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*Original Contribution*

# ABOUT WORK IN PROGRESS IN THE CONTEXT OF INTRALOGISTICS

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***ABSTRACT:*** *The current paper attempts, briefly and in general terms, to present the need for work-in-progress for the normal flow of the production process. This ensures the rhythmicity and continuity of the flow of production. The basis for achieving these two characteristics is also the so-called reserve, which should be in sufficient quantity.*

***KEYWORDS:*** *Intralogistics, Industrial manufacturing plant, Work in progress, Technological reserve, Production process.*

The topic of the current paper is the industrial production plant with its work-in-progress. The subject of the study is semi-finished products and their management in the production process. The aim of the presented setups is the normal flow of the flow production with appropriate rhythmicity and continuity.

It is known that intralogistics refers systematically to the internal production movement of material flows and corresponding processes in the production units of the industrial production enterprise. The engineering aspect of logistics is considered, and in this relation also the technological component of the microenvironment of effective logistics management. It represents the various types of interaction between raw materials, work-in-progress and finished products with the machines and mechanisms, being the main logistics function in production [1, p. 16, pp. 54 – 58; 2, pp. 543 – 544; 14, p. 56, p. 57; 23, p. 140; 24, p. 4; 25, p. 114; 26, p. 99].

The normative basis defines work-in-progress as inventory, i.e. a current tangible asset representing a set of costs from which production is expected to be produced [18, p. 24; 19, pp. 61 – 88; 20, pp. 119 – 135].

The above set of costs is associated with semi-finished goods, which are items of labour in an intermediate state and in production, i.e. they have passed through part of the production process. It may include only the first operation or all but the last. The foregoing assumes that while the production process is taking place, the articles of labour are in an intermediate state. In this connection, the main transitional stages resulting from the realization of relatively complete parts of the production process through which semi-finished products pass are:

a) blanks – obtained after completion of the preparation phase of the technological process;

b) workpieces – obtained after the machining phase of the technological process;

c) subassemblies – are obtained after the subassembly from the assembly phase of the technological process [3, p. 69; 4., pp. 14 – 15; 5, p. 109; 6, p. 93, p. 95; 7, p. 105; 9, p. 194; 12, p. 108; 17, p. 205].

It should be noted that the material flow of semi-finished products in the industrial production plant is carried out in batches. Each of them is a complex of semi-finished products, over which each technological operation of the corresponding partial process is performed without interruption with a single readjustment of the technical means used. In relation with what has been said, the complete composition of work items in an intermediate state establishes the work-in-progress of the industrial production enterprise, which is necessary for the normal course of the production process, ensuring the rhythmicity and continuity of the flow production. The basis for achieving these two characteristics is also the so-called process reserve, which must be in the necessary and sufficient quantity. This is divided into intra- and inter-process, and the sum of these represents the reserve of the industrial production plant. On the other hand, the intra-factory technological set-aside, which includes all types of semi-finished products located in the respective production unit, is at the following composition [3, p. 69; 4, p. 15; 5, c. 109; 6, p. 93, p. 95; 7, p. 105; 9, p. 195; 10, pp. 429 – 430; 11, p. 304; 12, pp. 108 – 109; 13, c. 14, p. 21; 15, p. 198; 17, p. 205; 22, pp. 182 – 183]:

a) in-process reserve – contains semi-finished products located on the workplaces and on which the technological operations of the respective partial process are directly performed. The quantity of this reserve depends on the number of workstations of each type and the number of semi-finished products processed simultaneously from them. The in-process internal reserve is defined as follows:

$$(1) \qquad Z_1 = \sum_{1}^{m} C_p \, . \, q$$

where:

$Z_1$ – size of the technological internal process margin *[pcs.]*;

$m$ – number of operations performed on the assembly line;

$C_p$ – number of jobs running in parallel across all operations;

$q$ – number of semi-finished products processed simultaneously at the workstations [5, p. 109, p. 111; 9, p. 195; 12, p. 109].

b) intra-works transport – contains semi-finished products that are moved between workplaces. The following variants of this type are available:

- variable in-transit delay – occurs temporarily when using an intermittent conveyor. This delay is present for a short time and its quantity is determined as follows:

$$(2) \qquad Z_2 = p.n$$

where:

$Z_2$ – size of the variable transport intra-chain reserve *[pcs.]*;

$p$ – transport lot size *[pcs.]*;

$n$ – number of operations that are performed on the assembly line [5, pp. 109 – 110; 9, pp. 195 – 196; 12, p. 109].

- permanent transport intra-target margin – exists permanently when using a continuous action transport vehicle. The quantity of this reserve is determined as follows:

$$(3) \qquad Z_3 = \frac{L_3}{S_3}.p$$

where:

$Z_3$ – size of the permanent inland transport reserve *[pcs.]*;

$L_3$ – length of the usable part of the continuous-action vehicle *[m]*;

$S_3$ – length of the step of the vehicle with continuous action *[m]*;

$p$ – transport lot size *[n.p.]* [5, p. 110, p. 112; 9, pp. 195 – 196; 12, p. 109].

c) guarantee internal process reserve – also called backup reserve, it compensates the impact of random interruptions in the operation of the production unit with continuity of technological process. The continuity referred to means that each operation must start immediately after the completion of the preceding one, with no waiting time available. The process thus proceeds without interruption. In terms of the work process itself, there is a continuous sequence of the individual types of work on individual jobs and the workload of the personnel. On the other hand, in terms of the workflow, there is a sequential succession of individual operations and production phases, i.e. the idea is not only to the continuous operation of individual jobs, but also to the continuous movement of work items from one job to another. In this connection, the following summary indicators serve for complex evaluation of the degree of organization of the production process in the industrial production enterprise [5, p. 110; 9, pp. 64 – 65, p. 196; 12, p. 67, p. 109]:

- intensity of the production process – characterizes the volume of output produced per unit time for its implementation over a given period of time. The value of this indicator is determined as follows:

$$(4) \qquad I_1 = \frac{Q}{T_1}$$

where:

$I_1$ – value of the production process intensity indicator;

$Q$ – the volume of output produced for a given period of time *[normh or lv]*;

$T_1$ – the time to carry out the production process during the same period of time *[hour]* [5, pp. 57 – 58].

- degree of continuity of the production process – the value of this indicator is judged by the continuity ratio. It is determined as follows:

$$(5) \qquad k_1 = \frac{T_1}{T_1 + T_2}$$

where:

$k_1$ – continuity factor *[$k_1 \rightarrow 1$]*;

$T_2$ – the downtime during the period of time within which the output was produced *[hour]* [5, p. 58; 16, p. 32].

The essential point about the presented two summary indicators is that the higher their values are, the higher is the degree of organization of the production process in the industrial production enterprise. In this regard, the guarantee margin is created, limiting the influence of the mentioned randomly occurring interruptions in the operation of the production unit with continuity of the technological process. This reserve margin should be created only after the most unreliable jobs. Its quantity is determined as follows [5, p. 58]:

$$(6) \qquad Z_{4_j} = \frac{T_{4_j}}{\frac{t_{5_{(j+1)}}}{M_{(j+1)}}} . \omega_1$$

where:

$Z_{4_j}$ – warranty margin after the job that performs the *j*-th process operation *[n.b.]*;

$T_{4_j}$ – the duration of accidental (unregulated) time losses at the workstation performing the *j*-th technological operation *[min.]*, i.e.:

$$(7) \qquad T_{4_j} = T_{a_j} + T_{b_j}.\varphi_j + d_j.t_{4_j}$$

where:

$T_{a_j}$ – the probable duration of the random interrupt *[min.]*;

$T_{b_j}$ – the likely duration of the period of reduced productivity *[min.]*;

$\varphi_j$ – the probable rate of decrease in productivity of the job performing the *j*-th operation;

$d_j$ – the probable out-of-norm waste produced during the period of reduced productivity at the workstation performing the *j*-th technological operation *[pcs.]*;

$t_{4_j}$ – operating time for the *j*-th operation *[min.]*;

$t_{5_{(j+1)}}$ – operating time for the *(j+1)*-th technological operation *[min.]*;

$M_{(j+1)}$ – the number of jobs that perform the *(j+1)*-th operation and are fed from the previous job performing the *j*-th operation;

$\omega_1$ – a safety factor characterising the random time loss *[$\omega_1$=1,1÷1,3]* [3, pp. 70 – 71].

d) intra-process turnover – periodic increases and decreases between jobs linked along the process line, which is the result of imperfections in production linkages. The time inconsistency is manifested in the successive execution of the *j*-th and *(j+1)*-th operation, and the productivity inconsistency is manifested in the different amount of output that is produced in the same time. The greater the time and productivity inconsistency, the longer the turnover period of the pattern. This is the time interval in which extensive productivity convergence occurs for jobs performing the corresponding pair of production operations. It is considered that the same amount of production passes through them, i.e. one transport batch of semi-finished products or one batch of semi-finished products [3, p. 71; 5, p. 110; 9, p. 196; 12, pp. 109 – 110].

In each period of turnover, the variation of the said set-aside follows the same pattern. In order to determine it, it is necessary to establish the points of change of the turnover set-aside, which represent the moments of commencement or completion of the *j*-th and *(j+1)*-th technological operations of the respective jobs [5, p. 113, p. 114 (Fig. 8.3)].

The time interval between two consecutive [*(k−1)*-th and *k*-th] change points in a given turnover period is the phase of change of the turnover margin. Within each phase, the change in the turnover margin follows a linear relationship. The turnover margin at the final *k*-th change point for each phase is determined by the turnover margin at the initial *(k−1)*-th change point and the change in the turnover margin in phase [*(k−1), k*] [5, p. 113]:

$$(8) \qquad Z_{5_k} = Z_{5_{(k-1)}} + \Delta Z_{5_{(k-1),k}}$$

where:

$Z_{5_k}$ – the turnover margin at the $k$-th change point for each phase;

$Z_{5_{(k-1)}}$ – the turnover margin in the initial *(k−1)*-th change point;

$\Delta Z_{5_{(k-1),k}}$ – the variation of the turnover margin in the phase *(k−1, k)* [3, p. 72; 5, p. 113].

The change in the turnover rate in each phase depends on the productivity of the jobs performing the *j*-th and *(j+1)*-th operations [5, p. 113]:

$$(9) \qquad \Delta Z_{5_{(k-1),k}} = q_j - q_{(j+1)} = \frac{T_{(k-1),k}}{\frac{t_{5_j}}{M_j}} - \frac{T_{(k-1),k}}{\frac{t_{6_{(j+1)}}}{M_{(j+1)}}}$$

therefore [3, p. 72]:

$$(10) \qquad Z_{5_k} = Z_{5_{(k-1)}} + \frac{T_{(k-1),k}}{\frac{t_{5_j}}{M_j}} - \frac{T_{(k-1),k}}{\frac{t_{6_{(j+1)}}}{M_{(j+1)}}}$$

where:

$q_j$ – the productivity of jobs performing the *j*-th operation during the corresponding phase *[count]*;

$q_{(j+1)}$ – the productivity of jobs performing the *(j+1)*th operation during the corresponding phase *[pcs.]*;

$T_{(k-1),k}$ – phase duration *[min.]*;

$t_{5_j}$ – the operating time for the *j*-th operation *[min]* ;

$M_j$ – the number of jobs performing the *j*-th operation during the corresponding phase;

$t_{6_{(j+1)}}$ – the operating time for the *(j+1)*-th operation *[min]*;

$M_{(j+1)}$ – the number of jobs performing the *(j+1)*-th operation during the corresponding phase [3, pp. 72 – 73; 5, pp. 113 – 114].

In the light of the foregoing, and in connection with the need to avoid downtime when using a means of transport with intermittent action, it should be noted:

- provided that the feeding operation is significantly longer than the consuming operation, a large margin should be created in front of the consuming operation to ensure the normal running of the process;

- provided that the feeding operation is significantly shorter than the consuming operation, a large margin is objectively accumulated after the feeding operation [5, p. 114 (Fig. 8.3); 8, p. 95; 9, p. 196].

The quantity of the average size of the turnover internal reserve is:

$$(11) \qquad Z_6 = \sum_{(k-1),k}^{(M-1),M} Z_{6_{(k-1),k}}$$

where:

$Z_6$ – average size of the turnover internal reserve *[issue]*;

$(M-1),\ M$ – jobs *[no.]*;

$(k-1), k$ – adjacent change points *[pc.]*;

$Z_{6_{(k-1),k}}$ – average size of the turnover margin in the modification phase [p. 3, pp. 72 – 73; 5, p. 109; 12, pp. 109 – 110].

The presentations suggest that the amount of incomplete inhouse production is:

$$(12) \qquad C_1 = Z_6 . \frac{C_2}{2}$$

where:

$C_1$ – cost of unfinished internal production *[BGN]*;

$Z_6$ – average size of the reserve of the internal process *[pcs.]*;

$C_2$ – cost per unit of internal production *[BGN]* [8, p. 95 – 96].

It was mentioned that the other type of technology reserve is inter-plant. It is formed by all semi-finished products that are located between production units connected in the technological chain and has the following composition [3, p. 69; 5, p. 115; 9, p. 196]:

a) inter-works transport reserve – consists of semi-finished products in the process of transportation between individual workshops. In this relation, when using a continuous conveyor, the quantity of this part is determined as follows:

$$(13) \qquad Z_7 = \frac{L_7}{S_7} . \eta_1$$

where:

$Z_7$ – size of the transport reserve *[pc.]*;

$L_7$ – length of the usable part of the continuously moving conveyor *[m]*;

$S_7$ – step length of the continuously moving conveyor *[m]*;

$\eta_1$ – the utilisation factor of the continuous duty vehicle *[$\eta_1$=0,97]* [9, pp. 196 – 197; 21, p. 203].

b) guarantee inter-workshop delay – it is created between individual workshops with organized flow production when there is a risk of interruption of the technological process due to accidents. It shall be calculated using the above formulas for the intra-workshop guarantee margin in the event that the last workstation on the supply line has a low degree of reliability. Then the first operation of the partial process carried out in the feeder line is taken as the next *(j+1)*-th operation [5, p. 113; 9, p. 197].

c) turnover between shops – it is created between shops with organized flow production, connected to each other in the course of the technological process, when there is not a good synchronization linkage, resulting in their different productivity. The turnover inter-workshop reserve ensures the normal operation of the rhythmic production of the output of the interconnected workshops. It is calculated by means of the above formulas for the inter-plant turnover margin, the jth operation being the last technological operation of the partial process carried out in the production unit upstream in the technological chain, and the *(j+1)*-th operation being the first technological operation of the partial process carried out in the next production unit. The turnover period for the pair of operations under consideration is determined by the longer of the two turnover periods for the respective production units [3, p. 73; 5, p. 115; 9, p. 197].

The proposed statement suggests the conclusion that work in progress is necessary for the normal course of the production process. It ensures the rhythmicity and continuity of the production flow, and the basis for achieving these two characteristics is the so-called technological reserve. This, in turn, should be in the necessary and sufficient quantity.

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