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Stohastic Model to Determine the Elements of the Production Cycle Time: Case of Serbian Textile Industry

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Abstract
The paper presents an original method of determining the elements of the production cycle time by using the modified work sampling method applied to a textile factory. It is shown that the movement of the elements of time can be viewed as a process and in the mathematical sense can establish control limits of error of ± 3 SD. The mean time of the production cycle of the groups created by the number of pieces in the series – t_{pcu} moving the hyperbolic function, which has the asymptote c, a function of the form $\bar{t}_{pcu} = c + b/\log n$, where all groups of the production cycle in the mathematical sense do not act like strata but are function $\bar{t}_{pcu}$ related to technology and deterministic factors of the production series.

Key words: *production cycle, production cycle time, work sampling, stochastic model, textile industry.*

∎ Introduction

Customers in todays global competitive environment demand products that are highly differentiated, low-cost, and high-quality, thus manufacturers must offer a wide variety of products in a cost-effective manner, with quick responses to changes in product designs and volumes. The most important organizational-technical indicators of production successfulness are the level of capacity utilisation and the production cycle. The goal is, in general, to reduce the total production cycle time, especially that associated with different types of stoppage and the optimization of both the lead and machine time within the sphere of machine capacity utilisation. Increased attention was focused on the level of machine capacity utilisation because machines are more costly and therefore have a greater impact on production effectiveness. Additionally optimisation of the time for transport, control, and packing is also important for the production cycle. A reduced cycle time can be translated into increased customer satisfaction. Quick response companies are able to launch new products earlier, penetrate new markets faster, meet changing demand, and make rapid and timely deliveries. They can also offer their customers lower costs because quick response companies have streamlined processes with low inventory and less obsolete stock.

In general companies coming from transitional countries, with Serbia among them, have problems with the quality of their business and production productivity. An inherited inefficient production system as well as transitional recession, common for all countries in transition, influence those companies and may be blamed for their insufficient competitive capacity - Serbian companies have been uncompetitive on the international market for a long period of time. Old technology, poor quality, unattractive packaging and high prices generally slow the response to market demands, and are the main reasons for the uncompetitiveness of Serbian products. The least competitive are the textile and manufacturing industries, as well as the metal industry and electronics, in which for years there has been no technological reconstruction. The average machine age in Serbia is 30 years. Comparing to the situation in the region, this is a delay of about 12 years. The greatest backwardness was noticed in textile companies (35 years), then in the machine industry (34.5 years).

The purpose of this investigation is directed at designing a new original method for monitoring the production cycle and its time elements by using the stochastic work sampling method, whose basis was set up by Tippett [11 - 13]. However, this method will be innovated and adapted to the investigation of a production cycle. The final goal is to optimise the duration of the production cycle time, i.e. the realisation of a predisposition to achieve competitiveness in the Serbian textile industry.

∎ Research problem

To ensure rational production and adherence to time schedules in production, quality planning of production and cor-

responding technical-technological calculations are needed to provide machine operating modes and the duration of machine operations as well as activities in the manufacturing process. This way, they are normed, normalised and standardised, thus elements of the production cycle (PC) time can be determined beforehand for machines, mechanisation means and manual work. In practice they are not deterministic but stochastic, especially under conditions of small and medium businesses, and as such they have to be monitored. In an experimental example, Niebel [10] illustrates the determination of elements of the production cycle (PC) time, showing that the production cycle C is divided into only three elements of the cycle time, $C = T_1 + T_2 + T_3$ (T_1 = running time to produce one unit of output, T_2 = normal time to service a stopped machine, T_3 = time lost by normal operator working because of machine interference).

The elements of the PC time are possible to monitor using the work sampling method, which was originally applied in the textile industry by Tippett [11 - 13], and taking into account the surveys of Barnes [1], Moder [8] and Richardson and Eleanor [10]. However, the original method has a restricted realm of use, and only three elements of the PC time were monitored: the machine in operation, the machine in preparation, or the machine is idle (+, ×, -).

Nevertheless the classical work sampling method established by Tippett and others is not appropriate for contemporary production systems, because in his research the main stoppage was due to poor material quality. The indispensible modification of the method presented by Klarin et al. [4, 5] aims to explain and justify both

the necessity and importance of using the shift level of utilization of the capacity as the stochastic variable in determining the total level of capacity utilization in the production process by using the method of work sampling on a sample comprising 74 Serbian companies. The conclusion drawn is that the shift level of capacity utilization as the stochastic variable in work sampling is the model which solves the problem of determining the total level of capacity utilisation in a convenient way with accurate results. On the other hand, on the basis of the research mentioned, Elnekave and Gilad [3] propose a digital video-based approach to enhance work measurement and analysis by facilitating the generation of rapid time standards, which serves as a computerised tool for remote work measurement with the ability to derive the rapid generation of time standards. The application of the modified work sampling method in the processing industry indicates that the methods of monitoring capacity utilisation applied in the processing industry, such as cement production, may also be used in the metalworking industry, which has a high level of capacity utilisation. Hence, the results of the analysis indicate that when the level of capacity utilization is high, this variable may be observed per day as stochastic, while, per machine, it may be a random variable, [6]. It is evident that today the more significant problem of monitoring and influencing the production cycle (the period from the item's entry into the production process to the receipt of a finished product and its packing) is less present in the literature by far.

Although a technical-technological indicator of the machine utilisation level, i.e., the time of operation against machine total available time, is a very significant

indicator in production and business operations and the stochastic model application itself very simple, it is more important to obtain those levels for the elements of the PC time. The PC time involves the time for making a unit or a series of units from putting them in production until their storage, and aside from being significant as a technical indicator, it is important as an economic indicator of freezing current assets, especially raw materials. There can hardly be any enterprise that does not monitor the PC time with documentation and analytically, but rare are those that monitor the elements of work within the PC and by analyzing those elements affect their reduction, and thereby that of the PC time.

This is the reason why in the present paper we prove experimentally the applicability of the original stochastic method to determine elements of the PC time using, as an example the results obtained by screening textiles plants with small scale production.

The representativeness of a screening sample per number and time of screening was established by means of mathematical parameters, SD and control limits, where elements of the PC time are observed as elements of the process function. The organisation of a sequence of operations, and in this regard determination of the machine time – t_{tm}, has the greatest impact on the production time as the most important PC time in small scale and serial production.

The organisation of a sequence of operations can be consecutive, parallel and combined. In a consecutive type of operation sequence, production proceeds in such a way that the entire series of units waits for all units of a series to be
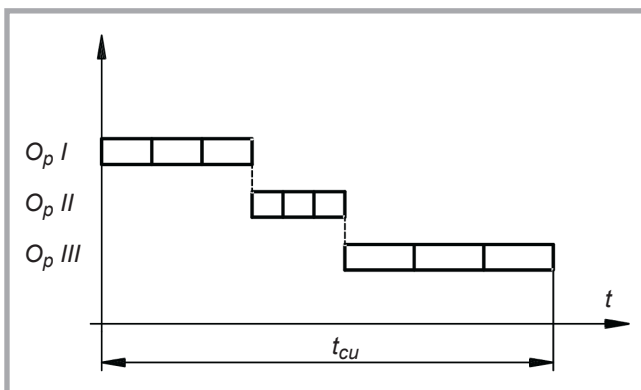

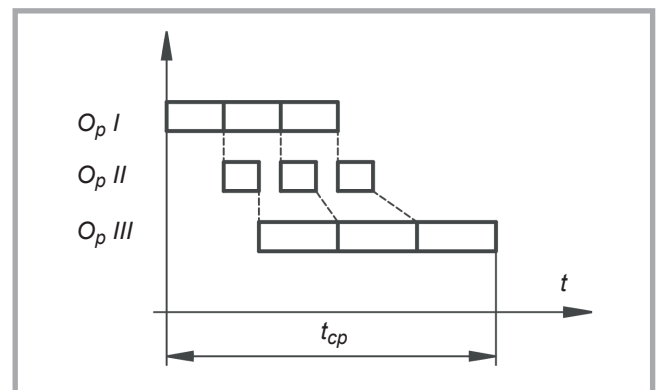***Figure 1.*** *Organisation of operation sequence for the consecutive type.*

Figure 2. *Organisation of operation sequence for the parallel type.*

finished on one machine, and only afterwards to be removed altogether onto another machine (operation), as is evident from *Figure 1*.

In the consecutive type of sequence of operations, the total time necessary for a series' production, i.e. the production cycle length is:

$$t_{cu} = n \sum_{i=1}^{k} t_{oi}$$

where,

n - number of items for production in a series,

k - number of operations for producing an item,

t_{oi} - time of individual operations' duration.

It is obvious from *Figures 1* and *2* that for the identical time duration of the technological machine time observed for the machine operating mode, for three operations for a series of three units, the PC time is much longer in a consecutive type of operation sequence. In effect, the PCs in *Figures 1* and *2* represent only the machine time involved before the time of waiting for the operation as well as the worker's manual work time related to a single unit. Therefore the technological machine time should be distinguished when the machine capacity is analysed and when the PC time is analysed and monitored, [5]. Particularly this refers to serial production, when the work sampling method is applied, and, in general, a work study is performed.

■ Methodological overview

Basics of the stochastic model to determine elements of the production cycle time

The production cycle is the period from the entry of a product part or a series of products into manufacturing to their receipt in the warehouse of finished products (or parts). The production cycle is indirectly dependent on the factors of the total supply-sales cycle as its part. For example, any increase in the supply time for parts from cooperating companies leads to a stoppage in the production cycle. Some elements of the cycle time are mutually influential in a similar sense.

In theory, the PC time (t_{pc}) is divided into the production time (t_p) and non-production time (t_{np}), and the production time is further divided into the technological time (t_t), with machine (t_{tm}) and lead

time (t_{pf}), non-technological time (t_{nt}) with time of control (t_c), transportation (t_{tr}) and packaging (t_{pk}). Non-production time is classified according to various causes of stoppages in production, and we made a screening of the most general and common ones caused by a lack of raw materials (t_{mr}), tools (t_{tl}), organisation (t_o), machine breakdown (t_b) and other troubles (t_{ot}), [2, 4].

A new, original method for monitoring the production cycle and its time elements by using the stochastic work sampling method - a modified work sampling method, will enable the determination of participation percentages of working time elements against the total duration of the production cycle and production. As this method is statistic and is based on a certain number of instantaneous observations of a certain activity, it is simpler to use and more efficient than the continual streaming method. Monitoring within the production cycle will involve technological time with lead time and manufacturing time, non-technological time with times for transport, control and packing, while non-production time includes stoppage due to poor production organisation, lack of materials, lack of tools, including the failure or breakdown of machinery and other types of stoppage, their interdependence, as well as impact factors such as the series size, organisational level and product characteristics pertaining to the factors mentioned.

Establishing the representativeness of the screening time duration

The representative screening time is related to the length of the production cycle time. It is clear that it must not be shorter than the production cycle time and that under identical production conditions it must be repeated a certain number of times in order to make the sample representative. Production and productivity are also related to the production dynamics which are planned at the operational level on a daily, weekly or monthly basis. Hence the production cycle for the above-mentioned periods is also provided for the purposes of monitoring and comparing. The third criterion for determining the screening time duration is the margin of error adopted in the stochastic model applied in these investigations, i.e. the number of instantaneous observations and their distribution per working time element.

The problem of determining the technological time

The screening performance requires precise definition not only of technological and mathematical problems but also of the practical screening process, as well as the establishment of working time elements. Thereafter the elements of the production cycle working time should be defined and, in particular, the difference between the elements of working time related to machinery, i.e. for the purpose of establishing the machine capacity only or within the production cycle, because these two are not the same. The elements of working time are determined according to Barnes [1], Maynard [7], Moder [8], Niebel [9], Richardson and Eleanor [10], Klarin et al. [6] and Čala et al. [2]. Theoretically speaking, the sequence of operations may be serial, parallel or combined. Therefore, depending on the type of sequence of operations, we know in advance that this portion of the cycle time lasts much longer in a serial type, where before moving onto the next operation the whole series waits to be completed by a single machine operation, while in a parallel type, after one machine part is completed on one machine, it immediately moves onto the next. In companies, the most common type of sequence of operations is combined. Not infrequently one part of the production cycle is parallel, another serial, and a third combined. The technological machine time (t_{tm}), viewing production against machinery, is exclusively linked to machine performance and the quality of technological calculations, and is mainly a deterministic category. However, if the production cycle is viewed from the aspect of the serial sequence of operations, the elements of the working time differ depending on the automation level. If production is automated, then t_{tm} for a series will be simply the sum of individual n equal operations. However, if each part has to be manually or mechanically conveyed for processing from a joint crate or some other room where a certain series of parts is stored, manual placement on the machine is the ancillary manual time (t_{pr}). In theory, this refers to individual pieces. Such time is not frequently encountered in literature (previous examples are papers [4 - 6]), dealing with the division of working time elements. In our investigations, the ancillary manual time will be treated as the technological machine time (t_{tm}).

Table 1. Frequencies of production cycle element occurrence.

Date	MIN	Time		Production time tp					Non-productive tnp					Number of items
		Beginn.	End	tpt	tm	tc	ttr	tpk	tmr	ttl	to	tb	tto	
27.09.11	980	7:00	30.09.11 12:00	5	12	5	2	4	1		3		5	17 protective trousers
27.09.11	990	7:00	30.09.11 12:00	6	10	6	2	5	3		2		5	
27.09.11	980	7:00	30.09.11 12:00	5	9	5	2	3	2	1	5		6	
13.10.11	640	7:05	18.10.11 12:40	2	7	3	4	3	1		2		3	17 SMB trousers
13.10.11	640	7:05	18.10.11 12:40	4	8	4	5	4	2		1		3	
24.10.11	793	9:00	26.10.11 13:10	6	7	8	5	3	2	1	6		5	12 fire suits
24.10.11	780	9:00	26.10.11 13:10	5	10	7	7	4	3	1	4		6	
24.10.11	760	9:00	26.10.11 13:10	8	9	6	2	4	2		3		6	
20.09.11	520	7:00	22.09.11 13:40	3	5	2	3	3	3		2	1	5	10 black overalls
20.09.11	480	7:00	22.09.11 13:00	4	5	3	2	3	1		2		5	9 SMB overalls
13.10.11	610	7:05	18.10.11 12:40	2	7	5	2	4	1		1		5	17 SMB trousers
20.09.11	460	7:00	22.09.11 13:40	3	6	3	1	2	3	1	1		4	10 black overalls
20.09.11	480	7:00	22.09.11 13:00	2	6	3	2	2	2		3		3	9 SMB overalls
06.10.11	620	8:04	10.10.11 13:35	2	6	5	1	4	2		4		3	18 hunting vests
18.10.11	820	6:00	25.10.11 12:10	6	9	5	6	2	5	1	2		3	115 black long-sleeved shirts
18.10.11	800	6:00	25.10.11 12:10	4	6	6	3	4	2		2		5	
04.10.11	520	7:00	05.10.11 12:55	1	6	3	3	3	1		1		3	14 blouses
04.10.11	540	7:00	05.10.11 12:55	2	5	5	2	2	1	1	1		4	
18.10.11	800	6:00	25.10.11 12:10	6	6	5	1	4	2		3		4	115 black long-sleeved shirts
29.10.11	1420	8:00	10.11.11 12:25	9	20	10	7	13	5	3	3	1	11	106 quilted jackets
29.10.11	1420	8:00	10.11.11 12:25	8	15	8	5	10	7	1	4	lighting 2	6	
29.10.11	1400	8:00	10.11.11 12:25	9	17	9	7	12	8	2	4	2	7	
15.11.11	1060	9:30	24.11.11 13:37	8	20	10	6	15	4	1	4		17	67 trousers
16.11.11	1000	8:00	25.11.11 09:35	6	16	13	4	9	4		3		9	63 blouses
15.11.11	1080	7:40	25.11.11 13:50	9	20	14	7	15	4	2	4		15	112 blouses
23.11.11	875	9:00	25.11.11 13:15	5	13	9	6	4	3		1	4	6	10 sweaters
	21,468			130	260	162	97	141	74	15	71	10	154	

It is also logical to add the ancillary machine time (for example, support moving a lathe) to (t_{tm}). The manufacturing lead time includes the receipt of the work order with documentation and the study of tasks, receipt of equipment, preparation of other components necessary for work, transport of finished pieces for quality control and cleaning up of the work place after a certain number of pieces (*n*) are manufactured, one at a time, non-stop (number of pieces in a series).

Figure 3. Diagram showing the levels of cycle time elements.

Figure 4. Machine time level.

■ Application of the model

Practical application of establishing the elements of the PC time mentioned is reduced to instantaneous observations of time elements, where the object of labour is moving through the production operations list. A series of units is distinctly marked by this document and an analyst (recorder) can readily identify it.

Screening is conducted according to randomly chosen times that are entered in a screening sheet related to one PC as well as the number of individual elements of work – frequencies. This way the data in *Table 1* are formed. Using the frequencies, we first calculate the % of individual elements against the total PC time, and afterwards, based on the PC time duration analytically screened, the time duration of individual elements of the working time is calculated.

Organization of the operation sequence in both enterprises where screenings were performed was of the consecutive type.
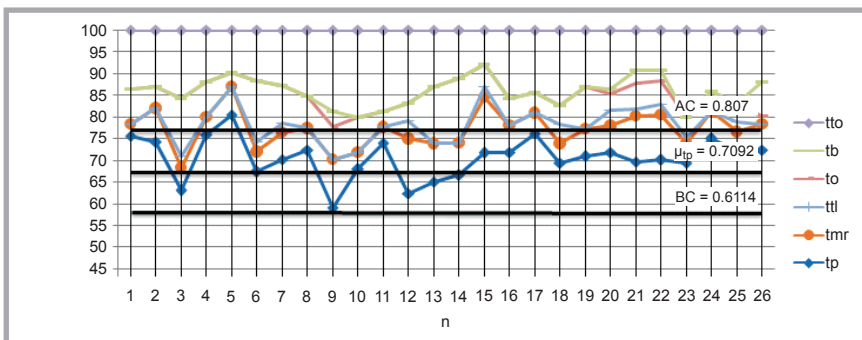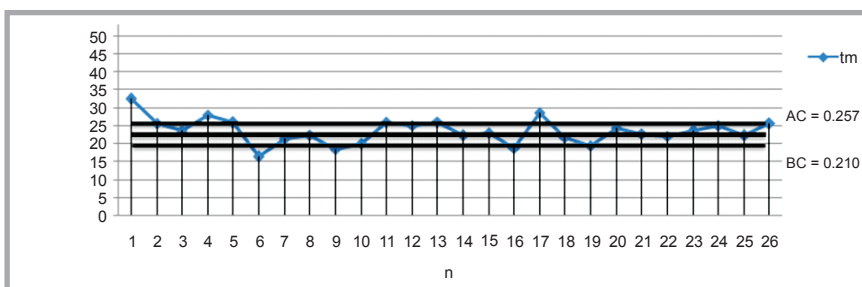
The experiment is related to a plant that produces military and firemen's clothing. The results of cycle monitoring are represented by diagrams only in *Figures 3* and *4*. Screenings were carried out from September 27, 2011 to November 13, 2011. Monitoring comprised 26 production cycles of different types of clothing and different series sizes, from 9 – 117 units, with time durations from 355 min for the shortest to 3700 min for the longest, while instantaneous observations ranged from 21 – 90.

Despite the significantly lower number of production cycles monitored for this enterprise (26), the stochastic variable of the production time level is more stable. Minimal deviation from the control limits is found in two points only (two samples): No 5, which exceeds the upper control limit AC by 0.57 per cent (0.8064 - 0.8007), while the lower point, No 9, exceeds the lower control limit BC by 1.84 per cent (0.5926 – 0.611). The production time level mean is $\mu_{tp} = 0.7092$, the upper control limit AC = 0.807, and the lower control limit BC = 0.611. The average levels for working time elements amount to $\mu_{tpt} = 0.1167$, $\mu_{tm} = 0.2334$, $\mu_{tc} = 0.1454$, $\mu_{tr} = 0.0871$, and $\mu_{tpk} = 0.1266$ for the production time and sum of times, respectively, $\mu_{tp} = 0.7092$ and $\mu_{tmr} = 0.0664$, $\mu_{tl} = 0.0135$, $\mu_{to} = 0.0637$, $\mu_{tb} = 0.009$ and $\mu_{tto} = 0.1382$ the for non-production time, or the sum of times $\mu_{tnp} = 0.2908$.

If the levels presented are compared to those for enterprise 1 (*Table 1*), it is evident that there are no significant deviations in the time elements. The highest levels of machine time are $\mu_{tm1} = 0.246$ and $\mu_{ttr2} = 0.2334$, followed by transport time level $\mu_{ttr1} = 0.152$, while in enterprise 2 this level is significantly lower $\mu_{ttr2} = 0.0871$. The control time and packing time levels do not deviate more significantly in the production time, while in the non-production time, in both cases the level of the other types of time approximates the sum of the other four times, $\mu_{tto1} = 0.165$ and $\mu_{tto2} = 0.1382$.

Considering the results given above, the analysis should be directed towards the problem of the elements of the transport time which can be reduced. Also the distribution of time elements in other types of stoppage should be considered from a mathematical standpoint in such a way that the most significant stoppage will be segregated within it.

This indicates that the experiment design and repeated screenings should focus on the possible size and frequency and whether the (anticipated) stoppages per type designed will emerge at all. The technical level of machine time elements μ_{tmi} deviates very little from the control limits (*Figure 4*), which for $\mu_{tm} = 0.2334$ amount to: AC = 0.2570 and BC = 0.2097.

From *Table 1*, we get the data in *Tables 2* and *3*. Data given in the tables represent mean values and SD_p for groups of screenings for PCs per series size. The group with number of items n = 9, PC time per unit $\bar{t}_p = 66.21\%$; the group with number of items n = 10, PC time per unit $\bar{t}_p = 64.77\%$; group with number of items n = 12, PC time per unit $\bar{t}_p = 70.05\%$; n = 14, $\bar{t}_p = 72.88\%$, n = 106, $\bar{t}_p = 70.26\%$; n = 115, $\bar{t}_p = 71.55\%$ or $t_{pcu} = 7.04$ min/kom. Therefore it is noticeable that there are 11 groups containing at least 9 units in a series, while the largest group has 115 units in a series.

Table 2 shows the size of each group with the number of units in a series for the PC time per unit $\bar{t}_p$ and production time $\bar{t}_{pcu}$ as well as mean values by groups and SD_p in % for t_p. *Table 3* displays mean values $\bar{t}_p$ and t_{pcu}, SD_p and the number of PCs screened by groups as well as the number of units in series in those cycles.

Table 3 also shows the log taken for the number of units in a series – log unit/ser, therefore the trends for the working time elements presented are given by a diagram in *Figure 5*. The stratified mean value of production during is:

$$\bar{\bar{t}}_p = \sum \bar{t}_{pi} \frac{f_i}{N} \qquad (1)$$

where f_i is the number of PCs with an identical number of units in a series, and N is the total number of production cycles. According to the data in *Table 3*
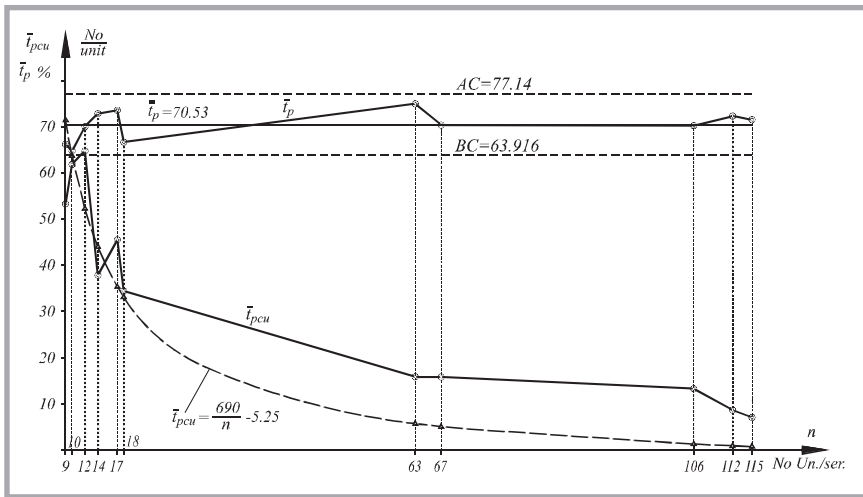
$$\bar{\bar{t}}_p = 66.21 \frac{2}{26} + ... + 71.55 \frac{3}{26} = 70.53$$

Table 2. PC time per unit in a series and the production time in % for enterprise II.

Number of items n	t_{pcu}, min/kom	t_p, %	SD_{tp},%
9	53.33	67.20	
9	53.33	67.22	0.99
$\bar{x}$	**53.33**	66.21	
10	52.00	59.26	
10	46.00	62.49	5.64
10	87.60	72.56	
$\bar{x}$	**61.87**	64.77	
12	66.08	67.44	
12	65.00	70.21	2.07
12	63.33	72.50	
$\bar{x}$	**64.80**	70.05	
14	37.14	76.19	
14	38.57	69.56	3.32
$\bar{x}$	**37.86**	72.88	
17	54.00	75.68	
17	54.00	74.36	
17	54.00	63.16	
17	37.65	73.6	5.22
17	37.65	80.64	
17	35.88	74.08	
$\bar{x}$	**45.53**	73.59	
18	34.44	66.67	0
$\bar{x}$	**34.44**	66.67	
63	15.87	75.00	0
$\bar{x}$	**15.87**	75.00	
67	15.82	70.40	0
$\bar{x}$	**15.82**	70.40	
106	13.40	71.95	
106	13.40	69.69	1.22
106	13.21	69.13	
$\bar{x}$	**13.27**	70.26	
112	8.64	72.33	0
$\bar{x}$	**8.64**	72.33	
115	7.19	71.80	
115	6.96	71.87	0.41
115	6.96	70.97	
$\bar{x}$	**7.04**	71.55	

Table 3. Number of cycles and number of units in a series.

No	Cycle no.	unit/ser	$\bar{t}_{pcu}$, unit/ser	$\bar{t}_p$, %	SD_{tp}	log (unit/ser)
1	2	9	53.33	66.21	0.99	0.954
2	3	10	61.87	64.77	5.64	1.000
3	3	12	64.80	70.05	2.07	1.079
4	2	14	37.86	72.88	3.32	1.146
5	6	17	45.53	73.59	5.22	1.230
6	1	18	34.44	66.67	0.00	1.255
7	1	63	15.87	75.00	0.00	1.799
8	1	67	15.82	70.40	0.00	1.826
9	3	106	13.27	70.26	1.22	2.021
10	1	112	8.64	72.33	0.00	2.049
11	3	115	7.04	71.55	0.41	2.061
$\bar{\bar{t}}_p$, %				70.53		

Figure 5. *Moving average values of the production time* $\bar{t}_p$ *and the mean production cycle in the series* $\bar{t}_{pcu}$.

the stratified standard deviation is given by the formula:

$$\sigma' = \sqrt{SD^2 + \sigma^2} \qquad (2)$$

where is :

$$\sigma^2 = \frac{\sum\limits_{j=1}^{l}\left(\bar{t}_p - \bar{\bar{t}}_p\right)^2 f_i}{N} \qquad (3)$$

$$\overline{SD}^2 = \frac{\sum\limits_{j=1}^{l} SD_j^2 f_i}{N} \qquad (4)$$

$$\overline{SD}^2 = \frac{0.99\cdot2 + 5.64\cdot3 + ... + 0.41^2\cdot3}{26} = 11.56$$

$\sigma^2 = 9.45$

$\sigma' = \sqrt{11.56 + 9.45} = \sqrt{21.01} = 4.584$

$SD_p < \sigma'$; $SD_p = 3.4$; $\sigma' = 4.584$.

SD is not the stratified standard deviation of all the elements of the production time given in *Table 1*. The amounts of control limits are the following:

$$CC = \bar{\bar{t}}_p \pm 3\sigma'\cdot\bar{\bar{t}}_p =$$

$$= 70.56 \pm 3 \cdot 0.04584 \cdot 70.56$$

$$AC = 77.14\%, BC = 63.92\%.$$

The mean value for all groups obtained using formula (1) is $\bar{t}_p = 70.53\%$, ranging from the bottom control limit BC = 63.92% to the upper control limit AC = 77.14%. The $SD_p < \sigma'$ (3.4 < 4.584), which means that the stratification of groups was unsuccessful.

Moving $\bar{t}_{pcu}$ can be approximated by the formula:

$$\bar{t}_{pcu} = c + \frac{b}{\log n} \qquad (5)$$

■ Conclusion

The production cycle is the most significant technical-technological indicator in production, in general, as well as in the textile industry, and it is necessary to steadily monitor and reduce it. In our experiment, the textile factory has been proven that the original stochastic model of monitoring elements of the production cycle time is applicable. Shortening the production cycle can be influenced by the ancillary elements of time. The movement of elements of time can be monitored through the establishment of mathematical control limits, where they are seen as a process. The production cycle mean value for the groups formed according to the number of units in a series t_{pcu} moves along a hyperbolic function which has asymptote c, $\bar{t}_{pcu} = c + \frac{b}{\log n}$, and mathematically these groups do not behave as strata, which means they are not linked to deterministic factors of technology and the number of units/series.

A large number of companies in Serbia, especially the textile industry, are faced with production problems. Often these include insufficient capacity, outdated equipment and technologies or delays in production. The textile industry in Serbia is faced with low productivity caused by a bad economic environment, a small number of employees, but also sufficiently

long mastered and controlled production cycles. One of the ways of monitoring and modelling to determine elements of the production cycle time is the stochastic model that we implemented in our study. The insights we obtained from randomly generated problems appears to agree with the common wisdom of manufacturing practice in general. Based on our experimental investigations it has been proven that in the practice of Serbian small and medium-sized enterprises with serial production in the textile industry, it is possible to design and apply a very simple but accurate enough stochastic model - a method to determine elements of the working cycle time, and in this way optimise the duration of the production cycle time. The results furnish empirical findings that provide insights into a number of managerial issues surrounding investment decisions in product-specific cycle time improvements and reductions, together with process redesigns.

A proposal for further investigations includes method application and control in other types of production, such as assembly processes, processes in the metalworking industry, etc. Further analysis should also be oriented to the issue of transport time as well as further division of time components of other stoppages to segregate the most significant ones. We are currently exploring extensions in this sense.

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INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

LABORATORY OF BIODEGRADATION

The Laboratory of Biodegradation operates within the structure of the Institute of Biopolymers and Chemical Fibres. It is a modern laboratory with a certificate of accreditation according to Standard PN-EN/ISO/IEC-17025: 2005 (a quality system) bestowed by the Polish Accreditation Centre (PCA). The laboratory works at a global level and can cooperate with many institutions that produce, process and investigate polymeric materials. Thanks to its modern equipment, the Laboratory of Biodegradation can maintain cooperation with Polish and foreign research centers as well as manufacturers and be helpful in assessing the biodegradability of polymeric materials and textiles.

The Laboratory of Biodegradation assesses the susceptibility of polymeric and textile materials to biological degradation caused by microorganisms occurring in the natural environment (soil, compost and water medium). The testing of biodegradation is carried out in oxygen using innovative methods like respirometric testing with the continuous reading of the CO_2 delivered. The laboratory's modern MICRO-OXYMAX RESPIROMETER is used for carrying out tests in accordance with International Standards.

The methodology of biodegradability testing has been prepared on the basis of the following standards:

■ **testing in aqueous medium:** 'Determination of the ultimate aerobic biodegrability of plastic materials and textiles in an aqueous medium. A method of analysing the carbon dioxide evolved' (PN-EN ISO 14 852: 2007, and PN-EN ISO 8192: 2007)

■ **testing in compost medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated composting conditions in a laboratory-scale test. A method of determining the weight loss' (PN-EN ISO 20 200: 2007, PN-EN ISO 14 045: 2005, and PN-EN ISO 14 806: 2010)

■ **testing in soil medium:** 'Determination of the degree of disintergation of plastic materials and textiles under simulated soil conditions in a laboratory-scale test. A method of determining the weight loss" (PN-EN ISO 11 266: 1997, PN-EN ISO 11 721-1: 2002, and PN-EN ISO 11 721-2: 2002).

The following methods are applied in the assessment of biodegradation: gel chromatography (GPC), infrared spectroscopy (IR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

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