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Analysis of Modular Manufacturing System in Clothing Industry by Using Simulation

Abstract
In this study, an application of the modular system in the clothing industry by using the ProModel Simulation package is presented. The modular system was designed for a base product working on three different motion principles which differ in some way from the ones presented in literature. The performance of the system was determined in terms of productivity, operators and machine efficiency, throughput time and work in process.

Key words: *modular manufacturing, simulation, pro-model, clothing.*

Introduction

Due to higher standards of living and rapidly changing fashion trends, clothing manufacturers have encountered unexpected demands and diversity. In order to respond as fast as possible to model and quantity changes and to produce high-quality, low-cost products, the manufacturers are favouring new production systems which are based on JIT. Because of its flexibility and simplicity, modular manufacturing has begun to be implemented in some organisations. The American Apparel Manufacturing Association has defined modular manufacturing as "a contained manageable work unit of 5 to 17 people performing a measurable task. The operators are interchangeable among tasks within the group to the extent practical and incentive compensation is based on the team's output of first quality output" [1]. In a modular system, processes are grouped into a module instead of being divided into their smallest components. As a rule, fewer numbers of multi-functional operators work on the machines which are arranged in a U-line. All the operators in the group are responsible for the quality of each item that are produced in the line. The system works when a problem of quality is reached; the operators in the group have to coordinate their quality work, which leads to an increase in quality. The modular system works on the principle of pull-type production systems, in which the job order comes from the last step to previous steps. Because of this, the amount of work in process is low, even working when no inventory is possible.

Review of the literature

The modular system was first implemented at Toyota in 1978 as part of JIT, and was known in the 1980s in the West as the Toyota Sewing System. Monden gave this system a U-turn layout and claimed that the main advantage of that system was that the amount produced can easily be arranged by changing the number of operators working in the system [2]. Gilbert showed that the main advantage of the system was the low amount of the work in process [3]. In 1990, Kuler & Dewitt reached encouraging results, and claimed that it was possible to produce quality products at much lower costs. They also determined that the throughput time of the products in the system was much shorter than in conventional systems. Furthermore, the system was quite resistant to worker turnover [4].

When the working principles of the systems in literature are analysed, it is seen that various researchers worked on different systems with different motion principles. The common point of the different studies is that the researchers have preferred to analyse the system by using simulation. In 1991, Wang & Ziemke simulated a system which was working on the motion principles based on the Toyota Sewing System. In this system, the following principle is stated: the items always move forward in the system, while the operators move forward with the item and then move backward for additional work. In the Toyota system, the operator moving backward for finding a work piece can interrupt the operator if he cannot find any work piece waiting to be sewn. Wang & Ziemke found that the system showed high performance, even though the operation times of each station varied considerably among each other. They also determined that after some time the operators formed their own work patterns [1]. Schroer et al. constructed a simulation package which is suitable for use in clothing manufacturing companies. This package can simulate the system according to three principles of motion, which are the rabbit chase, the Toyota sewing system and the mixed manufacturing module. In the rabbit chase, the operator works on all machines sequentially. For the mixed manufacturing module, the researchers described the bundle and time limits which are the basis for the decision taken by the operator [5]. In 1993, Schroer & Black dealt with the modular system as manned cells and offered to use decouplers which separate and link the cell, and function as a balancing element for different operation times [6]. Black & Chen constructed linked cells in the system according to the number of workers in the system, and added decouplers through that system. They studied the effects of changing the capacity of decouplers on the system [4].

Experimental

Model description

The modular system can readily be applied in firms that mainly produce standard products. In this study, the system is designed for an apparel company producing men's, women's, and children's casual and sports wear. The sweatshirt was chosen as the base product due to the high and constant demand for this product. After establishing the base product, the operational flow for that product was determined. The operations which are conducted on the same type of machine are combined together. The standard times for each operation are determined, and the combined operations times are added to all of them. Standard deviations for each operation were taken as 10% of the operation time.

The Promodel Simulation Package was used in the modelling, which was conducted in 3 steps; define, detail and display. In the program, information about the performance parameters was collected as statistics.

Three different motion principles were designed for the modular manufacturing model. The change in system performance was analysed by changing the number of operators and the allowed stock on hand. Moreover, the bottleneck station with a high operation time was analysed, a parallel line was formed and the increase in the system performance was determined.

The motion principles

Expanded rabbit chase

This name was given to this method as it differs from the rabbit chase method which has been generally encountered in the literature. All the operators in the system are multi-functional. The operator takes the work piece from the first station and performs all the operations in sequence to the last station. But if the operator meets another operator at the next station which he will work, he leaves the piece on that next station, and goes to take the work piece which is waiting at the station closest to the end of the U-line. Within this method, system performance with different number of operators was analysed. Also, the station which causes a bottleneck in the working condition with 5 operators, because it has the longest operation time, was paralleled and the change in the system's performance was observed.

Linked cell method (Table 1)

The number of cells is determined by dividing the total operation time by the number of operators. The operations are grouped according to this dividend found. The stations near each other were put in the same cell; the U-turn layout made this principle much more applicable. The cells were linked together with the decouplers, which allowed a number of inventory. In this method, the operator in any cell takes the piece from the first station of the cell, conducts all the operations in sequence and takes it to the last station of the cell. Within this method, the changes in the system's performance with different numbers of operator and different decoupler capacities were analysed.

Shared cells method (Table 2)

In this method, the system is again divided into cells. This method was formed to eliminate the bottlenecks that occurs in the linked cell method. In the linked cell method, the operators work in distinct cells, and as the total operation times of each cells are not exactly equal to each other, bottlenecks sometimes occur and the operators can find themselves idle while waiting for a work piece. To prevent these bottlenecks, operators in the cell are allowed to work in the last and first stations of the cells when his own cell is between them. The operator takes the work piece from the first station in his own working cell and takes it to the last station of that cell by making operations in sequence. If the operator who works on the next cell is not busy and is waiting for him to hand over the work piece, the operator gives the work piece to the operator who is not busy, and turns back. If the operator on the next cell is busy, then the operator of the previous cell continues to work on the shared station with the work piece which he has brought. Within this method, the effect of different amounts of operators and allowed inventory on the system's performance was analysed. In this system, the bottleneck station which makes the operation time longer (in spite of separating the system into shared cells) was also paralleled, and the effect of this on the system was observed.

The following assumptions and constraints were used in common for all 3 motion principles in the construction of the ProModel simulation model:

- All operators perform at the same efficiency at each station.
- The processing time at each station follows the normal distribution, with a standard deviation of 10 percent of the mean time.
- The machines are assumed to have no downtime.
- Decouplers can hold more than one part.
- The time for the operators to move between stations is assumed to be zero.
- There are always cut materials waiting at Station 1. Therefore, the system never waits on incoming parts.
- Within all systems, the work piece which is closest to the end of this U-line has priority.

Results of simulation

Productivity

The total productivity and the productivity per labour according to different numbers of operators and different motion principles is presented in Table 3.

The amount of productivity is highest with the RCB methods, where the worker has the freedom to work on all of the stations. The productivity in shared cells is also higher than the linked cell method, in which the operation times of each cell do not exactly correspond to each other. In the expanded rabbit chase and shared cells methods, the third station which caused the bottleneck in working condition with 5 operators was paralleled and simulated for that condition. From the results of the simulation, it is easily seen that adding a parallel station also increases the productivity, but not as much as expected.

Decoupler capacity

The effect of the allowed decouplers capacity in working conditions with 3 and 4 operators is presented in Figure 1.

As the decouplers' capacity increases, the total productivity increases. However, that increase occurs at a decreasing rate, and becomes constant after reaching the limit value. The increase in decoupler capacity increases the system's productivity by decreasing the amount of idle time of the operators who are waiting for the next work piece.

Table 1. *The number of stations and the total operation time of each cell in the linked cell method.*

Operator	Station No	Operation Time
3-cell situation		
1st operator	1, 2, 3, 5	201
2nd operator	4, 7, 8	192
3rd operator	6, 9, 10	189
4-cell situation		
1st operator	1, 6, 9	137
2nd operator	2, 4, 7	135
3rd operator	3, 5	144
4th operator	8, 10	156
5-cell situation		
1st operator	1, 2, 10	113
2nd operator	3	132
3rd operator	4, 7	102
4th operator	5, 8	102
5th operator	6, 9	123

Table 2. *The number of stations that each operator can work on of each cell in shared cell method.*

Operator	Station No
Shared Cell with 3 Operators	
1st operator	1, 2, 3, 4, 5
2nd operator	5, 6, 7, 8
3rd operator	8, 9, 10
Shared Cell with 4 Operators	
1st operator	1, 2, 3
2nd operator	3, 4, 5, 6, 7
3rd operator	7, 8, 9
4th operator	9, 10
Shared Cell with 5 Operators	
1st operator	1, 2, 3
2nd operator	3, 4, 5, 6
3rd operator	6, 7, 8
4th operator	8, 9
5th operator	9, 10

Table 3. Total productivity and productivity per labour according to different number of operators and different motion principles.

Kind of method	Total productivity with 3 operators	Individual productivity with 3 operators	Total productivity with 4 operators	Individual productivity with 4 operators	Total productivity with 3 operators	Individual productivity with 5 operators
Shared cell method (SC)	148	49.33	180	45.00	197	39.40
Shared cell method with parallel station (SCP)	0	0.00	0	0.00	217	43.40
Linked cell method with interval stock capacity of 1 (LC-1)	122	40.67	149	37.25	235	47.00
Linked cell method with interval stock capacity of 2 (LC-2)	129	43.00	157	39.25	240	48.00
Linked cell method with interval stock capacity of 3 (LC-3)	137	45.67	173	43.25	240	48.00
Expanded rabbit chase method (ERC)	160	53.33	191	47.75	263	48.00
Expanded rabbit chase method with parallel station (ERCP)	0	0.00	0	0.00	277	55.40

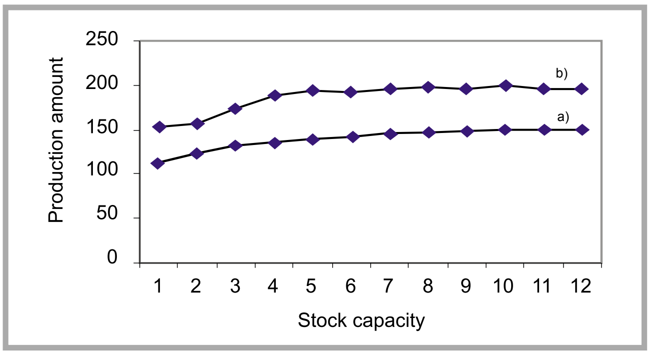

***Figure 1.** The effect of allowed decouplers capacity in working conditions with a) 3 and b) 4 operators.*

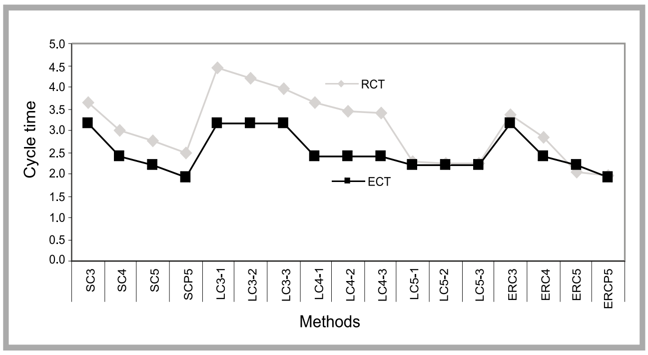

***Figure 3.** Expected and real cycle time according to different motion principles.*

Labour efficiency

The operators' efficiency according to the methods used is presented in Figure 2.

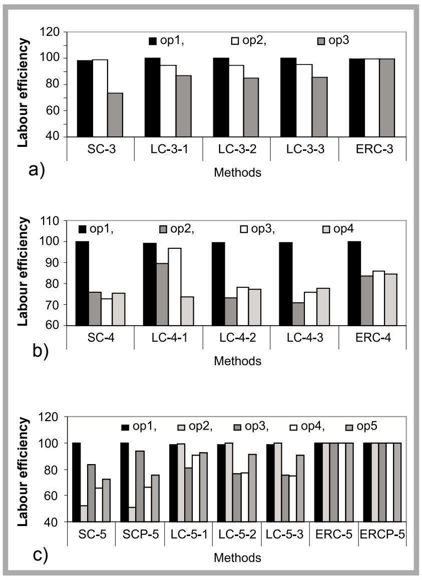

***Figure 2.** Operators' efficiency according to methods used, a) with 3 operators, b) with 4 operators, c) with 5 operators. (The first number in the abbreviations stands for the number of operators, the second stands for stock capacity).*

The work load is more balanced in the expanded rabbit chase method, depending on the freedom given to the operators. The work load in both the linked cell and shared cell methods depends on the total operation time of each cell. However in the shared cell method, the work load does not exactly show the total operational time differences of te different cells, as the operators are allowed to work at two more stations which do not belong to their own working cell.

Machine usage ratio

The machine usage ratio according to the different motion principles is presented in Table 4 (see page 96).

Machine usage ratio depends on the amount of the production of the system. The machine usage is low as the workers are moveable and there are fewer operators than machines. So there is no steady operator who works on each machine during all the simulation time. In the productivity analysis, it was seen that parallel stations increased the productivity; however, in the table above it is seen that the usage of both these parallel machines become quite low. This ratio can be increased if the number of workers in the system increases.

Cycle time

The expected and real cycle time according to different motion principles is presented in Figure 3.

The calculated cycle time, which is evaluated by dividing the total operation time for one product by the number of workers in the system, is only reached with the rabbit chase method, which also has the maximum productivity.

Throughput time

The throughput time according to different motion principles presented at Figure 4 (see page 96).

The throughput time is highest in the linked cell method, where it is allowed to work with interval stock. It is also seen that throughput time increases as the decouplers' capacity increases, irrespective of the amount of operators in the system. Analysing the results of Table 3 and Fig-

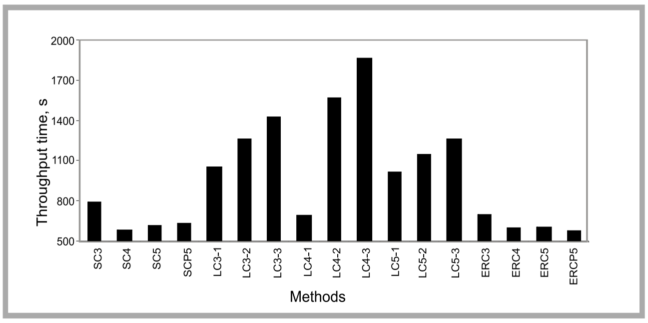

***Figure 4.** The throughput time according to different motion principles.*

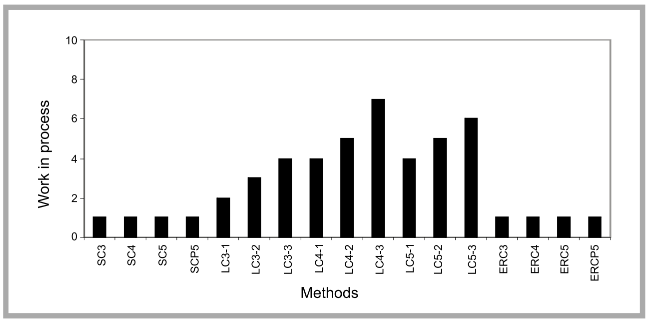

***Figure 5.** Average work in process in the system for different methods.*

ure 4 together, it can be said that the increase in the decouplers' capacity affects the throughput time much more than the productivity of the system.

Work in process

The average work in process in the system for different methods is presented in Figure 5.

The expanded rabbit chase and shared cell systems do not use any on-hand stock, so the work in process for both of these systems is low. On the other hand, it was seen in the linked cell method that the decouplers' capacity increases the average work in process, but again the amount of work in process hardly reaches 7, which is very low.

Conclusions

In this study, a modular manufacturing system working on the basis of three motion principles, the expanded rabbit chase, linked cells and shared cell methods, was developed using the ProModel simulation package program. The system performance in terms of productivity, machine and labour usage, throughput and cycle time and the amount of average stock on hand was analysed. The number of operators and the amount of demand were taken as control parameters. The effects of the amount of stock allowed and doubling the bottleneck station were observed.

It was found that the expanded rabbit chase system, which gives more freedom to the operators in terms of motion, showed the highest performance. In the expanded rabbit chase method, the operator who is blocked by another operator leaves the work piece he was working on in the blocked station, and goes to take up another work piece in another station. In the other two systems analysed, it was seen that the shared cell system showed higher performance than the linked cells method. The reason for the linked cell system's lower performance is the cells' unbalanced operation times. So the shared cells method, which was offered as having flexible cell regions and allowing the operators to use the stations which lie on two sides of the cell regions, showed higher performance. On the other hand, increasing the decouplers' capacity and doubling the bottleneck station increased the performance of the system where these situations were examined. It was seen that the increase in decouplers' capacity changes the performance to some extent, but after reaching a limit value, it has no further effect. When doubling the bottleneck station, it was observed that this eases the work flow to a certain point. However, eliminating the first bottleneck of the system can cause another bottleneck to occur, as is seen in the expanded rabbit chase method.

In conclusion, it was found that the expanded rabbit chase method in which the operators are given the freedom to determine their own work patterns was much more successful. The problems that occur during operation can be solved by doubling the bottleneck stations. On the other hand, the cell type production performance of the system can be improved by increasing the amount of the decouplers' capacity or by allowing some flexibility in terms of the cell regions, as in the case of shared cells.

***Table 4.** Machine usage ratio according to different motion principles.*

Machine No	SC-5	SCP-5	LC-5-1	LC-5-2	LC-5-3	ERC-5-1	ERCP-5
M1	8.81	9.69	10.71	10.75	10.82	11.58	12.25
M2	20.33	22.72	25.08	25.19	25.33	27.48	28.67
M3	81.76	60.80	98.78	99.62	99.62	99.32	74.31
M3-2		14.66					15.16
M4	3.73	4.08	4.54	4.54	4.48	4.93	5.24
M5	7.45	8.05	9.01	8.92	8.92	9.87	10.40
M6	20.00	21.97	24.70	24.88	24.59	27.07	28.20
M7	59.67	65.23	71.19	71.97	70.48	77.79	82.63
M8	55.05	61.00	67.40	67.56	65.88	72.88	77.37
M9	54.63	59.96	67.03	66.36	65.79	73.14	76.36
M10	40.12	44.10	48.87	48.87	48.49	53.75	56.34

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Received 18.05.2006 Reviewed 20.11.2006