Throughput time analysis in apparel manufacturing

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REZUMAT – ABSTRACT

Analiza timpului de producție în fabricarea confecțiilor

Timpul de producție este investigat pentru linia de asamblare a cămășilor pentru bărbați în companiile producătoare de confecții. Comparația se face între timpul calculat teoretic și cel real. Timpul de producție teoretic se calculează prin timpii de întârziere la pornire, timpii de întârziere și timpii de circulație a semifabricatelor între perechile succesive de operațiuni ale traseului critic ale fluxului de productie. Se evaluează influența mărimii lotului de semifabricate asupra timpului de producție și a procesului de lucru. Comparația dintre timpul estimat și cel real, arată că timpul estimat a fost cu 10% mai mic decât cel experimental. Evaluarea efectului dimensiunii lotului de semifabricate pe parcursul întregului timp de producție și al procesului de lucru demonstrează că mărimea acestuia, poate avea o mare influență asupra flexibilității și competitivității companiei producătoare de confecții.

Cuvinte-cheie: inventar în timpul procesului, mărimea lotului, proces de lucru, linie de asamblare

Throughput time analysis in apparel manufacturing

Throughput time is investigated for men's shirt assembly line in garment manufacturing company. The comparison is made between theoretically calculated and actual throughput time. The theoretical throughput time is calculated via starting lag times, lag times and bundle times between succeeding pairs of operations of the product flow process grid critical path. The influence of bundle size on throughput time and work in process is evaluated. The comparison of predicted and actual throughput time shows that predicted time was 10% lesser than experimental one. The evaluation of bundle size effect on throughout time and work in process shows that the bundle size can have great influence on company flexibility and competiveness.

Keywords: inventory in process time, bundle size, work in process, assembly line

INTRODUCTION

Works in process and throughput time in apparel manufacturing processes are important performance indicators relating directly to plant productivity. These parameters, significant to all industrial manufacturing processes, are especially critical in apparel manufacturing, an industry marked by seasonal product lines and the necessity for rapid changes in colour, style and material. Rapid throughput time can often be the vital competitive edge in a successful manufacturing business [1]. In order to respond promptly to customer demands, it is of critical importance to shorten lead times. It was shown that application of lean manufacturing technique shortens work in process and positively affects manufacturing cost and lead times [2]. To shorten lead times, and increase flexibility, some apparel companies, besides converting to new manufacturing systems also make use of IT technology [3]. There are number of factors affecting throughput time and work in process, and companies use various manual techniques or software for their calculation. Garment industry often confronts a major issue of very high lead times despites it short life cycle and unpredictable demand [4]. Buying cycle for the garment products starts generally a year in advance and the garment companies place and process their manufacturing orders 6 months to one year ahead of the coming seasons when the product is actually required and should be available in the stores for the sales [3, 5]. Higher lead time reduces the responsiveness and increases the chances of high inventory holding and therefore, problem of overstocking. Time-based competition focuses on time reduction; it also accomplishes substantial improvements in costs, quality, and productivity. Blackburn [6] and Stalk and Hout [7], describe case studies where manufacturing firms which managed to compress lead time by redesigning their business processes, achieved higher productivity, increased market share, reduced risk level, and improved customer service. Time-based manufacturing is a weapon for time based competitors. Time-based manufacturers implement a set of work practices designed to reduce throughput time. A literature review identified seven key practices including: shop-floor employee involvement in problem solving, reengineering setups, cellular manufacturing, quality improvement efforts, preventive maintenance, dependable suppliers, and pull production approaches [8–10]. Many of these time-based practices are key elements of just-in-time (JIT) philosophy as defined by Monden [11]. In fact, Abegglen and Stalk [12] observed that some JIT innovators became the first time-based competitors as their emphasis on speed boost their skills in time reduction throughout the value-delivery system. Case studies illustrate how some manufacturing firms have applied these seven time-based practices to cut response time and enhance competitiveness [6, 13]. However, large-scale empirical studies that investigate the relationships between these manufacturing practices and throughput time are unavailable. Many firms struggle in their attempts to reduce manufacturing throughput time, while the factor changes that can reduce manufacturing throughput time are not always understood [14]. While manufacturing throughput time reduction can indeed be a overwhelming task due to the many factors that influence it and their complex interactions, there are basic principles that, when applied correctly, can be used to reduce manufacturing throughput time. To apply the principles correctly, the basic factors that determine manufacturing throughput time must be clearly understood. The existence of a certainly determined number of steps in the textile manufacturing process development makes adequate to approach the optimization of this process with stochastic procedures theory. In that case, some authors design a suitable Markov chain that shapes the production and they show how it can be applied for estimating manufacturing times. At the same time, they describe the computer software for processing practical numerical data from specific cases [15].

The paper investigates possibilities of predicting throughput time in shirt manufacturing company and compares predicted and the actual throughput time, using starting lag time formula for calculation of throughput time. Also, the influence of bundle size on throughput time and work in process is analysed.

EXPERIMENTAL WORK

The product analyzed is a men's long sleeve dress shirt. The movement of the bundle in real production is monitored through all the critical path operations of the men's shirt flow process grid. Experimental throughput time is compared to calculated throughput time. For the calculation of throughput time for complete balanced manufacturing line, the starting lag time (further in text SLT) formula is employed [16]. SLT is the time lag which is unproductive time when the operator of the succeeding operation waits to start working since the operator on preceding operation have started working on bundle. Along with numerical calculation, the graphical block method for the calculation of the starting lag time is also applied. Using starting lag time (SLT) equations, throughput time and work in process, is calculated for various bundle sizes. SLT concept assumes production line to work with minimum work in process needed to prevent creation of bottlenecks, i.e. the situations where succeeding operator must wait the preceding one, to finish the bundle before transferring job to next operation. Depending on the defining operations on time level in flow process grid, there are 4 types of job sequence relationship possible situations and respective SLT calculations:

1. Situation where smaller number of operators supply larger one:

$$SLT = LTU\ (n_1 + n_2 - 1) \qquad (1)$$

   where: n_1 and n_2 are the number of operators in first and successive job respectively, LTU – lag time unit – represents the ratio between bundle time and the number of operators.
2. Situation where larger group of operators supply smaller one: $SLT = LTU\ (n_1 + n_2 - 1)$.
3. Situation where the number of operators in two successive jobs is equal: SLT is equal to bundle time.
4. Situation where the ratio between numbers of operators in two successive jobs is whole integer which yields a fraction composed of two whole numbers where one of which is 1: SLT is equal to larger bundle time.

Before starting calculation of SLT, we must define the critical path or the longest SLT path containing sequential operations on the product flow process grid which have largest time sum when moving the job through all time levels of flow process grid. This path will determine throughput time through assembly line. Minimum throughput time is calculated by summing the SLT values of all the pairs of successive jobs of the longest SLT path in flow process grid and adding the bundle time of the critical path last operation. Work in process is calculated when inventory in process time is multiplied by line output per hour.

RESULTS AND DISCUSSION

As suggested by Solinger [16], if we want technological map in the process to be an effective tool for planning, it must be designed with the concept of mathematical graphics with the formation of networks in the Y-axis and X-axis, where Y-axis represents the timeline of the production system while the length of the spatial line the production process and layout of equipment. This timeline's measured, represents the temporal relationship that exists between the workplaces and places for temporary storage during production. Y-axis also represents the longitudinal space connection between different workplaces and places for temporary storage. X-axis also represents the lateral connection between workplaces and places for temporary storage. The work flows from the bottom of the graph, (the first level of time i.e. initial), to the upper part of the graphics till the final level of the time (last operation).

Figure 1 shows a flow network of production process of men's shirts for a bundle size of 50 pieces. The assembly of the men's shirt is done through one main and 5 subassembly lines. For this case, the longest SLT path in flow process greed is sequence of operations in front subassembly line from A1 to F10. This is so because the time for this job sequence has longest times sum of all the parallel paths.

Total production time is equal to the sum of all time at the level of the Y-axis on the critical path. Time in each level is equal to the time required to produce a certain quantity of production units. Production equipment and workers at the workplace in the graph will be equal to those which are necessary to produce the required amount per unit time at a given level.

	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators	Operation cod	Bandle time, min	Operators
27							F10	7.0	1									
26							F7, F8, F9	21.0	3									
25							F6	7.0	1									
24							F3, F4, F5	96.0	14									
23							F2	42.0	6									
22							F1	14.0	2									
21							E14	7.0	1									
20							E13	35.0	5									
19							E12	70.0	10									
18							E11	7.0	1									
17							E10	56.0	8									
16							E9	70.0	10							B10, B11	14.0	2
15							E8	35.0	5	C13	14.0	2				B9	7.0	1
14							E7	42.0	6	C12	7.0	1				B8	7.0	1
13							E6	42.0	6	C11	21.0	3				B7	14.0	2
12							E5	56.0	8	C10	14.0	2				B6	14.0	2
11	D9	14.0	2				E4	7.0	1	C8, C9	56.0	8				B5	21.0	3
10	D8	14.0	2				E3	21.0	3	C7	7.0	1	C1, C2	14.0	2	B4	21.0	3
9	D7	56.0	8				E2	28.0	4	C6	28.0	4				B3	14.0	2
8	D6	14.0	2	D4	28.0	4	E1	35.0	5	C4, C5	28.0	4				B2	7.0	1
7	D5	21.0	3	D3	21.0	3	A10	21.0	3	C3	21.0	3				B1	14.0	2
6				D2	7.0	1	A9	21.0	3									
5				D1	14.0	2	A8	56.0	8									
4				A7	7.0	1	A4	21.0	3									
3				A6	14.0	2	A3	7.0	1									
2				A5	7.0	1	A2	35.0	5									
1							A1	7.0	1									
	SLEEVES			BACK, JOKE			FRONT			COLLAR			COLLAR STAND			CUFFS		

Fig. 1. Men`s shirt flow process grid critical path

The starting lag time (SLT), for all successive jobs on the critical path are depicted in table 1. Starting lag time consists of bundle time and lag time. Lag time depends on a succeeding operator ratio. In our case, every operation has from 1 to 14 operators. So there are more possible ratios between numbers of succeeding operators in a production line. If the number of operators are equal, or when the succeeding operation has one operator then the starting lag time is equal to bundle time.

Figure 2 represents calculation of lag time by graphical block method for the pairs of successive operation A4 and A8. The horizontal axis represents time to complete the bundle, while vertical axis represents the number of complete bundles. The lag time by this method is obtained by overlapping blocks of two successive operations. We see that 8 operators (on operation A8) should wait 9 bundles to be produced from previous three operators (operation A4) to start working. However, after 8 operators on A8 finish the first 8 bundles and want to proceed with work, we see graphically that there are only 6 finished bundles i.e. 2 less than required. So, succeeding operators should wait additional 7 minutes to have 8 bundles prepared for 8 operators. Graphically, it is the part where two blocks overlap. Block overlapping means that the second operation A8 should start 7 minutes later after enough number of bundles have been produced (9) on operation from the previous operation

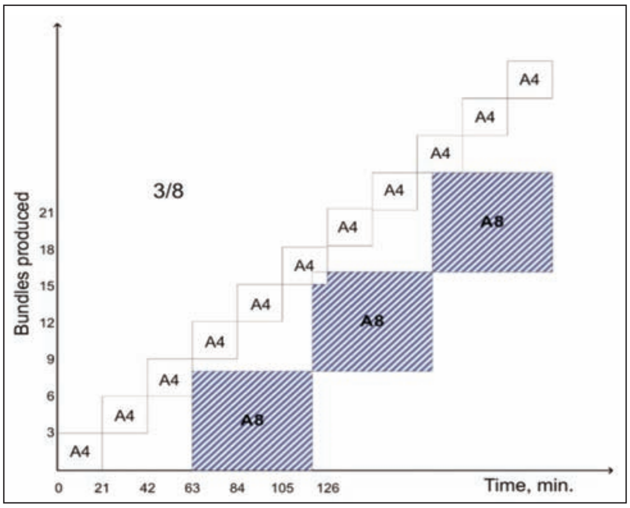

Fig. 2. Graphical calculation of lag time between operations A4 (3 operators) and A8 (8 operators)

Table 1

CALCULATION OF STARTING LAG TIME FOR CRITICAL PATH OPERATIONS FOR A BUNDLE SIZE 50							
Vertical FPG level	**Operation code**	**Operation name**	**Num. of operators**	**t_1, min**	**LT, min**	**BT, min**	**SLT, min**
1	A1	Crease left front part	1	7	0	0	0
2	A2	Topstitch left front part	5	35	0	35	35
3	A3	Crase right front part	1	7	0	35	35
4	A4	Topstitch right front part	3	21	0	21	21
5	A8	Attach pocket	8	56	7	63	70
6	A9	Sew 7 buttonholes on left front	3	21	14	56	70
7	A10	Cutt of neck opening and bottom excess	3	21	0	21	21
8	E1	Sew 8 buttons to front	7	49	0	63	63
9	E2	Close sholder seams	4	28	21	49	70
10	E3	Topstitch shoulred seams	3	21	14	28	42
11	E4	Cut off armhole excess	1	7	0	21	21
12	E5	Attach sleeves	8	56	0	56	56
13	E6	Topstitch sleeves	6	42	35	56	91
14	E7	Close side and sleeve seams	6	42	0	42	42
15	E8	Sew bottom hem	5	35	28	42	70
16	E9	Sew and topstitch collar stand	10	70	0	70	70
17	E10	Sew on cuffs	8	56	49	70	119
18	E11	Sew button to collar stand	1	7	0	56	56
19	E12	Cleaning threads	10	70	0	70	70
20	E13	Shirt inspeciton	5	35	0	70	70
21	E14	Cleaning threads by vacuum machine	1	7	0	35	35
22	F1	Put on and out shirt from vertomat doll	2	14	0	14	14
23	F2	Button up and ajdust shirt	6	42	0	42	42
24	F3, F4, F5	Fold and pack shirt	14	98	7	126	133
25	F6	Shirt control	1	7	0	98	98
26	F7, F8, F9	Pack and insert labels	3	21	0	21	21
27	F10	Put shirt in box	1	7	0	21	21
				∑	1281	175	**1456**

Codes: t_1 – time for production of 50 pieces bundle

(A4), in order to carry on operations without further waiting. These 7 minutes is actually the lag time between two operations.

Figure 3 represents graphically lag time calculation where 2 operators on operation F1 feed 6 operators on operation F2. Since the ratio of the number in preceding and succeeding operation is whole integer the lag time is zero. The starting lag time is just the bundle time. The 6 operators on F2 wait 2 operators on preceding operation to produce 6 bundles to start working and will not have to wait for the bundle till the end.

Throughput time is monitored for a bundle of size 50 in real production. The periods when operator works on bundle (bundle time) or waits for a job (waiting time) are recorded. The graphical presentation of theoretical throughput time for the bundle of 50 pieces and practical throughput time are depicted in figure 4 and figure 5 respectively. The theoretical throughput time is 1456 min while practical throughput time is 1617 min, so the real throughput time is greater that theoretical one.

This practical throughput time consists of 878 (bundle time) + 739 (waiting time) = 1617 min. The difference

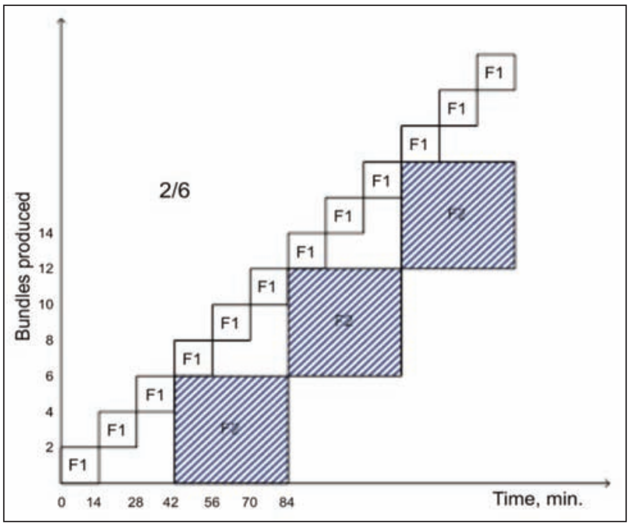

Fig. 3. Graphical calculation of lag time between operations F1 (3 operators) and F2 (6 operators)

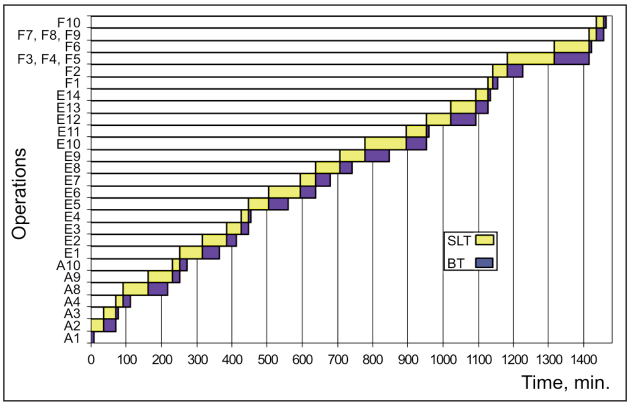

Fig. 4. Calculated throughput time in a shirt assembly line for bundle of size 50

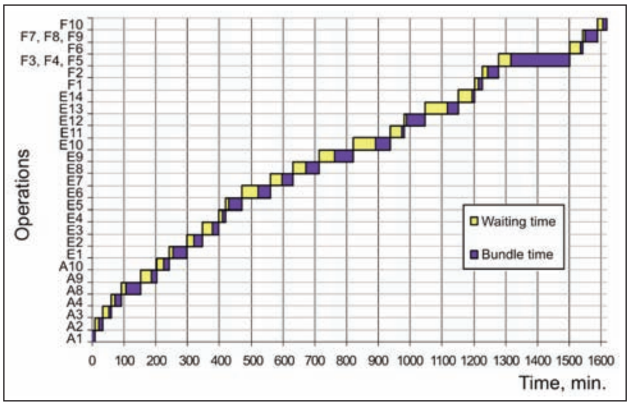

Fig. 5. Practical throughput time in a shirt manufacturing line for a bundle of size 50

is a result of factors influencing bundle time and waiting time in real production environment, such as: machine malfunctioning, insufficient output of preceding operation, bundle mixing, defects repairing etc. Bundle time in practical monitoring is 878 min i.e. 54% of the throughput time, while bundle time in theoretical calculation equals 1281 min which is 88% of the throughput time. Although the theoretical time is lesser than practical, it is pretty good approximation of the throughput time, since the difference between the two times is 161 min or 10%. The result confirms that this calculation can be used for predicting throughput time.

The figure 6 represents the lag time (waiting time) distribution from first to last operation in theoretical calculation and practical monitoring. Depending on the number of workers ratio between preceding and succeeding operation the theoretical lag time greatly time varies from 0 to 49 minutes. However, in practical monitoring we see even greater lag time variation and opposite to theoretical prediction, in actual production the lag time is observed at every operation of bundle progressing critical path.

Calculation of the throughput time and work in process is carried for the average size bundle of 10, 30, 50 and 70 pieces for a daily production capacity of 3054 pieces. The work in process is computed as the line output per hour multiplied by throughput time of

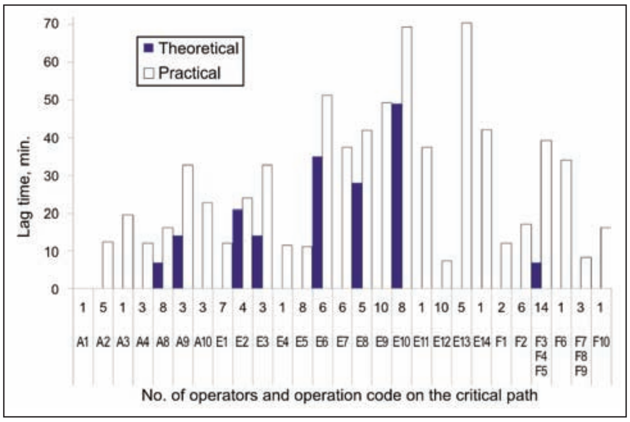

Fig. 6. Distribution of the lag time on critical path

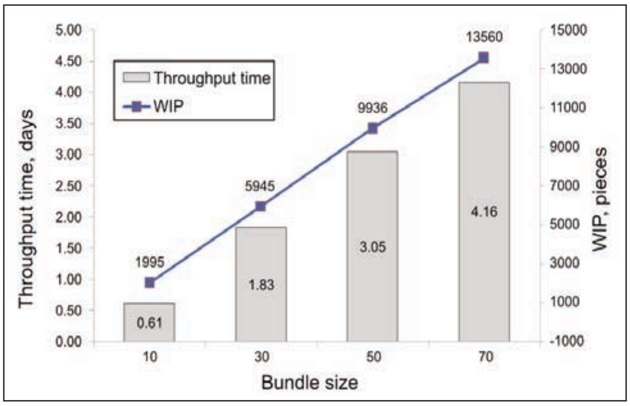

Fig. 7. Influence of bundle size on throughput time and work in process

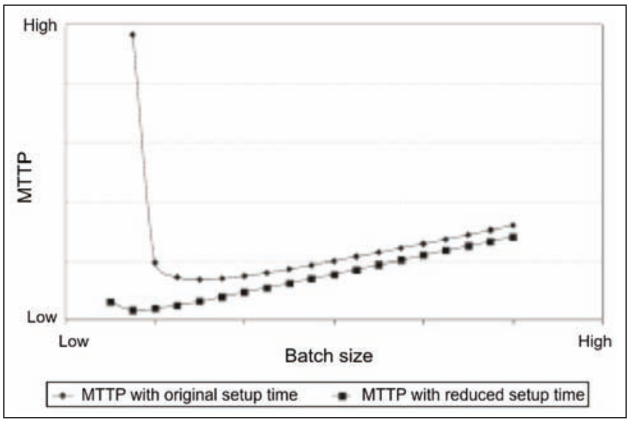

Fig. 8. Manufacturing throughput time per part (MTTP) vs. Batch Size

the bundle in production line. The results are presented in figure 7.

When bundle size increases from 10 to 70 the throughput time increases from 0.61 to 4.16 days. Consequently, the work in process increases about 7 times, from 1995 to 13560 pieces. Obviously, the smaller bundle enables faster order moving through the line and higher flexibility.

To reduce batch sizes, the plant needs to implement a policy to schedule production of smaller batches. However, if demand stays constant, smaller batch sizes increase the number of setups required. As the number of setups increases and more of the available capacity is used for setups, workstation utilization decreases, which causes queues to grow. Eventually, the increased queues negate any benefit to be obtained from batch size reduction and manufacturing throughput time per part (MTTP) increases rapidly (figure 8). Reducing setup time, as shown in the graph, would allow further batch size and MTTP reduction [1].

CONCLUSION

The throughput time in men's shirt assembly line is calculated using theoretical equations employing starting lag time formula and compared to practical throughput time obtained by monitoring bundle advancing through all the operations on assembly line critical path.

The practical throughput time for a bundle of 50 pieces was 1617 min which was longer compared to 1456 min of the theoretical one. The comparison of practical and theoretical throughput showed 10% difference suggesting that this technique can be successfully employed for predicting throughput time.

The comparison of bundle time and waiting time (lag time) percentage in throughput time showed that bundle time in real production was (54%) of throughput time, which was lesser compared to 88% of the throughput time in theoretical estimation.

The number of pieces in the bundle influences inventory in process time and work in process. For the same order quantity, the increase of the bundle size from 10 to 70 affects differences in throughput time for three and a half day and increase of the work in process from 1995 to 13560 pieces.

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