THE ELEMENTS OF PRODUCTION CYCLE TIME: THE CASES RELATED TO A STOCHASTIC MODEL

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ABSTRACT
The most important organizational-technical indicators of production successfulness are the level of capacity utilization and the production cycle. The aim of this paper is presenting a stochastic model to determine the elements of production cycle time, according to the results obtained for three characteristic Serbian enterprises. The originality of the model is based on the idea of using a work sampling method to monitor the production cycle, as one of the most significant indicators of production effectiveness and efficiency. It has been experimentally proved that for a corresponding representative set, the elements of working time range according to normal distribution law. Dynamically viewed, the mean value calculations can be used to establish control limits on three standard deviations for the individual elements of working time and thus to master the process.

KEY WORDS: production cycle, work sampling, production time

INTRODUCTION
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. The goal is to reduce the total production cycle time, especially that associated with different types of stoppage and the optimization of lead time and machine time within the sphere of machine capacity utilization. Our investigation is directed at designing an original method for monitoring the production cycle and its time elements by using an adapted Tippett's (according to Barnes, R., 1957) stochastic work sampling method. Tippet's method 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.
The indispensible modification of the method presented by Klarin el al. (2000) aims to explain and justify both the necessity and importance of using the shift level of the utilization of 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 utilization in a convenient way with accurate results. On the other hand, on the basis of Klarin el al. (2000), Elnekave & Gilad (2006) propose a digital video-based approach to enhance work measurement and analysis by facilitating the generation of rapid time standards, which serves as a computerized 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 utilization applied in the processing industry such as cement production may also be used in the metalworking industry which has a high level of capacity utilization. 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 (Klarin et al., 2010). 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 by far less present in the literature.

In (Niebel, 1980) an experimental example illustrates the determination of the elements of production cycle time, showing that production cycle C is divided into only three elements of cycle time, C = 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).

In paper by Agrawal et al. (2000) an approach to improve MRP-based production planning by means of targeting minimal product cycle times is presented. A number of works (Giri and Yun, 2005; Tzu-Hsien, 2009) consider the impact of machine breakdown on production cycle time, while Barbiroli & Raggi (2003) studied technical and economic performances related to innovations in the production cycle environment. An inventory model is linked with production cycle optimization in (Kun-Jen et al., 2009), whereas paper (Kodek and Krisper, 2004) gives an optimal algorithm for minimizing production cycle time for assembly lines, using linear mathematical programming which requires extensive calculations.

Models based on stochastic functions, or instantaneous observation methods (work sampling), have not been encountered in literature despite their ability to offer a simpler but accurate enough solution to the problem.

A STOCHASTIC MODEL TO DETERMINE THE ELEMENTS OF PRODUCTION CYCLE TIME – THE CASES

For the purpose of analysis, the production cycle is essentially divided into production time – t_p and non-production time t_{np} (Čala et al., 2011). The most common division of production cycle time in literature is presented in Fig. 1 (Čala et al., 2011).

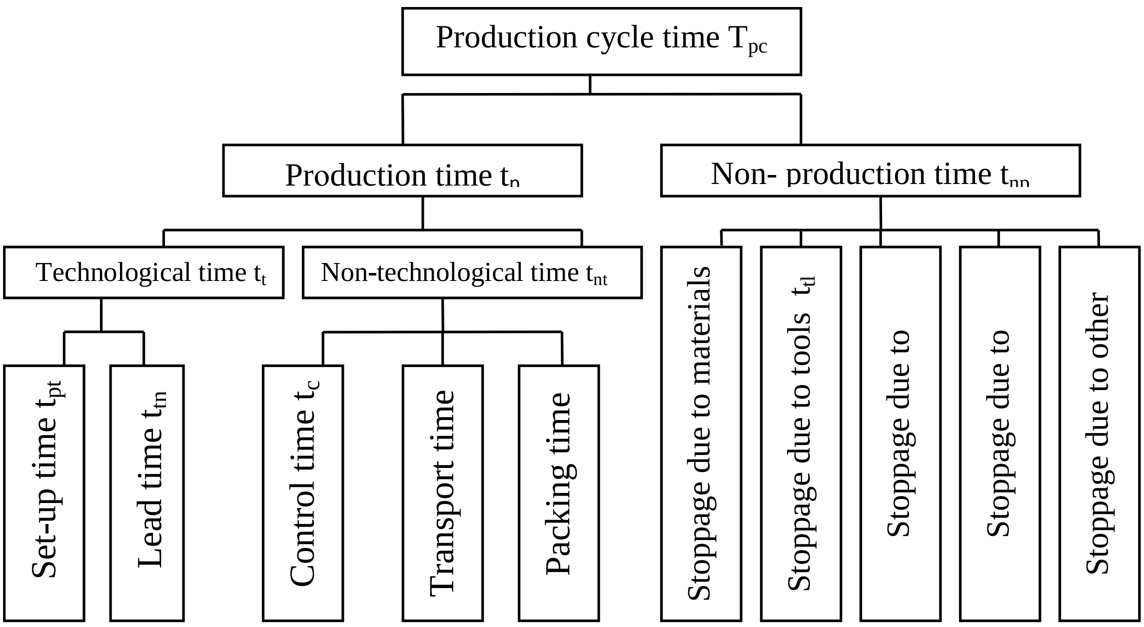

Fig. 1 Production cycle`s elements

The first most extensive experiment concerns an enterprise owned by a big German firm engaged in manufacturing car components. Screenings were performed from September 19, 2011 to November 4, 2011. Monitoring included 47 cycles of different series sizes (4 – 10 pieces) and the time duration ranged from the shortest (240 min) to the longest (420 min), with 10 - 30 instantaneous observations. The results of screening are shown in Tabs 1, 2 and 3 where only the first 5 cycles of 47 are given as well as the total result for all 47 cycles. The results are displayed per number of instantaneous observations of working time elements, the percentage of their participation in their total duration and per element of working time, as well as the total average values and standard deviations – SD.

Table 1 Production cycle`s elements by frequency of occurrence

Date	N_o of observations	Time		Production time					Non-production time					N_o of pieces
		Start	End	t_{pt}	t_{tn}	t_c	t_{tr}	t_{pk}	t_{mr}	t_{tl}	t_o	t_b	t_{ot}	
19.09.2011.	26	8:30	13:00	3	9	3	1	2	2		2	1	2	7
26.09.2011.	18	8:05	13:30	2	5	2	4	3	1				1	10
23.09.2011.	21								21					canceled
19.09.2011.	31	8:30	13:00	2	9	3	3	3	2	1	2	1	4	7
19.09.2011.	22	8:20	13:10	2	7	4	1	3	1		2		2	8
….														
N														
Σ	932			100	229	118	142	99	47	3	25	15	154	

Table 2 Production cycle`s elements by percentages of elements

Date	T_{pc}	Time		Production time					Non-production time					N_o of pieces	T_{pc} (min/piece)
		Start	End	t_{pt}	t_{tn}	t_c	t_{tr}	t_{pk}	t_{mr}	t_{tl}	t_o	t_b	t_{ot}		
19.09.2011.	270	8:30	13:00	12	36	12	4	8	8		8	4	8	7	38.6
26.09.2011.	325	8:05	13:30	11.11	27.78	11.11	22.22	16.67	5.56					10	32.5
23.09.2011.	310					10			100					canceled	0
19.09.2011.	270	8:30	13:00	6.7	30	18.18	10	10	6.7	3.3	6.7	3.3	13.3	7	38.6
19.09.2011.	290	8:20	13:10	9.09	31.82	31.82	4.55	13.64	4.55					8	36.3
….															
η	100			0.107	0.246	0.127	0.152	0.106	0.05	0.003	0.27	0.016	0.165		

Table 3 Production cycle`s elements by time duration

Date	T_{pc}	Time		Production time					Non-production time					N_o of pieces	T_{pc} (min/piece)
		Start	End	t_{pt}	t_{tn}	t_c	t_{tr}	t_{pk}	t_{mr}	t_{tl}	t_o	t_b	t_{ot}		
19.09.2011.	270	8:30	13:00	32	97	32	11	22	22		22	11	22	7	38.6
26.09.2011.	325	8:05	13:30	36	90	36	72	54	18				18	10	32.5
23.09.2011.	310					18			310					canceled	0
19.09.2011.	270	8:30	13:00	18	81	26	27	27	18	9	18	9	36	7	38.6
19.09.2011.	290	8:20	13:10	26	92	53	13	40	13		26		26	8	36.3
….															
Σ	15293			1632	3762	1939	2413	1709	704	40	376	271	2465		

It is evident from the table 1 that there were 932 observations in total, while the total time for all cycles amounts to 15 293 min. The average production cycle time - t_{pc} is 325 min and the average production cycle time per piece t_{pc} is 56.2 min. The results are also presented by diagrams in Figs 3, 4 and 5.

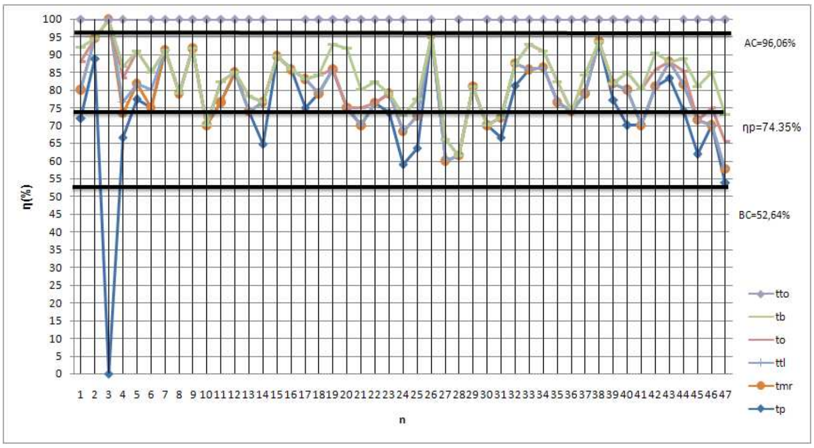

Fig. 3 Diagram showing the levels of cycle time elements for enterprise 1

The diagram in Fig. 3 shows that the mean level is μ_{tpt} = t_p /(t_{pt}+t_m+t_c+t_{tr}+t_{pk}) = 0.7435, while the control limits amount to *CC* = μ_{tpt} ±3·*SD*·μ_{tpt}=0.7435±3x0.7435x0.09735, AC=0.9606 , BC=0.5264, The mean levels of working time elements μ_{tpt}, μ_{tm}, μ_{tc}, μ_{tr}, μ_{pk} have relatively stable rates per individual cycle, i.e. when their sum total is higher, the individual levels are higher. The control time level is never higher on account of the machine time level. If we observe μ_{tm} within μ_{tp} we see that μ_{tm} has the highest values compared to the other elements and that its level behaved within the range of normal distribution law, with an approximate mean of μ_{tm}=0.244.

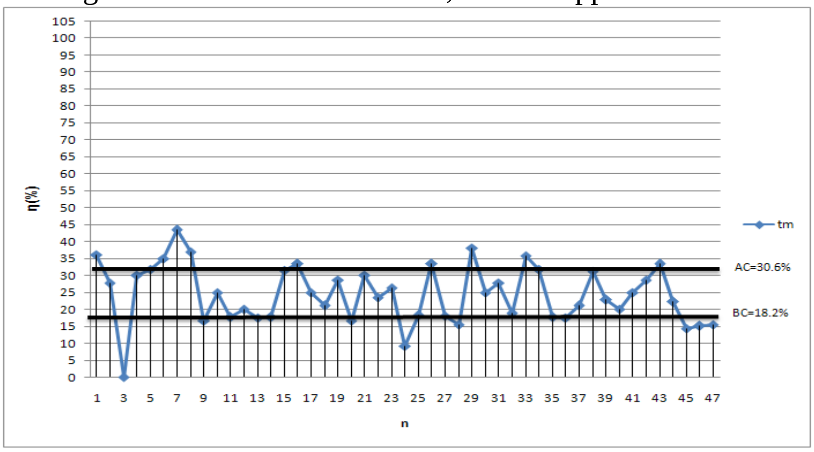

Fig. 4 Machine time level for enterprise 1

However, the control limits for this level cut too large a number of the μ_{tmi} points of this level in Fig. 4. From the results shown it is evident that the process thus presented has not been mastered, but for relatively narrow limits (AC=0.306; BC=0.182) only five points (values of μ_{tm}) have larger deviations.

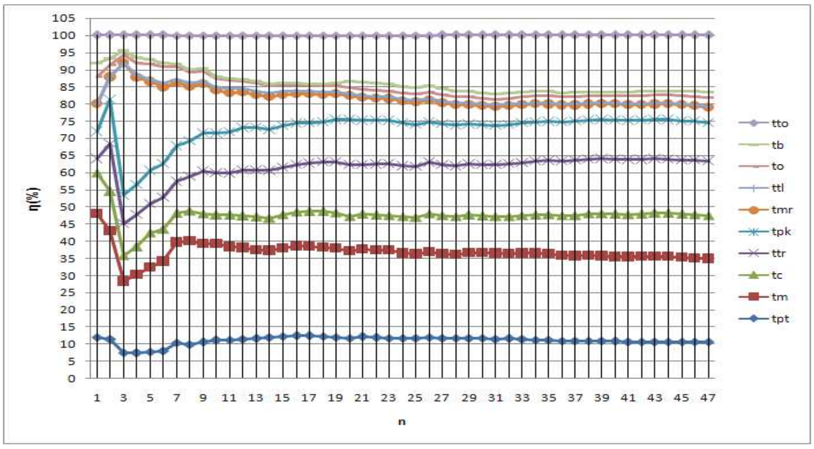

Fig. 5 Cumulative production time level for enterprise 1

The cumulative value of μ_{tm} approaches the mean value very quickly, which also indicates the stability of this level rate (Fig. 5). Levels of cycle time have normal distribution, since χ^2=3.070404 and χ_1^2=55.76, e.g. $\chi^2 < \chi_1^{2.}$

It is inferred that to master the process in metalworking industry conditions with a cycle designed for one shift duration and a corresponding series, it is necessary to make approximately 50 daily screenings and 1000 instantaneous observations, and the production cycle time is a stochastic variable that ranges along normal distance. This example shows that the hypothesis that it is possible to apply a work sampling method in monitoring the production cycle has been proved, which represents an original approach to solving this problem.

The second experiment is related to a plant that produces military and firemen clothing. The results of cycle monitoring are represented by diagrams only in Figs 6 and 7.

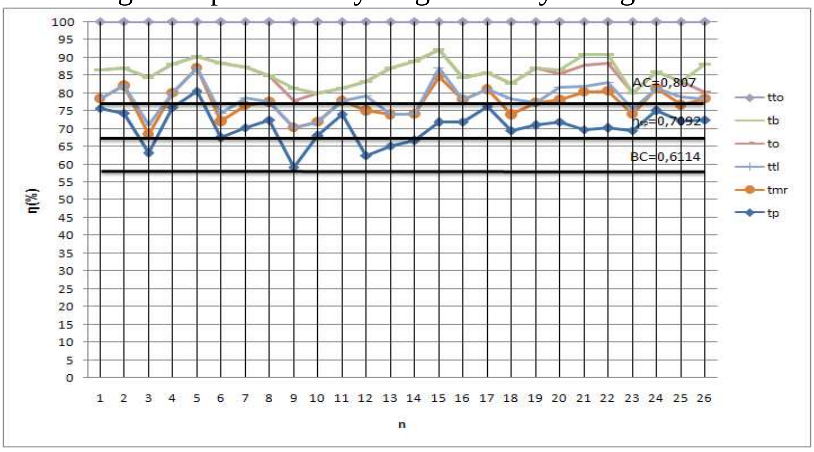

Fig. 6 Diagram showing the levels of cycle time elements for enterprise 2

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 pieces, with time durations from 355 min for the shortest to 3700 min for the longest, while instantaneous observations ranged from 21 – 90.

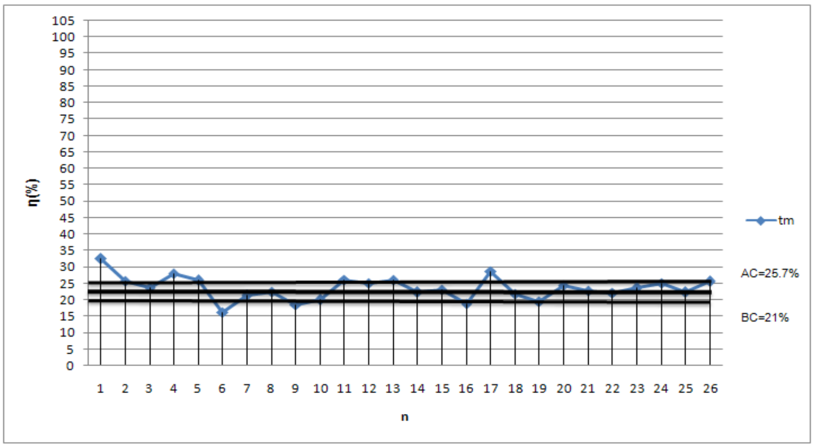

Fig. 7 Machine time level for enterprise 2

It is noticeable from the diagrams in Figs 6 and 7 that the rates of time element level in the production cycle are very similar to those from the first enterprise (Figs 3, 4, 5). Despite the significantly lower number of production cycles monitored for this enterprise (26), the stochastic variable of 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 μ_{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 μ_{tpt} = 0.1167; μ_{tm} = 0.2334; μ_{tc} = 0.1454; μ_{tr} = 0.0871 and μ_{tpk} = 0.1266; for production time and the sum of times respectively, μ_{tp} = 0.7092 and μ_{tmr} = 0.0664; μ_{tl} = 0.0135; μ_{to} = 0.0637; μ_{tb} = 0.009 and μ_{tto} = 0.1382 for non-production time, or the sum of times μ_{tnp}= 0.2908.

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

Considering the results given above, the analysis should be directed towards the problem of the elements of 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 experiment design and repeated screenings should focus on a possible size and frequency and whether the designed (anticipated) stoppages per type will emerge at all. The technical level of machine time elements μ_{tmi} deviates very little from the control limits (Fig. 7) which for μ_{tm} = 0.2334 amount to: AC = 0.2570 and BC = 0.2097.

The third characteristic experiment was carried out in a plant for manufacturing diesel engine parts which used to be a cooperating company for the plant producing 40 000 agricultural tractors annually before the onset of the transition process in Serbia. Today, the latter plant produces only 1000 tractors, while the former, in addition to diesel engine parts, also produces spare parts for the previously manufactured tractors. Monitoring involved the production cycle of injectors for high-pressure pumps (Bosch pumps). The screening period was from May 16, 2011 to June 8, 2011 and the results are presented by a diagram in Fig. 8.

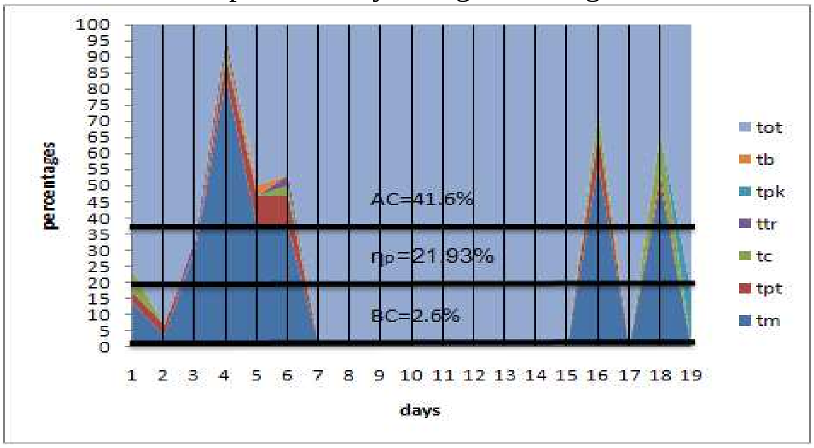

Fig. 8 Diagram showing the levels of cycle time elements for enterprise 3

The duration of the screening was 19 days and covered only one shift as the plant works on a single shift system. During that period two series of products were launched, the first with 1690 pieces on May 16, 2011 and the second with 1100 pieces on June 8, 2011. The biggest stoppages during intensive production time in the production cycle monitoring of the two series were due to the wait for the next machining operation, and from June 7, 2011 to June 15, 2011 the production process was not launched for organizational reasons. Despite being certified for ISO 9000 by RÜVCERT from Austria, the production organizational level is very low

It is evident from the diagram in Fig. 8 that the control limits range from AC = 0.416 to BC = 0.26, and the mean value of production time is μ_{p3} = 0.2193. Within the control limits, there are only two values of μ_p for the first and third day of screening making the process unstable. However, irrespective of the given conditions, the diagram provides valuable practical data, so that the production management can make efforts to improve production and shorten the production cycle, for example, by reducing the number of pieces per series.

DISCUSSIONS AND CONCLUSION REMARKS

It has been proved that it is possible to master the process by applying a modified work sampling method for a corresponding representative set of working time elements, whose range along normal distribution law, dynamically viewed, is enabled using mean value calculations to establish control limits on three standard deviations for some individual working time elements.

The method proposed is specific because the monitoring of machine operation is not performed per shift and day, but through production cycle elements. This method application in production practice shows that under conditions of organized production with a higher level of production time (0.5 – 1), for a sufficient number of production cycles, the cycles range according to normal distribution law and within the control limits determined by three standard deviations. The oscillations and means of the levels of all working time and stoppage elements facilitate a comparison of production over time or in similar type enterprises and thus enable a time reduction for the following cycles.

Based on our experimental investigations it has been proved that in the practice of small and medium-sized enterprises with serial production it is possible to design and apply a very simple but accurate enough stochastic model to determine the elements of working cycle time and in this way optimize the duration of production cycle time.

It is proposed that further investigations should focus on the application and testing of the model in other types of production, for example, assembly and the like. Further analysis should be directed at the problem of reducing the elements of transport time, and the further division of time elements in other types of stoppage so that the most important elements within time are segregated.

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