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PROCEDURAL AND SOFTWARE SUPPORT OF SIMULATION SYSTEMS FOR CONTINUOUS – DISCRETE PRODUCTION COMPLEXES

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Abstract: The paper is concerned with simulation of continuous-discrete production systems using the computer application software for metallurgy. The concepts are formulated for creating simulation systems, software and databases. The examples of solution of control and project application problems using the developed simulation systems are described in this paper. *Copyright © IFAC*

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Simulation can be efficiently used in research, design and control of sophisticated production systems. A modern simulation system should meet the following requirements:
- the semantics of the modeling languages should lend itself readily to obtaining a model of the objects simulated which interprets their behavior for long time periods (ideally, for the lifetime);
- the formalized description of the object simulated should help revealing its properties which cannot be identified otherwise;
- the modeling language chosen should be user friendly;
- based on the research into various simulation means for continuous-discrete processes and their application to the metallurgical production which is continuous-discrete by its nature, the team of the Institute of Control Sciences of the Russian Academy of Sciences (ICS RAC) has developed a special simulation algorithm and the concepts of building simulation systems (Vlasov *et al*., 1983; Vlasov and Belov, 1995).

The procedure aims at solving the problem of analysis and synthesis of different versions of computerized technological complexes (CTC) of the modern metallurgical production.

With the conventional approach to simulation, the model is treated as an algorithm whose computation simulates the functioning of the system in question. Assuming that a simulation model is a “black box”, one can interpret it as a triple $<X,Y,P>$, where X and Y are input and output of the model; P stands for model parameters. To change the version of the system simulated (or the version of the simulation system) one has to change the values of the parameters P. During the exercise X and Y vary in time. To change the simulation model it is necessary to develop a procedural and software tool enabling the use of various versions of the system studied. The integrated design (ID) based approach developed at the ICS RAN in the early 1980s was used to obtain such a tool for the CTC simulation models (Vlasov *et al*., 1983).

The integrated design in accordance with (Vlasov *et al*., 1983). requires that the problem is approached at several levels. At the lower levels the so-called practical variables are chosen, i.e. modes involving equipment with the fixed design properties which impart to the products the required consumer features. Upper levels imply the definition of the technology operator and the domain of constraints for the variables, parameters and controls, i.e. the type and nomenclature of the equipment, design and assembly patterns, the material used for fabrication of the equipment are chosen out of a number of candidate versions assuming a preliminary choice of the lower level for each variant. These problems are, as a rule, combinatorial in nature and their solution can be approached by different methods of variant ordering by a number of optimality criteria. Note that the problems belonging to the highest level can be extrapolated to become strategic, planning, economic, etc. It is relevant, though - for this statement - that all of them are ultimately covered by alternative variants of the original statements of the projects. The above ID can be achieved via man-machine computer simulation aimed at a specific class of objects and equipped with the respective assembly models, the models of their relations and joint operation, the models of their control system functioning, etc. In other words, the method of solution proposed is the problem-oriented man-machine simulation.

Simulation of the main design solutions for a specific application - metallurgy - and the feasibility study not only of their technological aspect but also of their control at different levels, as well as the respective modeling are done in accordance with (Vlasov *et al*., 1983). Note that what is meant here is the object type, but not its specific implementation at a plant. This means that the simulation system and the software package, which have brand IMITAMP, developed by the ICS RAS, contains invariant components which can be used regardless of which specific plant the simulation system or the complex of simulation models are developed for. (The abbreviation IMITAMP stands for Simulation of Computerized Metallurgical Production in Russian). On the other hand, the specialized software simulation tools utilized in the IMITAMP complex, i.e. the language GPSS PC™ and the C^{++}- based user software modules make it rather easy to introduce object characteristics and parameters specific for the plant in question (Smirnov *et al*., 1998). Here are the main problems solved using components of the IMITAMP and man-machine simulation package. Let us start identifying the three main areas to which these problems belong:

- the CTC project management for metallurgical plants including CAD in these applications (Smirnov *et al*., 1998; Rozhkov *et al*., 1990).
- the comprehensive analysis of the interrelated functioning of technological and organizational components of the CTC and the coordinated choice of the equipment configuration and the control system parameters (Vlasov and Belov, 1995);
- the CTC control aiming at optimal efficiency parameters defined as the main ones, e.g. quality control, energy-saving control etc. (Smirnov *et al*., 1998; Rozhkov *et al*., 1990).

The main problems and the task of multiple analysis and synthesis of the CTC of the metallurgical production were solved using the software and information kit developed by the ICS RAS.

The specificity of the task of analysis and synthesis of the CTC (namely, the need to account for the current control) and the parameters of the hardware (RAM, ROM, digit capacity, etc.) involved in the simulation impose limitations on the possible period of simulation from one shift to a week or a decade of operation at a real shop, plant, etc. Another reason for restricting a simulation period is the impossibility of efficient planning of production for a long period. This is why to determine the parameters of the long-term functioning we have to synthesize the results of the short-term simulation of the CTC functioning. Hence, the following algorithm is proposed for assessing the CTC production capacity as the basis for a rational choice.

The CTC study involves several hardware configurations. Values of standardized parameters of the *k*-th version of the CTC which do not change for long periods of functioning make up the contents of the file $-O^k$ (*k* is the index of the version in question). For each *k*-th version of the CTC the users create the set $w^k \in w_j^k$, where w_j^k is the *j*-th variant of the short-term functioning of the *k*-th version of the CTC.

Among the standardized CTC parameters we can identify the ones which can assume different values during the short-term functioning of the CTC. These parameters can, for example, include CTC control algorithm parameters (hardware type, the concept of choosing equipment for the next operation etc.). Specific values of the variable CTC control parameters which are used during the functioning of the variant w_j^k make up the information of a file of the type u_j^k.

To exclude from the simulation period the time interval corresponding to the primary loading of the hardware, one has to set up in the model the initial state of the main CTC components based on the information of the special starting data file z_j^k , this is needed to describe the inventory at the starting moment of the simulation period. Files z_j^k are formed either by the designer or coincide with P_i^k (containing the description of the final state of the CTC inventory) which is generated by the so-called process flow organizational model (POM) software in the process of simulation of the *i*-th mode of functioning. Note, that when z_j^k and p_i^k coincide, the mode w_j^k is defined as cyclic. The coincidence of the data structure in the files describing the initial and final inventory renders feasible the stop/start mode of simulation of long-term operation modes. To obtain different w_j^k efficiently the designers need a tool for generation of specific parameters of input and output material flows. In a general case the CTC output material flows are presented as timelines for the end production units (elements in a set $E = \{e_i\}$), generated by the output timeline database maintaining package. The package contains tools for drafting versions, their analysis and updates, as well as deleting information for the invalid schedules. The timelines e_i are compiled either by the user or via the long-term production simulation, or simulated requirements set forth by the production steps following the CTC in question. The CTC input material flows can be presented by timelines for the starting production unite (elements in the set $B = \{b_i\}$), generated by the input timeline database maintaining package. The package contains tools for drafting versions, their analysis and updates, as well as deleting information for the invalid schedules. The timelines b_i are compiled either by the user or via the long-term production simulation, or simulated requirements set forth by the production steps following the CTC in question. In a general case when w_j^k is simulated in accordance with the PO model of the CTC, the simulation package (SP) except for file p_j^k, registers the schedules for nominal and auxiliary hardware functioning or schedules for processing material flow units (file r_j^k), as well as aggregate operation parameters (file c_j^k).

By splitting the analysis of the simulation results into two levels we can reduce the need in the basic simulation hardware used (ROM, simulation time, etc.) creating thereby the grounds for applying the CTC's PO model to the solution of various design problems. This is achieved by modifying the information structure in section h_j^k to add additional schedule analysis software but leaving untouched the PO model software.

Analysis of initial data and simulation results for w_j^k is used for taking a decision on whether it is epresentative (typical) and efficient. In case the decision is positive the description of w_j^k is complemented with the sections p_j^k, c_j^k, h_j^k, thus yielding

$$x_j^{kt} = \left(O^k, z_j^k, b_j, e_j, u_j^k, t_j, p_j^k, c_j^k, h_j^k\right) \in X^k$$

of a rational mode of functioning of the *k*-th version of the CTC at t_j (element x_j^{kt} in the set X^k). Otherwise, the designers start on the generation of the new mode.

To determine the production capacity of the CTC $\left(M_T^k\right)$ in the period T (where T – a month, a quarter, or a year) it is necessary to integrate parameters of the CTC long-term functioning modes $\widetilde{w}_i^{kT} \in W_T^k$. The integration of $\widetilde{w}_i^{kT}$ is achieved by obtaining a sequence $Y = \{d_l \otimes x_l^{kt}, l = 1, L\}$, where d_l denotes the number of times $x_l^{kt} \in X^k$ is included in the integration. The sequence Y is acceptable if the following integration requirements are met:

-A1- *Decomposition of the time period T into component periods.* $T = \sum d_l * t_l$.

-A2- *Constraints for the running time of basic units* $d_l * t_{\alpha l} \leq F_\alpha^{kT}$ *, where* F_α^{kT} *is the time limit for the use of the* α *-th unit of the k-th version of the CTC in the period T.*

-A3- *Interim states of the inventory are equivalent* $z_{l-1} \equiv p_l \forall l - 2 + L.$

Parameters of the mode $\widetilde{w}_i^{kT}$ can be obtained using the stop-start simulation mode, as well as via the logic convolution of the values of the respective functioning parameters of short-term modes, included into the synthesis (for example, $V_i^{nkT} = \sum d_l * V_l^{kn}$ for the volume of production parameters for the *n*-th product type). The programs for logic convolution of simulation results form the basis for the software package designed to generate and analyze the long-term functioning modes. When the synthesis of $\widetilde{w}_i^{kT}$ yields itself easily to formalization this package includes programs of computer-aided synthesis to optimize the sequence Y in accordance with the specified criterion (for example, maximizing the output of a certain item in the range).

The structure and main features of the PO models of the CTC in metallurgy depend on their intended use within the integrated system (IS) of the CTC CAD with the structure as in (Vlasov *et al.*, 1983; Vlasov and Belov, 1995). A number of universal languages and simulation systems have been analyzed and, as a result, the General Purpose Simulation System (GPSS) and tools for its implementation (the GPSS PC family) are shown to be optimal for use in the development of the PO models of the CTC in question. Main features of obtaining PO models of various types with the use of the GPSS family in general are identified to set up the procedure of obtaining PO models with the use of the GPSS family for the above applications.

In a general case the description structure of the PO model corresponds to the structure of the CTC in question and consists of the following interrelated sections: *the simulation time monitor routine (STM); description of the material flows studied (MF); description of the investigated states of the main and auxiliary hardware (HW); description of the control algorithms and information flows involved (C).*

The specific features of the CTC in question make their models essentially different from those of the classical queuing systems (QS). It seems feasible, however, that the formalized description of the PO models can still retain the main concepts and constructions of the QS provided that their interpretation is made slightly broader. The tight research schedules, the general purpose nature of the PO models, constant updating of the models as the study becomes more profound, make particularly useful the application of the language and software tools of general purpose simulation systems (GPSS) to the development of the PO models. The segment-wise arrangement of the GPSS software package makes it efficient to use the structural description of the CTC functioning in the development of the PO model, contributes to the transparency of the model functioning, creates conditions for the flexible modification of the PO model (e.g. control algorithms or hardware state graphs). Advanced means for statistics collection and software testing available in most software versions of the GPSS language help essentially reducing the time needed for the development of the PO model software.

In the MF segment the parameters of input/output products and the technological process contents are analyzed to determine the types and parameters of the simulated material flow units. The HW segment describes the types, parameters and simulated states of the main and auxiliary hardware of the CTC, as well as the rules for transition of the hardware from one state to another in different production situations presented as graphs. One of the issues in the formation of the C segment is the identification in the technological circuit of the CTC of the so-called "leading segment" whose functioning influences significantly the efficiency of the complex as a whole. This, for example, can be the liquid steel production in converters or other units, without which no further production is possible. The "leading segment" production is characterized by expensive resource consumption (power, heat, material resources for starting and operation, etc.) and a much more complicated process control compared to other processes.

For the CTC with the "leading segment" process upstream the technological line the main aim of the C algorithms is to plan and control processing routes to final products for the input material flow units, generally, this includes several CTC processes. The PO models of such CTC allow a minimal margin for modifying input flow parameters which are governed by the schedule of the planned functioning of the hardware of the "leading segment", whereas they are quite flexible with respect to the output of the finished products. Such models are referred by the present authors to *direct OP models,* because control algorithms C treat as their main information element the current values of the MF units and scheduled involvement of all subsequent units. It is characteristic of all studies done with direct PO models to determine rational parameters of the finished product output modes for a given input flow.

For the CTC with the "leading segment" process downstream the technological line the main aim of the C algorithms is to involve the logistics segments to maximally support the specified mode of the finished product output which mainly depends on the schedule of the "leading segment" hardware. The PO models of such CTC allow a relatively flexible mode for the input material flow leaving a minimal margin for modifying output flow parameters. Such models are referred by the present authors to *reverse OP models,* because control algorithms C treat as their main information element the parameters of the output material flow and the current state of the MF elements required to support the processes in the "leading segment" and scheduled involvement of all subsequent units. It is characteristic of all studies done with reverse PO models to determine the parameters of the input material flow required to meet the product output targets fully.

For the CTC with the "leading segment" processes both upstream and downstream the technological line it is not an easy task to build such CTC algorithms which would take care of the parameters of both, initial and final processes, due to the lack of flexibility in modifying modes of input and output material flows. To study such CTC's the authors propose *coordination PO models*. In these models the control algorithm C aims at coordinating only related processes (ignoring information on the scheduled use of other units).

A characteristic feature of all studies done with coordination PO models is to determine whether the scheduled modes of semi-finished product delivery agree with the finished product output mode, and to search for rational coordination parameters in various production situations.

The IS CAD for the CTC, as proposed in [1,2], and the interaction of dynamic elements of the PO model segments call for the following procedures to be implemented in the simulation experiment software: *data exchange between the front end files and model variables in the ROM; parameter information exchange between the transactions; time referencing of critical events for continuous components.* These procedures are more efficiently implemented using the general purpose programming languages. In view of the above the authors have improved and adjusted to different applications the combined programming tools consisting of the GPSS and general purpose programming languages of the C^{++} type.

CONCLUSIONS

In case application of described concepts the experiences of creating simulation system for continuous-discrete CTC can be utilized with the utmost efficiency and since they in essence are also systems for support of decision making during the simulation experiments.

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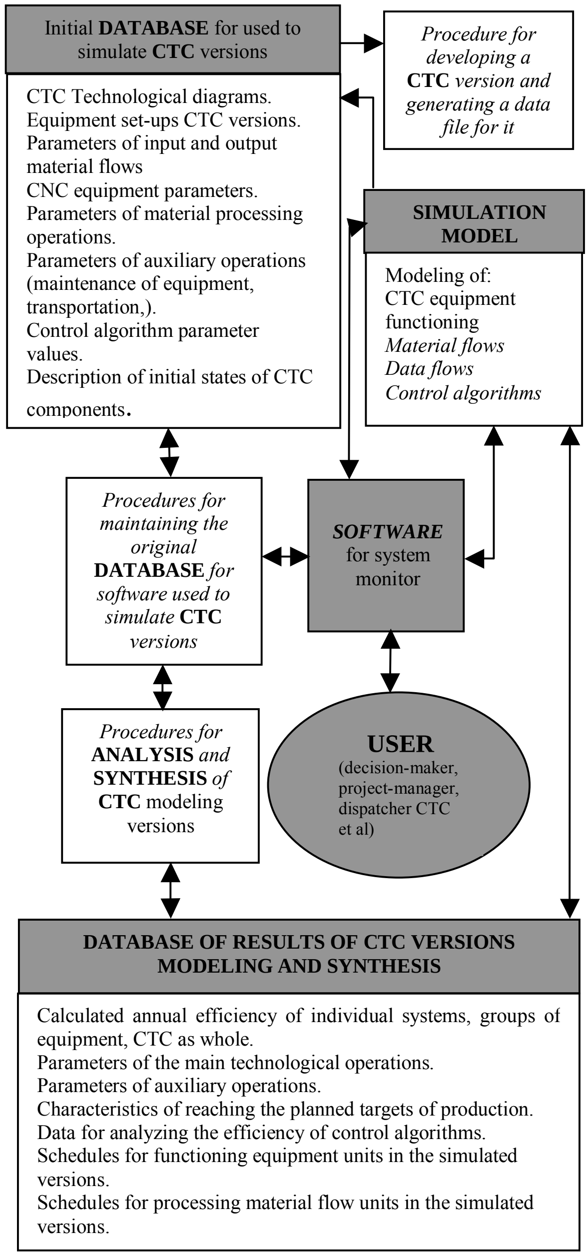

Fig. 1.