРЕБЛЕНИЯ НА МНОГОНОМЕНКЛАТУРНОМ МАШИНОСТРОИТЕЛЬНОМ ПРЕДПРИЯТИИ

Изложен подход к созданию темпоральной модели знаний (ТМЗ) для построения на ее основе интеллектуального ядра системы поддержки принятия решений по организации производства товаров народного потребления на многономенклатурном машиностроительном предприятии. Отличительной чертой создаваемой модели является возможность учета временных зависимостей, имеющих место в производственных процессах. Указанная особенность ТМЗ даст возможность эффективного решения ряда задач, связанных, прежде всего, с обеспечением ритмичности производственных процессов.

**Ключевые слова:** машиностроительное предприятие, товары народного потребления, система поддержки принятие решений, модель знаний, темпоральная логика.

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