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ESTABLISHING TECHNOLOGICAL CYCLE TIME LENGTH OF THE PRODUCTION PHASE IN THE COMBINED MODE OF WORKPIECE MOVE

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Abstract: *In the literature there are a number of different formulas for calculating technological cycle time length depending on the mode of workpiece move, with the confusion being present especially in the combined mode of organization of the sequence of operations flow. Taking into account this fact, the paper develops two models for calculating technological cycle time length of the production phase according to the combined mode of workpiece move. Validity check is done for the existing and developed relations.*
Key words: *manufacturing cycle, technological length, combined mode of workpiece move*

1. INTRODUCTION AND RELATED WORK

In terms of theoretical considerations, industrial practice and duration, three types of cycle time length can be distinguished: technological cycle time or ideal manufacturing cycle ($T_t \equiv T_{ci}, t_t \equiv t_{ci}$), manufacturing (real) cycle (T_{cs}, t_{cs}) and projected manufacturing cycle (T_{cp}, t_{cp}), Fig. 1.

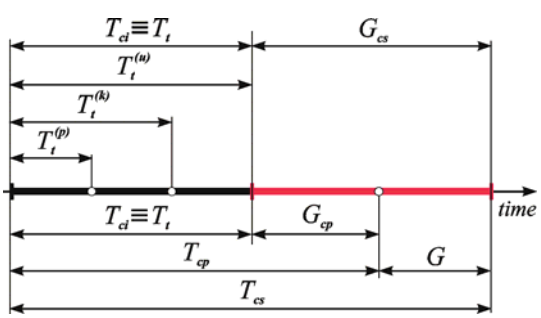

Fig. 1: Types of cycles as determined by duration

Time dimension of the technological cycle includes the projected times necessary for performing all technological operations, of the production phase (t_t) or complex item (T_t), on the items of a single lot. The benchmark points of the technological cycle (TC) of any production phase were defined at the start of manufacturing the first item in a lot, on the first operation, and at the end of manufacturing the last item in a lot, on the final technological operation. The production phase (PPh) implies a segment of the manufacturing and technological process characterized by a sub-set of technological operations by means of which the workpiece is transformed from one to another qualitative condition.

The TC length (t_t) of PPh is affected by the total number (n) of operations, time of technological operations $\theta_n = \left(t_i, i = \overline{1,n}\right)$, lot size ($q$) and batch ($p$), as well as by the workpiece move (WM) that can be consecutive (U), parallel (P) and combined (K), relation (1). In the current Russian literature other parameters are also used, e.g. number of workplaces (c_i), formula (2). Given that this is an organizational element, influential in cycle projection, its impact on TC is eliminated, assuming that each technological operation is executed in a single workplace ($c_i = 1$).

$$A = \{n, \theta_n, q, p, WM\} = \left\{n, \left(t_i, i = \overline{1,n}\right), q, p, \{U, P, K\}\right\} \Rightarrow$$
$$t_t = \left\{t_t^{(u)}, t_t^{(p)}, t_t^{(k)}\right\} \qquad (1)$$

The combined type of work flow in manufacturing process is most often encountered in serial production. Its goal is to eliminate downtimes emerging at some workplaces (operations) at parallel type due to different duration of successive operations [12].

Calculations of TC according to the combined mode of WM $t_t^{(k)}$ are performed in the literature using different formulas: (2) [1, 9, 15, 16, 17, 19, 22], (3)

[10, 18], (4) [5, 14], (5) [3, 4], (6) [2], (7) [13, 21], (8) [6, 8, 11, 12] i (9) [20]. Formula (3) is similar to formula (2), which is employed in the Russian literature, however p = 1 is adopted for the lot size of the production-transport batch and the number of workplaces is identical to the number of technological operations, i.e. $c_i = 1$.

$$t_t^{(k)} = q \cdot \sum_{i=1}^{n} \frac{t_i}{c_i} - (q-p) \cdot \sum_{i=1}^{n-1} \min_i \left\{ \frac{t_i}{c_i}, \frac{t_{i+1}}{c_{i+1}} \right\} \quad (2)$$

$$t_t^{(k)} = q \cdot \sum_{i=1}^{n} t_i - (q-1) \cdot \sum_{i=1}^{n-1} t_{ki}, \; t_{ki} = \min_i \{t_i, t_{i+1}\} \quad (3)$$

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left[t_{i\max} + \sum_{j=1}^{s} \left(t_{vj} - t_{mj} \right) \right],$$

$$t_{vj} > t_{j-1} \wedge t_{mj} < t_{j+1} \quad (4)$$

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_j t'_{oj} + \sum_j t''_{oj} \right),$$

$$t_{oj-1} < t'_{oj} > t_{oj+1} \wedge t_{oj-1} > t''_{oj} < t_{oj+1} \quad (5)$$

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_j t'_{oj} - \sum_j t''_{oj} \right),$$

$$t_{oj-1} < t'_{oj} > t_{oj+1} \wedge t_{oj-1} > t''_{oj} < t_{oj+1} \quad (6)$$

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot t_{i\max} + (q-1) \cdot (t_{i\max} - t_{i\min}) \quad (7)$$

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1) \cdot \left(\sum_k t_k - \sum_j t_j \right),$$

$$t_{k-1} < t_k \geq t_{k+1}, \quad t_{j-1} \geq t_j < t_{j+1} \quad (8)$$

$$t_t^{(k)} = \sum_{j=1}^{n} t_j + (q-1) \cdot \sum_{j=1}^{n} (t_j - t_{j-1}) \cdot I_j,$$

$$t_j \leq t_{j-1} \Rightarrow I_j = 0 \wedge t_j > t_{j-1} \Rightarrow I_j = 1 \quad (9)$$

Formulas (2), (3), (4) and (9) are based on the comparison of time between two adjacent operations, formulas (5), (6) and (8) are based on the comparison of time between three adjacent operations, whereas calculations of TC using formula (7) are based on the operations of the shortest and longest time length. In [7] formulas (4), (5), (6) and (7) are denied, however comparison between the results obtained using formulas (2), (3), (8) and (9) has not been considered in the literature and investigations so far.

2. VALIDITY CHECK OF THE EXISTING AND INVESTIGATIONS OF THE NEW MODELS

Investigation of the formula for calculations of TC of PPh x_j in the quantity of q according to the combined mode of WM by the batches of p = 1 piece will be based on the comparison of time for:

1) three adjacent operations, Fig. 2 – model 1, and

2) two adjacent operations (α-1, α), Figs 3 and 4 – model 2.

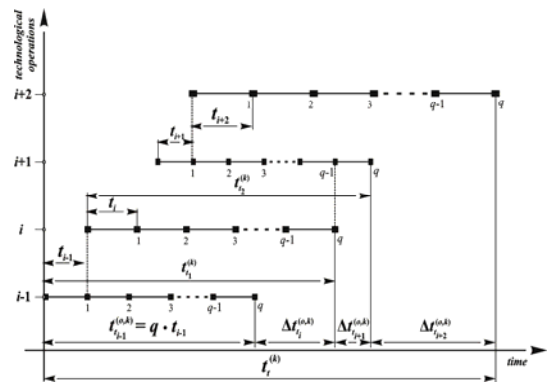

Fig. 2: Graphic representation of a combined mode of workpiece move in the manufacturing process

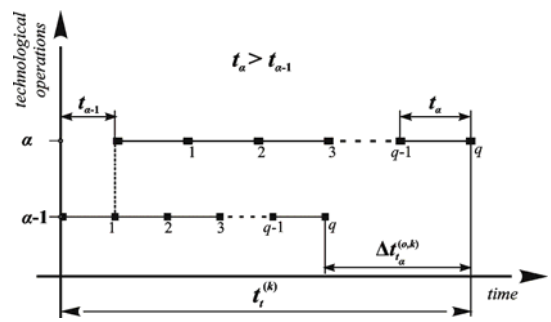

Fig. 3: $\theta_2 = (t_{\alpha-1}, t_\alpha), t_\alpha > t_{\alpha-1}, p = 1$

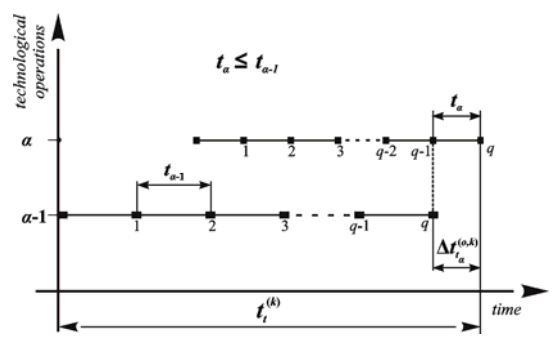

Fig. 4: $\theta_2 = (t_{\alpha-1}, t_\alpha), t_\alpha \leq t_{\alpha-1}, p = 1$

Using the corresponding proofs [23] with Fig. 2, on one hand, and Figs 3 and 4, on the other hand, formulas (10) and (11) were developed.

Using the example of a multivariate creation of a chosen PPh, determined by four alternative technological procedures V_j, each of which has ten operations, check validity of the existing formulas (2)-(9) is performed and of the formulas developed in this paper (10) and (11), based on the results obtained by the help of the formulas and Gantt charts. Table 1 gives the elements required for applying the formulas and Table 2 presents values of the technological cycle time obtained by appropriate formulas and Gantt charts (Fig. 5).

$$t_t^{(k)} = \sum_{i=1}^{n} t_i + (q-1)\cdot\left(\sum_k t_k - \sum_j t_j\right), \left(\forall x_j \middle| j=\overline{1,m}\right) \in PPh \wedge A = \{n, \theta_n, q, p=1, K\},$$

$$t_k \in \left(t_i \middle| i=\overline{1,n}\right) \wedge k = \left\{\left\{k=1 \middle| t_1 \geq t_2\right\}, \left\{k=\overline{2,n-1} \middle| t_{k-1} < t_k \geq t_{k+1}\right\}, \left\{k=n \middle| t_n > t_{n-1}\right\}\right\} \wedge$$

$$\wedge\, t_j \in \left(t_i \middle| i=\overline{2,n-1}\right) \wedge j = \left\{\overline{2,n-1} \middle| t_{j-1} \geq t_j < t_{j+1}\right\} \tag{10}$$

$$t_t^{(k)} = \sum_{\alpha=1}^{n} t_\alpha + (q-1)\cdot\left(t_1 + \sum_{\alpha=2}^{n}(t_\alpha - t_{\alpha-1})\cdot F_\alpha\right), \left(\forall x_j \middle| j=\overline{1,m}\right) \in PPh,$$

$$\forall \alpha | t_\alpha > t_{\alpha-1} \Rightarrow F_\alpha = 1 \wedge \forall \alpha | t_\alpha \leq t_{\alpha-1} \Rightarrow F_\alpha = 0,\ A = \{n, \theta_n, q, p=1, K\} \tag{11}$$

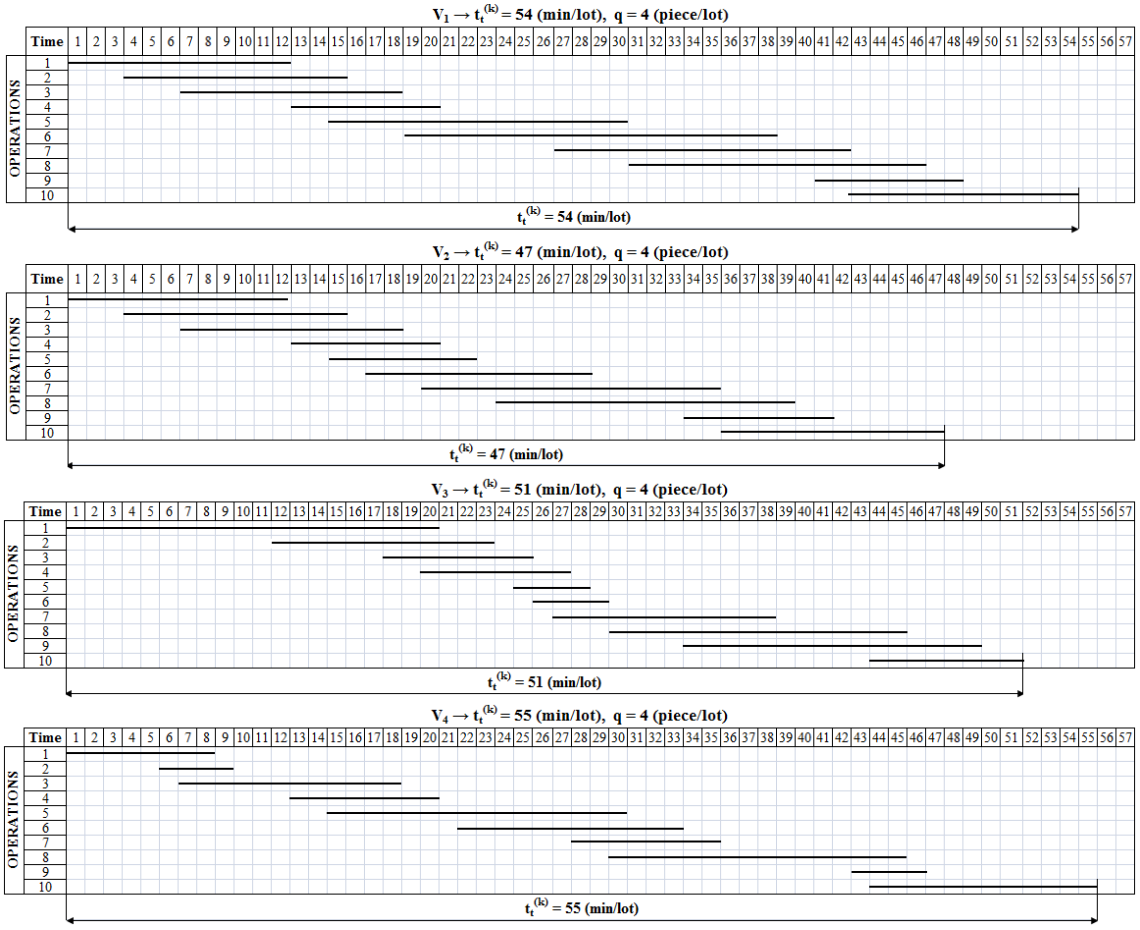

Fig. 5: Gantt charts with cycle values $t_t^{(k)}$ by variants V_j

Table 1: Representation of the parameters required for the calculation of TC t_t depending on the variant of manufacturing V_i and formula

Technological procedures $\theta_n, n=10$		$\sum_{i=1}^{n} t_i$	$\sum_{i=1}^{n-1} t_{ki}$	t_1	$t_{i\max}$	$t_{i\min}$	$\sum_{j=1}^{s}(t_{vj} - t_{mj})$	$\sum_j t'_{oj}$	$\sum_j t''_{oj}$	$\sum_k t_k$	$\sum_j t_j$	$\sum_{i=1}^{n}(t_i - t_{i-1})\cdot I_i$		$\sum_{i=2}^{n}(t_i - t_{i-1})\cdot F_i$
V_j	$t_i, i=\overline{1,10}$ *min/lot*											I $t_0 = t_1$	II $t_0 = 0$	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
V_1	$t_1=3, t_2=3, t_3=3, t_4=2, t_5=4, t_6=5, t_7=4, t_8=4, t_9=2, t_{10}=3$	33	16	3	5	2	4	5	4	11	4	4	7	4
V_2	$t_1=3, t_2=3, t_3=3, t_4=2, t_5=2, t_6=3, t_7=4, t_8=4, t_9=2, t_{10}=3$	29	11	3	4	2	3	0	2	10	4	3	6	3
V_3	$t_1=5, t_2=3, t_3=2, t_4=2, t_5=1, t_6=1, t_7=3, t_8=4, t_9=4, t_{10}=2$	27	12	5	5	1	3	0	0	9	1	3	8	3
V_4	$t_1=2, t_2=1, t_3=3, t_4=2, t_5=4, t_6=3, t_7=2, t_8=4, t_9=1, t_{10}=3$	25	15	2	4	1	8	11	6	16	6	8	10	8

Table 2: Values of TCs $t_t = \{t_t^{(u)}, t_t^{(p)}, t_t^{(k)}\}$, depending on the mode of WM for q = 4 and p = 1 piece

Variants	$t_t^{(u)}$	$t_t^{(p)}$	Formulas notation for the calculation of TC $t_t^{(k)}$ with cycle values in *min/lot*										
			(2), (3)	(4)	(5)	(6)	(7)	(8)	(9) - I	(9) - II	(10)	(11)	Gantt chart
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
V_1	132	48	84	60	60	36	57	**54**	45	**54**	**54**	**54**	**54**
V_2	116	41	83	50	35	23	**47**	**47**	38	**47**	**47**	**47**	**47**
V_3	108	42	72	**51**	27	27	54	**51**	36	**51**	**51**	**51**	**51**
V_4	100	37	**55**	61	76	40	16	**55**	49	**55**	**55**	**55**	**55**

3. CONCLUSION

On the grounds of obtained results, Table 2, the following can be established:

- The TC values obtained with the help of Gantt charts, according to the combined mode of WM (Fig. 5), are identical with the results obtained using formulas (8), (9-II), (10) and (11). Formulas (8) and (10) are based on comparing time between three adjacent ($\alpha-1, \alpha, \alpha+1$) operations, whereas (9-II) and (11) on comparing time between two adjacent ($\alpha-1, \alpha$) technological operations. Formula (9) does not contain an unambiguous definition of the value t_{j-1} for j=1, that is, the expression: $t_0 = ? \Rightarrow (t_1 - t_0) \cdot I_1 = ?$. The application is conditioned for the value $t_0 = t_1$ (9-I) and $t_0 = 0$ (9-II), Table 2, columns 10 and 11.
- Other formulas do not produce satisfactory results. Formulas (5), (6) and (7) yield values $t_t^{(k)}$ that are lower compared to the values $t_t^{(p)}$ for individual variants of manufacturing, which is not feasible in practice.

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