Improving simulation adequacy of production processes by jointly applying the planned and situational reservation logic of jobs in the machine parts manufacturing batch

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Abstract. The logic of setting priorities for a workstation reservation is proposed. The workstation reservations need for machining operations of manufacturing a production parts batch. Examples of planned reservation of workstation at the manufacture of batch parts with different technological cycles are considered. It is shown that the comprehensive application in simulation modelling of situational logic and the logic of planned reservation of workplaces can significantly increase the appropriateness of the simulation production processes.

1. Formulation of the problem

The method of simulation modeling is founded a good application for simulation of continuous production processes in large-series and mass machine-building enterprises.

Currently, this method is being developed and is beginning applied in the modeling of non-flow production processes at multi-item serial machine-building enterprises. However, the appropriateness of the results of simulation modeling of multi-item enterprises is insufficiently good. One of the main reasons is the use in simulation of material flow for of non-flow productions, traditional methods and routing logic for modeling flow productions [1-2].

In simulation modeling, the routing of the material flow is carried out in accordance with the specified routing logic, according to current production process state [2]. The routing logic of the material flow sets the rules for the flowing of the material flow through the workplaces - (WP). Sets the rules for material flow transformation on each WP. As well as the rules for determining the sequence of use of the next WP in queue of machine operations. A feature of the routing logic used in simulation is the development of rules at a specific decision point. In this case, the WP and the execution time of the next technological operation of processing a given nomenclature position is not known. Therefore, this logic can be considered situational logic.

Situational routing logic has standard rules and special rules. Standard rules are part of the libraries of many simulation systems. These include the following: LIFO (Last In First Out), FIFO (First In First Out), etc. Special rules take account for the features of production processes, which is implemented at the particular enterprise. That rules are developed for each individual project [1,3].

Let’s look at the work of situational logic in modeling the manufacture of batches product A.

The production program of product A is 100 pcs. Product A is manufactured in batches, each 25 pieces. Parts have the following route. Pieces come from the purveying plot. Then they are processed...
by cutting at section No. 1. After that, the pieces go to heat treatment producing at section No. 2 — the WP of the COM. After heat treatment, the workpieces arrive at section No. 3 for cutting too. Operations of processing pieces at plot No. 3 include alternative choices (Figure 1) [1,3].

Figure 1. The scheme of flows of material in manufacturing of product A: D1 - solid line, D2 - line with dots, D3 - dashed line.

The technological route for the manufacture part - D3 consists of two operations, which is performed at plots No. 1 and No. 3. Routes parts D1 and D2 consist of three technological operations (Figure 1). D1 and D2 also have heat treatment at the COM workstation (plot No. 2).

Situational routing logic can be set by a large number of rules. The choice of the most right combination of rules can be determined by type of production, characteristics and specification of production processes, and performers skills. For our example, the following logical rules were defined:
- FIFO, - batch with the smallest processing cycle has primary right.

These rules do not take into account the setting of primary rights in manufacture of batches of parts which is included in one batch of the product kit. Batch of the product kit include all batches with parts D1, D2, D3

For convenience, of the marking batches of parts on the gantt chart, the notation is introduced: X.YZ. X is the batch number, YZ is the Part Number (Di),

For example, the record “1, D2” means: the first batch of part No. 2. In result of applying the specified situational routing logic during simulation modeling, the follow gantt chart with workstations reservation is formed, Figure 2. Reservation of workstations is carried out for the manufacture of batches of parts. Routing logic includes a processing cycles and travel time between workstations. The duration of the reservation is indicated in conventional units of time (c.u.) [4-6].

Situational routing logic led to a tight load workstation. In this case, parts from the next batch of kits were processed before parts from the previous batch. For example, “2, D3” were processed earlier than “1, D1” (Figure 2). Such cases lead to an increase in production time kit product, and volumes of work-in-progress. The production cycle for the manufacture of the first batch of product kit is Pc(1pk). Cycle is increased due to processing “2, D3” (Figure 2). The cycles for the production of the second and third batches of product kits Pc(2pk) and Pc(3pk) are likewise increasing. The situational routing logic doesn't allow to setting the rules for routing the material flow on a far modeling horizon. This con is a significant limitation in the modeling of non-flow production. For example, there is no possibility of setting primary rights for reserving workstations. Reserving is need for performing operations of the manufacturing parts or assembly units in technological process. The technological cycle such operations can be lie on a critical path and it determines the duration of manufacturing end products or assembly. Besides, situational routing logic doesn't allow to reserve workstations for manufacturing batches of parts lying on the critical route of manufacturing an assembly unit [3,6,7].
Situational logic well-works in modeling of flow production systems. However, the use of only situational routing logic of material flow when modeling non-flow production systems does not allow taking into account the primary rights arising in the planning of production. This leads to insufficiently appropriateness simulation results [8].

The cooperate use of situational routing logic and logic with mechanisms primary rights for routing of material flow, can significantly improve the modeling appropriateness of non-flow production systems in the longer term.

The insufficiently developed theory support for modeling the production processes of multi-item machine-building enterprises regarding the combination use of situational routing logic and the logic of setting primary rights for reserving workstations on a long modeling horizon does not allow us to appropriate simulate the processes of manufacturing batches of parts which is had different technological cycles. One of the tasks which arise in the development of simulation models of the processes of manufacturing assembly units is the development of a routing logic of material flows for determining workstations for the manufacture of batches of part included in one product kit. Technological operations of manufacturing parts included in one product kit often compete with each other for the same workstations. To solve this problem, a combine method of situational logic and the logic primary rights in the manufacture of batches of parts included in one product kit is proposed [6-8].

Let's consider an example of the combine of situational logic and the logic of primary rights in the manufacture of the product kit of which parts have different technological cycles. Consider the production cycles of manufacturing kits of product A by two strategies which apply combination logics [9-12].

**Strategy No. 1:** Hard reservation of workplaces. Reservation of workplaces for the manufacture of a batch of parts having the longest production cycle in the manufacturing interval of the all production program. The definition of jobs for the manufacture of the other batches of parts is based on situational routing logic.

**Strategy No. 2:** Flexible workplaces reservations. Reservation of workplaces for the manufacture of the first batch of parts having the longest production cycle. For the manufacture of the other parts batches of this product, workplaces are determined according to the situational routing logic.
2. Application of the first strategy

Let's consider a strategy for hard reservation of workplaces.

In the marking of parts, we add additional description: X.YZ.AB. Where AB is the applying logic: SL (situational logic) or PR (logic using primary rights).

In the start of the simulation model, workplaces are reserved for the manufacture of a batch of parts having the longest production cycle. Batch of D2 has the largest manufacturing cycle in the manufacture of a batch of product-kit A of 25 pcs.

Reservation of jobs for the manufacture of four batches of D2 is showed in Figure 3.

The technological cycle of manufacturing the first batch of parts D2 $T_c(1, D2) = 15.75$ c.u., and the production cycle for the manufacture of all four batches of $P_c(4, D2) = 30.75$ c.u.

The duration of the manufacture of the first batch of D2 is determined by the duration of the technological cycle, which is calculated as the sum of the durations of all operations, including processing and movement. At the same time, delays in processing the first batch of billets, due to expectation of vacating workstations, don't arise. Such delays appear when processing subsequent batches of D2. Therefore, the duration of their manufacture is determined by the corresponding production cycles, and not technological [3,8,13].

Figure 3. Gantt chart of hard reserving workstations in the manufacture of all batches of D2.

Let's fill the Gantt diagram with the operations of manufacturing all four batches of D1 and D3 (Figure 4). On the Gantt chart (Figure 4), a hatched rectangle shows the reservation of WP COM for processing the first batch of D1 according to situational routing logic. Checking this possibility shows that the processing of the first batch of D1 on PM COM doesn't have time to complete before the planned start of processing the second batch of D2. Therefore, the processing of "1, D1, SL" will begin after WP COM will free after processing of "2, D2, PR". Prior to the processing of "2, D2, PR", the WP COM will be in a state of forced downtime. Simultaneous processing of batches of parts D1 and D2 at the COM WP is impossible due to different heat treatment mode. By the described logic, a Gantt chart of processing 4 batches of all parts included in the product kits A was built (Figure 4). Reducing the manufacturing cycle of all batches of D2 led to the fact that the 4th batch of D1 was on the critical path. The estimated production cycle of all four product kit batches (4 Pc) was 35.5 c.u.

The combined use of the logic of reservation of workplaces with primary rights and situational routing logic for the strategy of hard reservation has led to an increase in the production cycles of manufacturing batches of machine sets of product A compared to the calculated values of the corresponding cycles of manufacturing batches of parts D2.
Thus, the strategy of hard reservation of jobs leads to the uncontrolled emergence of new critical ways of manufacturing batches of parts, that exceed the base critical path.

3. Application of the second strategy

The second strategy is based on the reservation of workplaces for the manufacture of the first batch of parts with the largest production cycle. For the manufacture remaining batches of parts included in the product kit, workplaces are determined according to the situational routing logic. Such situational logic doesn't include the priority of processing batches of pieces included in one product kit.

Situational routing logic takes into account the following rules for reserving workplaces when performing the latest processing operations for workpieces of parts included in one batch product kit:

- among operations for which primary rights is not applied, the lowest priority is given to the processing of the workpiece, the production of which ends at this workplace [2,3,8].
- if the initial critical path of manufacturing one batch parts is exceeded by a batch of another part, then the batch of second part becomes a priority and workplaces are reserved for its manufacture (second batch has a primary rights now).

In this case, the reserve of workplaces for processing other batches of parts is shifted to a later date if the start time of the reserve has not yet arrived at the time of the reservation of jobs for processing a priority batch of parts. If such for such reserve the operation has been processing, then the reservation of a priority batch of parts at this workplace will occur immediately after the end of operations.

Let's consider the logic of routing the material flow in the manufacture of parts of product A in the main steps.

Step 1. The following operations are performed (Figure 5):

(t₁) WP is reserved for the manufacture of the first batch of part D2, which has the largest production cycle, workplaces are also reserved for the manufacture of the first sets of other parts included in the first batch of the product kit A; (t₂) reservation and the start of manufacturing the second batch of part D3; (t₃) the critical manufacturing path of the first batch of D2 is not exceeded, therefore, we reserve the workplace for manufacturing the second set of parts D2 and determine the time of the critical manufacturing path of the second batch of parts.

Step 2. At this step, the following logical operations are performed (Figure 6):

(t₄) finished processing the first batch of D1. Since the batch D2 remained the priority, the reservation of the COM workstation for processing D1 is made after processing D2. The inclusion of the parts batch in one batch of the product kit is not a priority condition; (t₅) processing of the second batch of D3 has ended and RM 2ST1 is reserved for their processing; (t₆) processing of the second batch of D2 has
ended, no change in the critical path has occurred. Production of batches of D2 remains a priority; \((t_7)\) processing of the third batch of D3 has ended. For their subsequent processing, WP 2ST1 is reserved [14-16].

\[
P_{c}(2, D2) = 2.0, 75
\]

\[
T_{c}(1, D2) = 15.75
\]

Figure 5. Gantt chart of reserving jobs: step 1.

Step 3. The following operations are performed (Figure 7):

\[
P_{c}(3, D2) = 25.75 + 3 = 28.75
\]

\[
P_{c}(pk1) = 17.75
\]

\[
P_{c}(pk2) = 20.75
\]

Figure 7. Gantt chart of workplaces reservations in step 3.

\((t_8)\) processing of the first batch of D1 in the COM workplace has ended. Hatched rectangles indicate batches of parts whose reservation for processing should be performed according to situational routing logic. The production cycle for the production of the first batch D1 exceeds the technological cycle for the first batch D2. In this case WP 2ST1 is forcibly reserved for subsequent processing of the first batch D1 immediately after processing "2, D3, SL" (the second batch D3 is already being processed). WP COM and 2ST1 are reserved for processing the second batch of parts D1; \((t_9)\) processing of the 3rd batch of D2 has ended. The analysis shows that the processing cycle of the 2nd batch of D2 remained on the critical path, so the WP for processing the 4th batch of D2 is reserved according to the logic of the planned reservation.

Step 4. The following operations are performed (Figure 8):

\[
P_{c}(4, D2) = 30.75
\]
Figure 8. Gantt chart of workplaces reservations in step 3.

(t10) processing of the second batch of D1 on WP 1ST3 has ended. WP is reserved for processing the third batch of D1; (t11) processing of the fourth batch of D3 has ended. By the situational routing logic, WP 2ST1 is reserved for the subsequent processing of batch parts D3; (t12) processing of the third batch of D1 on WP 2ST1 has ended, this WP is reserved for processing the fourth batch of D1. According to situational routing logic, WP COM is reserved for processing the third batch of D1. (t13) processing of the third batch of D1 in the COM section has ended. Hatched rectangles is batches of parts which is subject to situational logic. The critical path is exceeded, D1 forcibly reserves a WP 2ST1 immediately behind "3, D3, SL". WP COM and 2ST1 are reserved for processing the third batch of D1. (t14) processing of the 3rd batch of D2 has finished, the production cycle of the third batch of D2 remained on the critical path, therefore the reservation of WP for the production of the 4th batch of D1 use situational routing logic. In result we got a deviation of Pc(pk) from TC (1, D2) by time. The deviation is caused by the lack of prioritization of the production of batches in the frame of one batch of product kit.

Additional logic is involved: in the event of a forced wait of a free WP due to its planned reservation for another operation, a check is carried out to determine the minimum cycle for the pair of these operations in different sequences. If the end production cycle of these operations will be less than set before, then the operation with the low priority will perform, while the operation with the planned reserve will be performed later. The Gantt chart will take the form shown in Figure 9. The hatched rectangle shows an alternative WP for processing "4, D3, SL".

Figure 9. The Gantt chart reservation of workplaces.
4. Conclusion
The results of modeling the execution program for using only situational routing logic, combined logic with hard reservation, flexible routing logic, and flexible routing with considering changing priority in the frames of one batch product kit are presented in table 1.

Table 1. The simulation results of the manufacture of product kit A

| Batches product-kit | Time critical path | Situational routing logic | Hard reservation workplaces | Flexible reservation workplaces | Flexible reservation workplaces with using primary rights in frames one production kit |
|---------------------|--------------------|----------------------------|-----------------------------|-------------------------------|-----------------------------------------------|
| Pc(1pk)             | 15,75              | 17,50                      | 16,25                       | 17,25                         | 15,75                                         |
| Pc(2pk)             | 20,75              | 31,00                      | 24,25                       | 20,75                         | 20,75                                         |
| Pc(3pk)             | 25,75              | 33,50                      | 32,25                       | 28,75                         | 29,00                                         |
| Pc(4pk)             | 30,75              | 35,50                      | 35,50                       | 35,50                         | 35,50                                         |

Using only situational routing logic has led to the formation of the largest production cycles for the manufacture of the first three batches of product kits. Situational routing logic does not influence on the priority of parts included in various batches of product kits. This leads to an increase in production cycles for the manufacture of batches of product kits. The strategy of hard reservation of the WP fixes the planned reservation of workplaces and does not allow managing their reservation when changing critical ways manufactured parts. The values of production cycles are reduced compared to using only situational logic. The flexible reservation strategy of WP allowed to obtain the best results. The flexible reservation strategy of the WP allows to take into account changes in critical paths in the manufacture of batches by coordinating the logic of planned and situational reservation of WP. To ensure high appropriateness of modeling production processes, the logic of flexible reservation of WP must be adapted to the conditions of a particular production [3,8,16-18].

Thus, combine the flexible application in simulation modeling of the logics of primary rights and situational route reservation of workplaces can significantly increase the appropriateness of the simulation production processes and get a more reliable result.

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