Development of Simulation Model of Continuous Casting Machine with Dry Change of Steel Ladles

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Abstract. Results of development of a multiagent simulation model of continuous casting machine with dry change of steel ladles are presented. An algorithm for cutting slabs as well as implementation of this algorithm to the multiagent model of the resource conversion process has been described. The simulation model of the continuous casting machine work is implemented in a metallurgical enterprise information system. During experiments with the model, information is used on the duration of real production processes. This information is formed by the data preparation module of the information system. As a result of simulation-evolutionary modeling with the developed model, recommendations have been obtained for increasing number of units of products going to customers without rejection and reassignment.

Keywords: Simulation, evolutionary modeling, data preparation, continuous casting machine, dry change of steel ladles.

INTRODUCTION

Simulation for analysis and optimization of the processes in organizational and technical systems is widely used in practice [1-3]. A metallurgical enterprise information system (MEI-system) developed by "I-Teco" JSC jointly with the Ural Federal University includes a data collection and analysis subsystem and modeling subsystem containing modules for creating processes models, processes optimization, data preparation, and models integration [4-6]. The models integration module solves the problem of applying models in real-time control and decision making processes[6]. The data preparation module solves the problem of analyzing and converting information collected from sensors of the production processes and stored in the data warehouse of the MEI-system in order to further use this information during simulation.

We consider the work of a two-strand continuous casting machine (CCM) [7] with the following characteristics: ingot pulling speed out of the mold v is 0.8 meters per minutes, mold length is 1 meter, and turning zone length is 50 meter. We analyze the CCM work for bottling a series of melts. Each melt i is characterized by the following parameters: mass of steel in the steel ladle M^i, steel brand G^i with a given density ρ^i, requirement for dry change of steel ladles (not to mix the current melt with the previous one), cold dimensional length of the slab (CDL),and slab section area F^i. Input data contain parameters of the steel brand and CDL.

ALGORITHM FOR CUTTING SLABS ON THE BORDER OF MELTS

Algorithm for cutting slabs on the border of two melts without dry change of steel ladles is given in [6]. This algorithm is expanded by situations presented in Table 1. The term "belt" means the slab'sdefect at the boundary of the melts.Parameter $L$is the length of the extruded ingot from the last intended cut slab until the signal arrives about the beginning of the next melt. Parameter K is a calculated slab's number of the current melt that pulled out of the mold at the moment of receipt of thenext melt start signal. Parameters$L$and K are measured at the exit of the mold.

TABLE 1. Algorithm for cutting slabs with the demand of dry change of steel ladles on the border of melts.

Condition	Decision
L>700cm	In the (i-1) melt there are k slabs with the CDL^{i-1} length. Slab (k+1) with the $CDL^{k+1}=L$-200cm length is reassigned (from order i-1). Slab (k+2) with the CDL^{k+2}=500cm length has defects (reassignment from order i). Slab (k+3) with the new CDL^{i} length will be the first in the i-th melt.
$L\leq$700cm and no belt on slab (k+1) and 507cm<($CDL^{i-1}+L$-200cm)<1030cm	In the (i-1) melt there are (k-1) slabs with the CDL^{i-1} length. Slab k with the CDL^{i-1} length is reassigned (from order i-1). Slab (k+1) with the new CDL^{i} length will be the first in the i-th melt.
$L\leq$700cm and no belt on slab (k+1) and ($CDL^{i-1}+L$-200cm)$\geq$1030cm	In the (i-1) melt there are (k-1) slabs with the CDL^{i-1} length. Slabs k and (k+1) with the $CDL^{k}=(CDL^{i-1}+L$-200cm)/2 length are reassigned (from order i-1). Slab (k+2) with the new CDL^{i} length will be the first in the i-th melt.
$L\leq$700cm and no belt on slab (k+1) and ($CDL^{i-1}+L$-200cm)$\leq$507cm and belt on slabs k or (k-1)	In the (i-1) melt there are (k-1) slabs with the CDL^{i-1} length. Slab k with the $CDL^{k}=CDL^{i-1}+L$+150cm length (but not less than 507cm) has defects (reassignment from order i-1). Slab (k+1) with the new CDL^{i} length will be the first in the i-th melt.
$L\leq$700cm and belt on slab (k+1)	In the (i-1) melt there are k slabs with the CDL^{i-1} length. Slab (k+1) with the $CDL^{k+1}=L$+150cm length (but not less than 507cm) has defects (reassignment from order i-1). Slab (k+2) with the new CDL^{i} length will be the first in the i-th melt.

The main stages of the CCM work are given in [6].At the beginning of the work, a tundish is installed on the CCM, a fuse is introduced into the mold, and the steel ladle is ready for casting into the tundish. After passing the extruded ingot from the mold through the turning zone, the ingot is cut into slabs with a gas-cutting tool. Slab cutting is carried out according to the algorithm based on the given CDL, moment of arrival of the signal for the next melt start, and steel brands at the border.

DESCRIPTION OF THE SIMULATION MODEL

In the module for creating processes models of the MEI-system, a simulation model has been developed(Fig. 1).

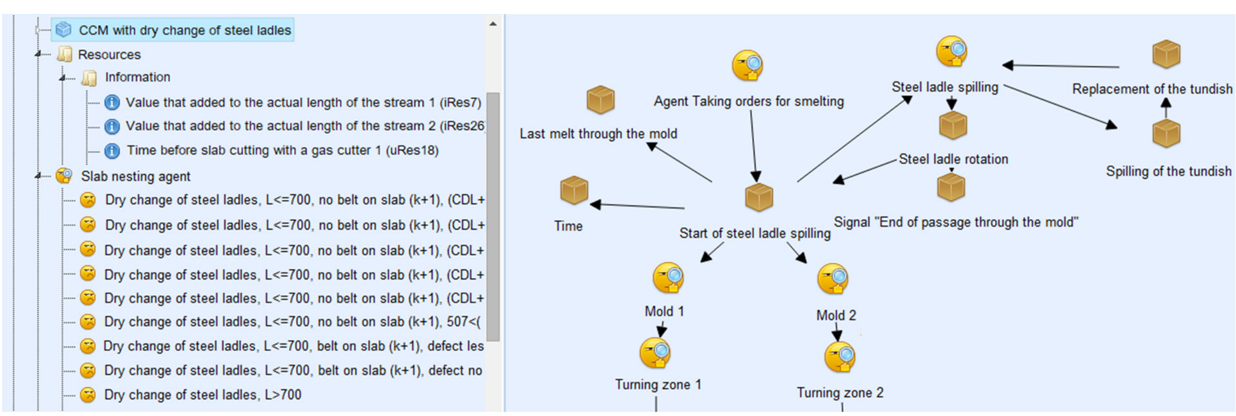

FIGURE 1. The structure of the simulation model of the continuous casting machine with dry change of steel ladles.

Agents of the model are used to perform logic of working with orders for slabs and cutting slabs at the border of melts; operations of the model are used to visualize duration of the work of the CCMelements. A slab nesting agent implements the algorithm for cutting slabs depending on the value of the parameter *L*, type of transition at the melt boundaries, and presence of dry change of steel ladles for the current melt.

Work of the CCM simulation model can be divided into the three blocks: 1) block describing the states of the steel ladle / tundish including description of steel casting from the steel ladle, filling the tundish with steel from the steel ladle, steel pouring from the tundish, turning a rotary stand with the steel ladle, and simultaneously continuing of steel pouring from the tundish; 2) block describing the work of the CCM elements – mold, turning zone, and gas cutting – on each of the two CCM strand; 3) block describing generation and removal of orders.

ANALYSIS OF THE EXPERIMENTS RESULTS

Developed simulation model of the CCM work has been used to solve the problem of determining the effective sequence of the supplied melts in order to increase the number *N* of slabs sent to the order without rejection and reassignments in a series of 25 melts.

To solve the problem, a method of planning experiments for simulation-evolutionary modeling given in [8] has been used. To carry out an evolutionary search, various transpositions of the sequence of 25 melts coded into bit chromosomes have been used as alternative decisions. The criterion for maximizing the number of slabs *N* calculated using the simulation model has been chosen as the criterion for the effectiveness of chromosome (or decision). When conducting experiments with the model, data, which have been feed at the model's input, have been generated by the data preparation module of the MEI-system. Data contained the calculated average values of the execution time of the CCM operations based on the analysis of statistics of the real processes flow (Fig. 2).

As a result of the evolutionary-simulation experiment, 10 generations of chromosomes have been formed in the processes optimization module of the MEI-system; each of generation contains 6 chromosomes (decisions). Further, the decisions of the last generation have been considered (decision P1 - decision P6), the effectiveness of which is shown in Fig. 3. Decision P1 is characterized by the melts grouping before serving on the CCM depending on the steel brand and the dry change of steel ladles requirement in the following sequence of groups: A-B-A_D-B_D. When specifying a steel brand, the letter “A” means high quality steel, the letter “B” means low quality steel, and the index “D” indicates the presence of the requirement on dry change of steel ladles.Decision P2 is characterized by sequence of groups: A-A_D-B-B_D, decision P3is characterized bysequence: B-B_D-A_D-A, decision P4is characterized bysequence: B-B_D-A-A_D, decision P5is characterized bysequence:A_D-A-B_D-B, decision P6is characterized bysequence: A_D-A-B-B_D. The effectiveness of the basic decision P0 corresponding to the order of the melts supply according to the initial data and the effectiveness of the decisions P7 and P8 with the order of the melts grouping according to the increase and decrease of CDL respectively (regardless of the steel brand)are also presented in Fig.3.

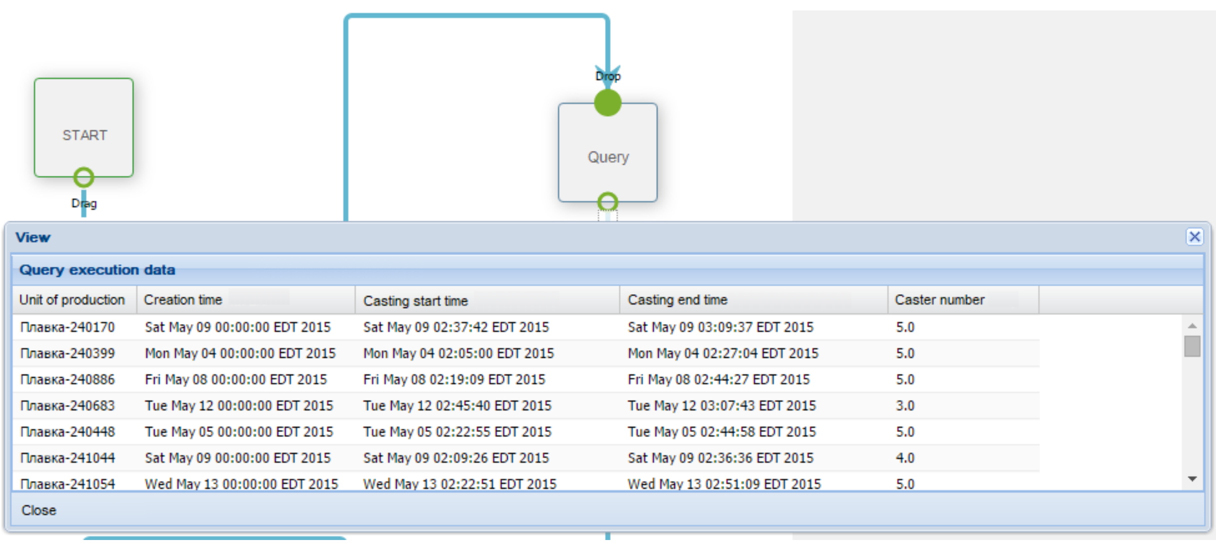

FIGURE 2. The results of finding the casting time on the CCM using the module of data preparation of the MEI-system.

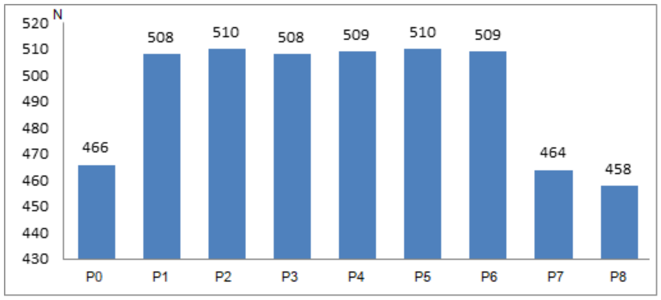

FIGURE 3. Comparison of the decisions P1-P8 effectiveness.

As it follows from the figure, the decisions with the best result - P2 and P5 - are characterized by feeding on the CCM first the melts with high quality steel, while the sequence of melts does not depend on whether they have requirements for dry change of steel ladles or different sequences of the cold dimensional length of the slab.

CONCLUSION AND FUTURE WORK

Application of simulation and evolutionary modeling for the analysis of the operation of the continuous casting machine with dry change of steel ladles is considered. In the MEI-system, the simulation model of the continuous casting machine work has been developed and experiments have been carried out using the data preparation module for model execution. Practical recommendations have been developed to ensure the maximum number of slabs sent to the order without rejection and reassignments in a series of 25 melts when solving the problem of determining the effective sequence of supplying melts to the continuous casting machine depending on the steel quality, length of the finished slabs, and requirements of dry change of steel ladles. The aim of further research is application the developed model to solve problems of analysis and optimization of technological and logistic processes.

ACKNOWLEDGMENTS

The reported study was funded by RFBR according to the research project № 18-37-00183.

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