Rules for Construction of Simulation Models for Production Processes Optimization

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Abstract. In this work, the rules for construction of multiagent simulation models for production processes optimization are proposed. The proposed rules are related to implementation of the push strategy when describing processing the objects in the model. The push strategy involves managing the operations priorities in order to support processing of objects in accordance with the "first came first out" rule and in order to perform firstly all works related to the critical path. The method of the production processes optimization has been developed on the basis of the proposed rules and implemented in the metallurgical enterprise information system. The method has been applied to solve the problem of logistic processes optimization of the metal rolling shop of the metallurgical enterprise. On the basis of simulation results, concrete practical recommendations have been made.

Keywords: simulation, multiagent modeling, sheet rolling shop, automated information systems

1 Introduction

For formalization and subsequent simulation of technological, logistic, and organizational (business) processes, a simulation multiagent model of the resource conversion processes [1] is applied to the metallurgical enterprise information system (MEI system) [3–6]. The following elements are the main ones of the multiagent resource conversion processes (MRCP) model [1]: operations, agents [7, 8, 10–12], sources and receivers of resources, resources, mechanisms, and orders. Resources are consumed (decreased) when the operation is performed and mechanisms are used (blocked). At the operation end, the blocked mechanisms are released.

We consider the rules for construction of simulation MRCP models for production processes optimization.

2 Rules for construction of simulation MRCP models

When constructing a simulation model of the enterprise processes (in the module for creating models of the MEI system), the following submodels have to be built:

1. objects' generation model (objects are units of production (UP) / projects / orders); each object in the MRCP model is represented as an instance of an order with a set of attributes;
2. model of processes (technological, logistic, and organizational) related to the processing of the UP on aggregates and equipment and UP transportation; in the MRCP model, the route for processing order is formed by a chain of blocks consisting of converters (operations and agents);
3. model of supply of consumed resources (raw materials, materials, and semi-finished products); in the MRCP model, the resource supply route is formed by a chain of blocks consisting of operations and agents;
4. model of the mechanisms work (machine tools, equipment, aggregates, vehicle, personnel).

Production processes simulation and optimization dictate the following particular requirements and the corresponding rules for construction a simulation model.

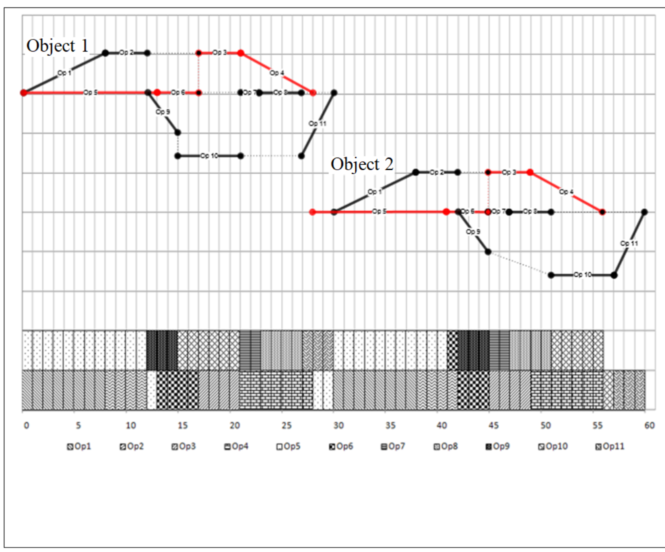
1. Limitation of the consumed resources amount in the production process (for example, energy resources). In the case of exceeding the limit for the total costs, this object (UP or order) becomes unprofitable.
2. Limitation of the used mechanisms amount (the limited number of qualified personnel, production capacities of machine tools, aggregates, equipment, vehicle units, and loading and unloading equipment).
3. The need to apply the "first came first out" (FIFO) strategy when object is processed since delays in the processing (or production, or execution) of a separate object (UP / order) lead to a number of additional costs (temporary, energy, material) and can lead to defect and premature deterioration of equipment and aggregates and even their breakdowns. In this regard, the push strategy for the "unit of product" object should be applied to the model blocks: the priority of the model blocks should increase from the initial stages of the processing (execution) to the final stages.
4. The use of parallel (in time) execution stages of different works on the UP production. The works (operations / corresponding blocks of the simulation model) related to the critical path should have priority higher than those of the parallel works.

Application of these rules for construction of simulation models and the method for analyzing and eliminating the bottlenecks of the MRCP processes [2] allows solving problems of the resources balancing and production processes optimization.

3 Comparison of the rules for construction of simulation models and the method of analyzing and eliminating the bottlenecks of the MRCP processes with the critical path method

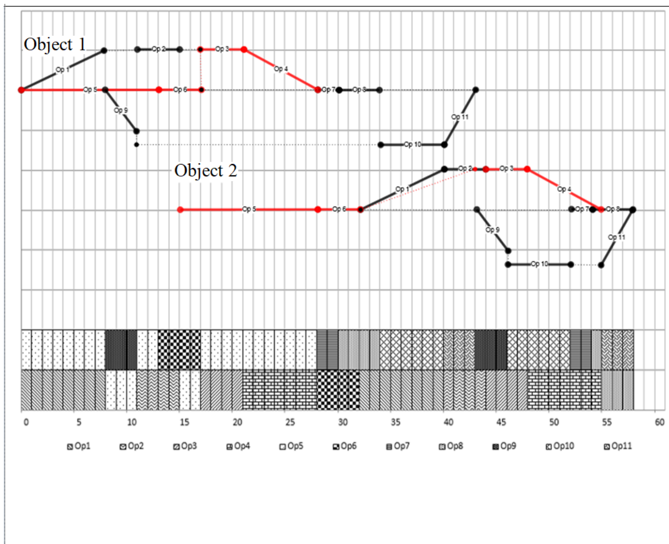
To analyze bottlenecks in project management (including production), the network model is most often used. The model together with the critical path method [9] makes it possible to determine the time reserves for individual works. Application of the simulation model with the push strategy of the operations priorities leads to the effect of the fastest "pushing" of the works.

To confirm effectiveness of the push strategy used in the simulation models, we consider possible cases of parallel execution (in time) of two objects: two orders for the production of a set consisting of the three UP. The first UP in the order is made during processing on operations *Op1*-*Op2*-*Op3*-*Op4*. The second UP in the order is made during processing on operations *Op5*-*Op6*-*Op7*-*Op8*. The third UP in the order is made during processing on operations *Op9*-*Op10*-*Op11*. We consider the case when two operations can be performed in parallel in time. The highest priority is assigned to works related to the critical path. The following situations are possible related to the start time of orders: 1) "Object 2" begins at the end of the critical path of the "Object 1" (CPM method is applied, Fig. 1), 2) "Object 2" begins immediately after the end of the *Op2* work of "Object 1" (the push strategy is applied, Fig. 2).



Object 1	Start	End
Op1	**0**	8
Op2	8	12
Op3	17	21
Op4	21	28
Op5	0	13
Op6	13	17
Op7	21	23
Op8	23	27
Op9	12	15
Op10	15	21
Op11	27	**30**
Object 2		
Op1	30	38
Op2	38	42
Op3	45	49
Op4	49	56
Op5	**28**	41
Op6	41	45
Op7	45	47
Op8	47	51
Op9	42	45
Op10	51	57
Op11	57	**60**

Fig. 1. "Object 2" begins at the end of the critical path of the "Object 1" (orders portfolio duration is 60 units of time).



Object 1	Start	End
Op1	**0**	8
Op2	11	15
Op3	17	21
Op4	21	28
Op5	0	13
Op6	13	17
Op7	28	30
Op8	30	34
Op9	8	11
Op10	34	40
Op11	40	**43**
Object 2		
Op1	32	40
Op2	40	44
Op3	44	48
Op4	48	55
Op5	**15**	28
Op6	28	32
Op7	52	54
Op8	54	58
Op9	43	46
Op10	46	52
Op11	55	**58**

Fig. 2. "Object 2" begins immediately after the end of the *Op2* work of "Object 1" (orders portfolio duration is 58 units of time).

One of the assessments of the problem being solved is the evaluation of the total duration of the orders "Object 1" and "Object 2", *i.e.*, orders portfolio duration. The variant of the order portfolio in Fig. 1 (with a total duration of 60 time units) differs by 2 units of time from the variant shown in Fig. 2 (total duration 58 time units). If there are penalties in the model of the order portfolio for increasing the time of work for an individual order, then situations are possible when the variant in Fig. 1 will be more economical than the variant in Fig. 2. The duration of individual objects for the variant in Fig. 1 was 30 and 32 units of time, and for the variant in Fig. 2, it was 43 and 43 units of time.

From the point of view of resource consumption equalization, the recommended rules for developing the simulation model allow one to obtain good indicators of the resource utilization factor. The resources equable use can be influenced both by the structure of the network graph and by the approaches of the resources balancing (including selection and fixing a certain operation by the resource for its performing). The form of the "tail" of the function of resource consuming (and the utilization factor) is affected by the proportionality of the number of parallel operations to the number of resources. When allocating resources between the tails of the network graphs of different objects, the effect of increasing the duration time of individual objects can be observed and, thus, the penalty time of an individual object can be increased.

It should be noted that there are specific objects in the metallurgical enterprise subject area with a very short useful life, for example, unit of product that has left after processing on the aggregate and is waiting for the next treatment wherein the temperature and the corresponding physical parameters of the UP must be within the specified range according to the technology.

Results of the methods comparison are presented in Table 1. The word “YES” in the table means support by the method of the corresponding functional that is specified in the column “Comparison criterion”.

Table 1. Comparison of the new method and the critical path method

Comparison criterion	CPM	MRCP
Accounting for the use of mechanisms	YES	YES
Accounting for resource consumption	NO	YES
Accounting for resource supplies	NO	YES
Accounting lifetime of consumed resource	NO	YES

The module for creating models of the MEI system supports the rules for construction of simulation models aimed at applying the push strategy when conducting production processes and implementing the method of analyzing and eliminating bottlenecks in the MRCP processes.

4 The method of analyzing and eliminating bottlenecks in the MRCP processes

A block diagram of the method of analyzing and eliminating bottlenecks in the MRCP processes is shown in Fig. 3. We use in the figure the following abbreviations: MCM is the module for creating models of the MEI system; MIM is the module for the integration of models of the MEI system; MQB is the module of the query builder of the MEI system; EPO is the module of the enterprise processes optimization of the MEI system; PBPC is a standard permanent business process of a metallurgical enterprise to change production processes.

We consider the main stages of the method (the numbering of stages in accordance with the numbering of the blocks of Fig. 3).

1. If the MRCP model of the production processes has been previously built in the MCM module, then proceed to the next stage.
2. In order to update the model input data with real data of production processes in the EPO module, it is first necessary to update the values of the model variables by interacting with the MIM and MQB modules.
3. This is the initial MRCP model.
4. Formation of the experiments plan is the choice of such input (controllable) parameters of the model, the values of which have the greatest influence on the values of the output (estimated) parameters of the model.
5. Simulation experiments are conducted in the EPO module according to the plan of experiments until an optimal or effective solution is found.
6. This is the initial experiment plan.

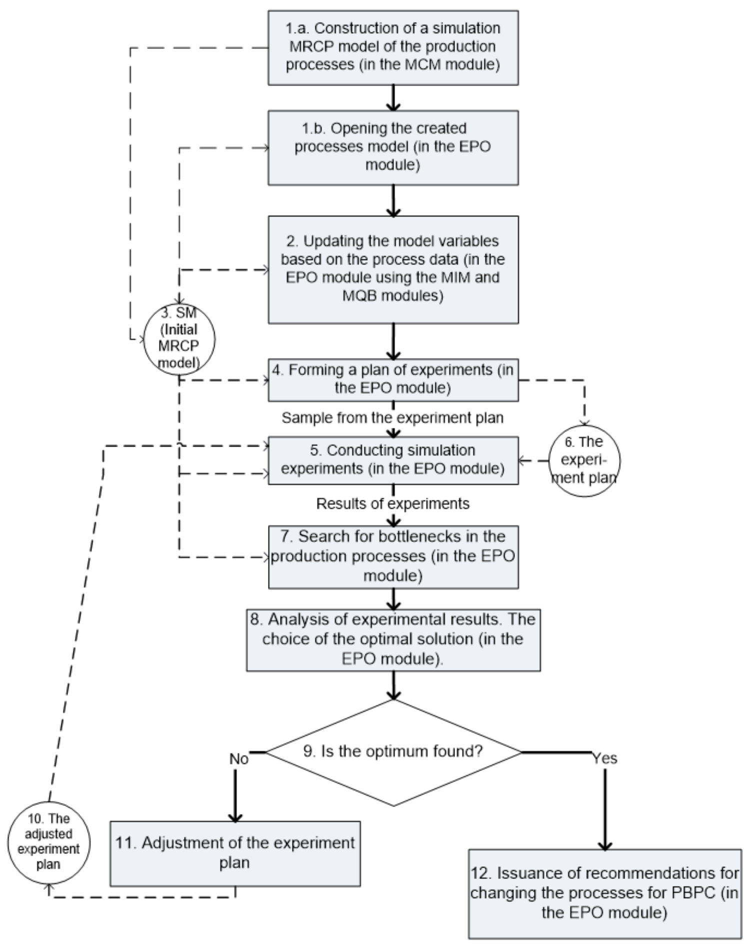


Fig. 3. Block diagram of the method of analyzing and eliminating bottlenecks in the MRCP processes

7. In the diagnosis of bottlenecks, the following parameters of the MRCP processes are analyzed: coefficient of use of the operation, mechanism, agent; the average waiting time of the order in the queue for the processing by the operation or agent; operations' downtime due to lack of mechanisms and / or input resources. To assess the dynamics of the operations' and agents' work, the average queue of orders for the operation and agent is analysed.
8. As a result of the experiment, statistics of the execution of operations and agents, the expenditure and formation of the resources and orders, and the use of mechanisms in the operations of the MRCP processes are formed. Based on the statistics analysis, bottlenecks are diagnosed and a decision is made to change (convolve / unfold) the MRCP processes. The change in the MRCP processes is carried out by the following actions: removal /

addition of a parallel operation; removal / addition (decreasing / increasing) the amount of mechanisms used by the operation; increasing / decreasing in the number of resources; removal / addition an agent rule, deleting an agent. At this stage, the choice of the optimal solution is made.

9. If at the previous stage the optimal solution has been found, then go to the 12th stage, otherwise to the 11th (see Fig. 3)
10. This is the adjusted experiment plan.
11. If the optimal solution has not been found at the stage 9, the experiment plan is adjusted and then transition to the stage 5.
12. If the optimal solution has been found at the stage 9, then recommendations on the processes change are issued. This stage initiates the launch of the PBPC process to improve the production processes in order to eliminate bottlenecks.

The method and rules for construction of simulation models have been tested on the case study of balancing the resources of the construction company China Wan Bao [2] and the problem of logistic processes optimization of the metal rolling shop of the metallurgical enterprise in the MEI system.

5 The problem of logistic processes optimization of the metal rolling shop of the metallurgical enterprise

In this study, the problem was to develop a simulation MRCP model for the joint operation of the two rolling shops: hot rolling shop (HRS) and cold rolling shop (CRS). It is necessary to determine the key parameters for the optimal operation of the two shops over the course of three days: 1) the minimum number of slabs in the input warehouse “Slab storage” at the beginning of the simulation, ensuring continuous supply of slabs every three minutes in the heating furnaces of the HRS during the entire simulation time; 2) number of objects in the output warehouse “Rolls storage” at the end of the simulation; 3) loading of all aggregates in percent at the end of the simulation.

In the MCM module of the MEI system, an MRCP model of metallurgical production processes has been developed with application of the proposed rules for construction of models. The structure of the model is shown in Fig 4.

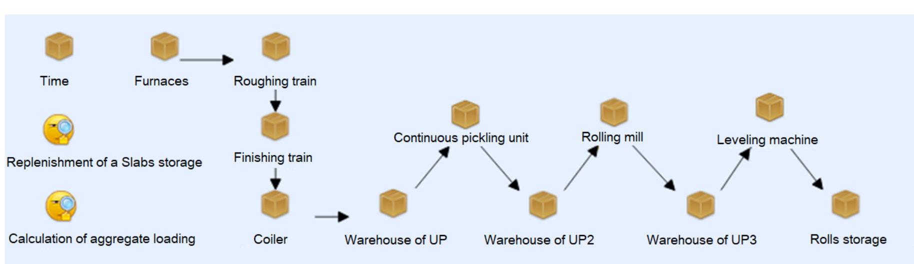


Fig. 4. The structure of the model of two rolling shops work

In the construction of the model, the push strategy has been applied: the priority in processing the model operations increases from the initial stage of processing in the furnaces to the final stage of processing at the leveling machine. In this model, the order "Single object for processing" (*z1*) is used. The order contains the following attributes: *z1-bake* indicates which of the four furnaces will process the slabs batch; *z1-camp* indicates which aggregate will process the object in the CRS; *z1-howSlab* indicates how many slabs went to this aggregate; *z1-timeOutput* indicates at what time the batch of slabs will leave the HRS.

With the developed simulation model, a number of experiments have been carried out according to the plan of experiments in the EPO module of the MEI system. As an input parameter of the model, the parameter K "Number of objects in the warehouse "Slabs storage" has been taken. As a result of the experiments with the model, the following output parameters have been obtained: *Twait* is the total waiting time of the Slabs storage replenishment for loading slabs into the heating furnaces of the HRS in minutes; N is the number of objects in the warehouse "Rolls storage" at the end of simulation; L is the aggregates' current loading at the end of simulation in percentage. The experiments results are presented in Table 2.

Table 2. The experiments results

Output paramter	K=300	K=360	K=400	K=440	K=480	K=500	K=520	K=540
Twait, minutes	237	136	68	47	11	13	0	0
N, number of UP	556	549	558	565	569	560	567	566
L of Roughing train	62.93	64.61	65.68	65.95	66.53	66.50	66.67	66.67
L of Finishing train	62.94	64.66	65.69	65.96	66.54	66.51	66.68	66.68
L of Contin. pickling	96.31	94.94	96.63	97.31	98.64	97.17	98.59	98.18
L of Rolling mill	92.13	92.30	92.12	93.37	94.81	93.18	94.11	93.88
L of Leveling mach.	68.72	67.77	68.82	69.25	70.30	69.15	70.21	70.15

As follows from the analysis of Table 2, the continuous supply of slabs to sheet rolling shops (*Twait*=0 min) is provided in experiments with K more then 500 UP. Also in these experiments, the maximum loading of the aggregates of the shop is provided. Among the selected experiments (K more then 500), the minimum value of the input parameter K is provided in the experiment with K=520.

Thus, it can be concluded that availability of the 520 units in the warehouse "Slabs storage" at the beginning of the simulation provides the best values of the output parameters of the simulation model for the work of hot and cold rolling shops: in this experiment, continuous supply of slabs in the furnace is provided and a high load of aggregates of the HRS and CRS shops is also provided.

6 Conclusion and future work

In this paper, the following additional principles for construction of simulation models for the subject areas of technological, logistic, and organizational (business) processes are proposed.

1. When developing a simulation model of processes or a portfolio of orders for the production of UP, it is necessary to classify all operations in three types of priorities: the highest priority for critical path operations; the average priority for operations preceding the operations of the critical path; the lower priority for other operations.
2. If the subject area and technological operations allow one to use interrupts of operations, then in the construction of the model, the operations can use relative and absolute priority, otherwise, the prohibition of interrupts is set.
3. Application of the push strategy (FIFO) to modeling the order fulfillment processes for the production of UP is recommended.

The obtained theoretical results (the method of analyzing and eliminating the bottlenecks in the MRCP processes) and the developed principles for building models enabled to implement the software of the EPO module of the MEI system, which uses the methods of expert, simulation, multiagent modeling, and network planning.

The rules for construction of simulation models have been applied to solve the problem of logistic processes optimization of the metal rolling shop of the metallurgical enterprise. As a result of a series of experiments with the model of the processes studied, the following result has been obtained: the required number of slabs in the warehouse "Slabs storage" at the beginning of the simulation is 520 units.

Future work is related with the further construction of simulation models for metallurgical production with the help of the MCM and EPO modules of the MEI system.

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