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A Quantitative Analysis of Cellular Manufacturing in Apparel Industry by Using Simulation

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Abstract:

Purpose: This research, by using the SIMIO simulation platform, provides a quantitative and comparative analysis of how the efficiency of four different cell production modes is affected. It is hoped that the results will be of some help for garment factories to optimize their production lines.

Design/methodology/approach: The SIMIO simulation platform was employed in the research and comparisons were made of the simulation test results about the four popular cellular manufacturing modes.

Findings: The operation mode, number of operators, and number of buffer areas are key factors affecting the production line efficiency, and need to be reasonably set to achieve the highest efficiency.

Originality/value: As most research literature so far is qualitative, this research provided a simulation-based quantitative analysis of the production efficiency under different cell production modes.

Keywords: cell production, SIMIO, simulation, apparel industry

1. Introduction

Cell production refers to a kind of production mode in which the production line is arranged as an integrated unit of equipment and workstations based on the operation procedures and in a particular order (for example U-shape layout). The American Apparel Manufacturing Association has defined cell 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”. In a cell system, processes are grouped into a module instead of being divided into their smallest components, and fewer numbers of multi-functional operators stand still, or move counterclockwise within the particular production area to perform the assigned tasks. Compared with the traditionally specialized flow-line production method, cell production can swiftly adapt to variable order type and quantity. When appropriately applied, it ensures flexible production capacity, lower labor and equipment cost, improved production efficiency. It therefore becomes a significant component of the lean production where JIT is pursued, and is widely adopted by many industries including apparel manufacturing, electronics assembly and machining in Japan, Europe and America.

The ever improving living standards and rapidly changing fashion trends are pushing apparel manufacturers to respond as fast as possible to model and quantity changes and to produce high-quality, low-cost products. Given this challenge, new production systems were adopted and experimented in the apparel industry, and the cell production is widely favored.

2. Review of the literature

Researches about cell production mainly focused on two aspects: one was about the advantages of cell production, while the other was about performance of various cell production modes, though most researches include these two aspects at the same time.

Fatma and Canan (2007) introduced that the cell 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 (TSS). They cited other researchers’ research findings and listed advantages of cell productions modes. Bischak (1996) examined the performance of a manufacturing module with moving workers and found that the production system helped to achieve quality products at lower costs and reduced lead time. Besides, it could easily adapt to high employee mobility.

Researchers favored simulation in studying performances of different cell production modes. Wang and Ziemke (1991) simulated a system based on the Toyota Sewing System (TTS) and found that the system showed high performance, even though the operation times of each station differed considerably with each other. They also noticed that after some time of

operation, the workers would form their own work patterns. Adams and Schroer (1999) established a simulation based on the Rabbit Chase (RC) mode of cloth manufacturing, and worked out the law between output volume and time consumed. Black and Schroer (1993) put forward the Linked Cell (LC) production mode which used decouplers to connect, balance and buffer elements within the cell so as to achieve high efficiency. Wang and Tang (2009) studied the cell management method for manufacturing systems where parts were processed across different cells. They constructed a model and algorithm, and used a simulation to verify the effectiveness of its method. Scholars like Netland (2013), Walter and Tubin (2013), Karim and Arif-Uz-Zaman (2013) and Amin and Karim (2013) studied the assembly line layouts of cell production systems and evaluated their performances. These research finds are of great values for further studies.

Past researches are of limited value for the real manufacturing world, as they mainly validated the effectiveness of cell production system or focused on particular cell production modes. There was a lack of quantitative comparison between these different cell production modes. Besides, for a particular cell production mode, important elements that affect the overall performance of the system were not adequately studied. This paper aims, by using simulation, to compare four major cell production modes that are most frequently adopted in the clothing making industry, and try to find out the key factors that impact the overall performances of these different cell production modes.

3. Popular cell production modes

There are many different cell production modes being used in the production industry, however the Sub Cell, Shared Cell, Rabbit Chase and Toyota Sewing System are most frequently applied in the apparel industry. This chapter will give a description of the operation of the above four cell production modes.

3.1. Sub Cell (SC)

Just as Figure 1 illustrates, a production cell is divided into several sub-cells, which collaborate with each other to finish the whole process of work. Operators are only responsible for the work of their own cells. Sometimes the work of downstream and upstream stations can also be included in the neighboring cells. That is to say, operators are responsible for many tasks in both sides along the U-shape line so as to balance the whole production procedures. For example, Op1 can be responsible for the work in Station 1, 2, 12 and 13.

Labor division is adopted in the Sub Cell production mode, which has low requirements for operators' comprehensive labor skills. They are only required to finish the work in their own

cells. While enjoying less investment of equipment, Sub Cell mode requires labor division to balance the production line. When necessary, a product buffer area in the sub-cell is necessary so as to reduce the loss when the production line is not in balance. The quantity of work-in-progress in the buffer area depends on the demands of production balance, and there are usually much work-in-progress.

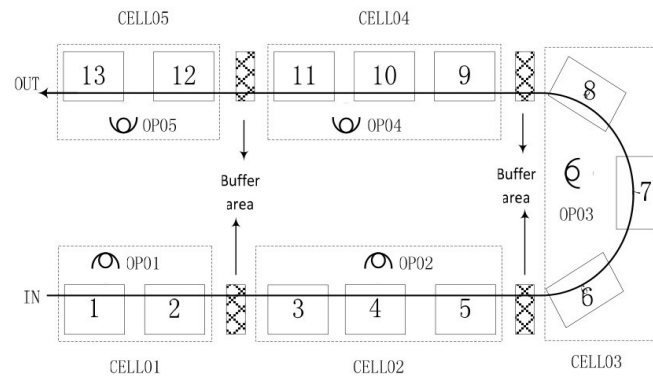


Figure 1. Sub-Cell (SC)

3.2. Shared Cell (SHC)

Just as Figure 2 illustrates, to reduce buffer area and capacity (namely, to reduce the number of work-in-progress), the first and last station in each sub-cell is designed as a “shared position” (the station labeled with St in Figure 2). Neighboring operators hand over work in the shared station or in the buffer area.

In Figure 2, there is an “intersection point” before and after each shared station and a “buffer area” after the first station in each sub-cell (except the first cell). Each operator can decide the shared station for work handover depending on whether the neighboring operator is busy or not. For instance, after the completion of the work of Station 1, Op1 will hand over work to Op2 in the “intersection point” after the Station 2 when Op2 is waiting; nevertheless, when Op2 is busy with work of other stations, Op1 will continue to finish the work of Station 3, then hand over work in the intersection point after Station 3 or put the products in the buffer area after Station 3, and finally return to Station 1 to perform next cycle of work. In the Shared Cell mode, work handover between neighboring procedures should be performed in the intersection point or buffer area after one procedure is finished, instead of between operators directly in the processing procedure. In the Shared Cell mode, there may be some work-in-progress in the buffer area.

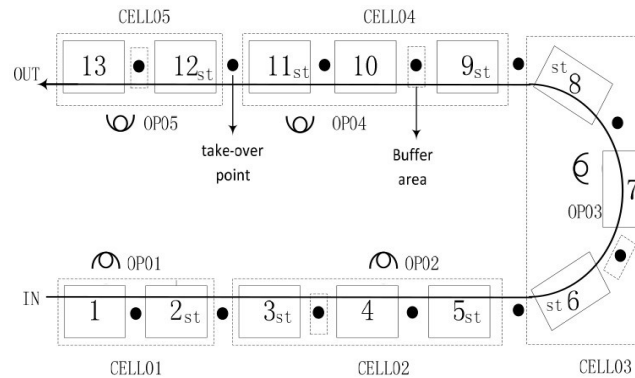


Figure 2. Shared Cell (SHC)

3.3. Rabbit Chase (RC)

Just as Figure 3 illustrates, instead of labor division, operators share the whole production line and are respectively responsible for manufacturing one product in an orderly way (from Station 1 to Station 13). Different from Sub Cell and Shared Cell modes which have no particular demands for the production line layout, Rabbit Chase production cell needs a U-shape layout and operators who are proficient in the work of all stations. Operators perform their work in a “chase manner”, thus line jam may arise when some operators finish their work too slowly. According to Black and Schroer (1993), jam is not likely when the number of operators is less than 3. But as the number grows, a jam is more likely. In the Rabbit Chase mode, there is no buffer area between different stations and there is no extra work-in-process.

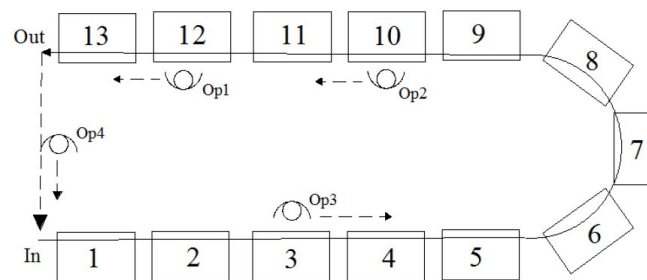


Figure 3. Rabbit Chase (RC)

3.4. Toyota Sewing System (TSS)

TSS can also be called Bucket Brigade or Expand Rabbit Chase. Just as Figure 4 illustrates, operators share the whole production line. Each operator receives the work-in-progress at the starting point or from the former one, processes it till the end of the production line or hands it over to the next operator, then returns to the initial station. In this mode, the handover of work can take place at any time and any place. As shown in Figure 4, Op1 and Op2 hand over

work at Station 3, but they may hand over work at Station 2 or 4 next time; after the handover, Op1 returns to the starting point while Op2 performs the work counterclockwise till the handover of work to Op3. The Toyota Sewing System cell production mode is a self-balancing system. Only through several trials, intersection positions will tend to be stable, and the whole production line will stay stable and balanced. In this mode, each operator is multi-skilled. Operators will be rated according to their working proficiency, and those who are the most proficient are always put at the ends of the line in order to improve the whole production efficiency. Like RC mode, there is no buffer area between different stations and there is no extra work-in-progress in TSS.

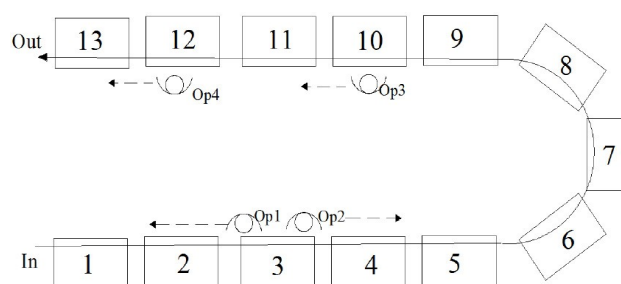


Figure 4. Toyota Sewing System (TSS)

4. Simulation establishment

For the production process of a certain garment which include 9 work steps as shown in Table 1, we establish the SIMIO simulation model. Most of the process in that production cell is the sewing operation accomplished by manually operated sewing machines (different types) and the operation time has certain random fluctuations.

4.1. Data collection

We use a stopwatch to conduct the data acquisition of ten-day operation time during the period of 2013.01.07-2013.01.11 and of 2013.01.14-2013.01.18. We employ the continuous recording method to conduct consecutive time measurement 50 times (10 trial observations) at 8:00(start-up time in the morning), 9:30, 11:30 (half an hour before going off work), 13:00 (start-up time in the afternoon), 14:30 and 16:30 (half an hour before going off work) respectively. The data acquisition frequency of each station is 3000 times (300 times each day). Then after we employ the triple standard difference method (the absolute error is $\pm 3\%$ and the reliability is 95%) to remove the outlier, we use Minitab to carry out the data fitting analysis and find that manual operations basically accord with the triangular distribution of certain parameters shown in Table 1.

Step	Operation	Operation time/s	Step	Operation	Operation time/s
1	Seam pockets	T(48.1,50,51.5)	8	Sew elastic bands	T(27.8,30.1,33)
2	Seam pockets into pants	T(68.2,70.1,72)	9	Seam buttons	T(14.3,15.2,16.5)
3	Seam(connect) two legs	T(57.6,60,64.1)	10	Make button plackets	T(8.9,10.2,12.1)
4	Sew two legs	T(37.2,40.2,44)	11	Seam rubber stitch	T(12.5,15.3,17)
5	Sew pants opening	T(91.4,95.8,100.3)	12	Test	T(17.2,20,35.6)
6	Flip pants	T(15.4,18,23.3)	13	Package	T(18.1,20,24.2)
7	Flanger	T(37.8,40.2,42.1)			

Table 1. Operation process and time measurement

4.2. Basic SIMIO model

Establish the basic model of cell production under the SIMIO environment. As shown in Figure 5, each server in the model stands for a workstation and corresponds to the equipment M and each Node represents the procedure handover point or buffer area.

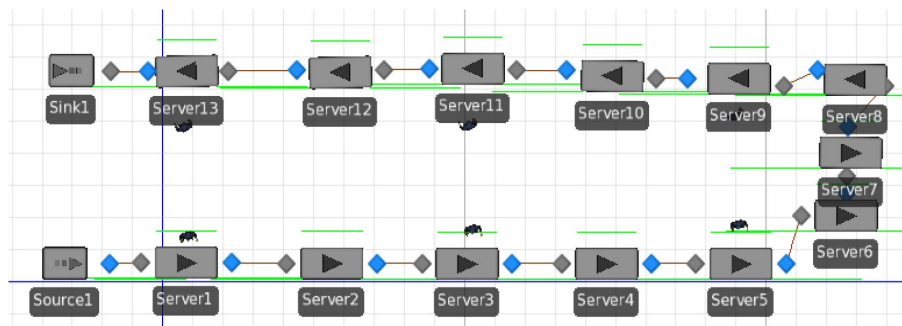


Figure 5. The basic model under SIMIO environment

4.3. Assumptions and constraints

Make the following assumptions and constraints in the SIMIO model:

1. there are no obvious differences in skill level among operators and each operator has identical efficiency for each procedure;
2. the processing time of each procedure complies with the standard operation time shown in Table 1;
3. assume that equipment failures are not taken into consideration;
4. buffer areas between cells can accommodate multiple articles being processed;
5. the walking time between different devices by operators is unified to be set to 2 seconds. Time in Table 1 does not include walking time;

6. there are no shortage problems in the first station;
7. all materials and articles being produced flow uni-directionally in cells according to the FIFO principle. Non-conforming products are only discovered and treated accordingly in the test process.

In the SIMIO model, the efficiency of different models is tested by controlling the number of operators and the volume of permitted standard articles being processed. We need to carry out sub-unit divisions under the SC and SHC model. When there are 3, 4 and 5 operators, the sub-unit division results are shown in Table 2. Under the SHC model, each operation unit has dynamically shared stations.

According to the data in Table 1 and Table 2 and relevant assumptions and on the basis of base models, we establish four simulation models including the SC (separated type), SHC (station-sharing type), RC (rabbit-chasing type) and TSS (Toyota garment type) and compare and analyze the variations in production capacity and buffer capacity under these four models by changing the number of operators (controlling takt time) and the number of operating standard articles being processed.

Number of cells	Number of operators	SC model Tasks	SHC model Tasks	Shared stations
3	1	1,2,3	1,2,3,4	3,4
	2	4,5,6,7	3,4,5,6,7,8	3,4,7,8
	3	8,9,10,11,12,13	7,8,9,10,11,12,13	7,8
4	1	1,2,9,10	1,2,8,9,10,11	2,8,9,10,11
	2	3,4,8	2,3,4,7,8,9	2,3,4,7,8,9
	3	5,6,7	4,5,6,7,8	4,7,8
	4	11,12,13	10,11,12,13	10,11
5	1	1,2	1,2,3	2,3
	2	3,4	2,3,4,5	2,3,4,5
	3	5,6	4,5,6,7	4,5,6,7
	4	7,8,9,10,11	7,8,9,10,11,12	6,7,11
	5	12,13	11,12,13	11,12

Table 2. Sub-unit divisions under SC and SHC model

5. Test and result analysis

According to the actual operation of production line, we set 3~5 operators, 0~3 buffer capacity under the SC model, 100-day operation time of SIMIO simulation model with 8 hours each day and 10-day of Warm up time parameters. Then we operate the simulation model and conduct the output volume and buffer capacity analysis.

(1) The analysis result of output volume is shown in Table 3 (the number after SC and SCH stands for the buffer capacity. For example, SC-1 means that the buffer capacity is 1. The buffer area is not set up in production cells under the RC and TSS model).

Operation model	Daily output			Daily output per capita		
	3 operators	4 operators	5 operators	3 operators	4 operators	5 operators
SC-0	154	197	258	51.33	49.25	51.6
SC-1	161	203	278	52.67	50.75	55.6
SC-2	163	203	278	52.67	50.75	55.6
SC-3	159	203	278	53	50.75	55.6
SHC-0	146	178	213	48.67	44.5	42.6
SHC-1	168	203	272	56	50.75	54.6
SHC-2	168	201	273	56	50.25	54.6
SHC-3	168	201	273	56	50.25	54.6
RC	170	225	276	56.67	56.25	55.2
TSS	171	225	282	57	56.25	56.4

Table 3. Test result of output volume

From Table 3, we know that:

- when there are 3 operators: SC-3 has the highest output while SC-0 has the lowest output under the SC model, which indicates that higher output can be gained when the maximum designed buffer capacity is 2; SCH-1, SCH-2 and SCH-3 have identical output under the SHC model. We can see that the increase of buffer capacity will not lead to more output; the outputs under the RC and TSS model are basically the same, both above the highest output under the SC and SHC model.
- when there are 4 operators: SC-1, SC-2 and SC-3 have the same output and the increase of buffer capacity will not lead to more output under the SC model; SCH-1 has the highest output under the SHC model, which indicates that maximum output can be obtained when the buffer capacity is 1; the outputs under the RC and TSS model are basically the same, both above the highest output under the SC and SHC model.
- when there are 5 operators: maximum output can be acquired when the buffer capacity is 1 under the SC model; maximum output can be acquired when the buffer capacity is 2 under the SHC model; the output under the TSS model is higher than the highest outputs in the other three models.
- when there are 5 operators under the SC model, the production cell per capita has the highest output; when there are 3 operators under the SHC model, the production cell

per capita has the highest output; when there are 3 or 4 operators under the RC model, the production cell per capita has the highest output; when there are 3 operators under the TSS model, the production cell per capita has the highest output.

Therefore, from the perspective of output, when there are 3~4 operators, we should prioritize the TSS or RC model; when there are 5 people, we should prioritize the TSS model. From the perspective of output per capita, we should prioritize the TSS model. When production demand has been fixed, we can set a reasonable number of people based on production demand and choose the appropriate operation mode according to Table 3 to obtain the maximum productivity.

(2) Buffer capacity. Transform the buffer capacity under the SC model and test the output results under different capacity as shown in Figure 6.

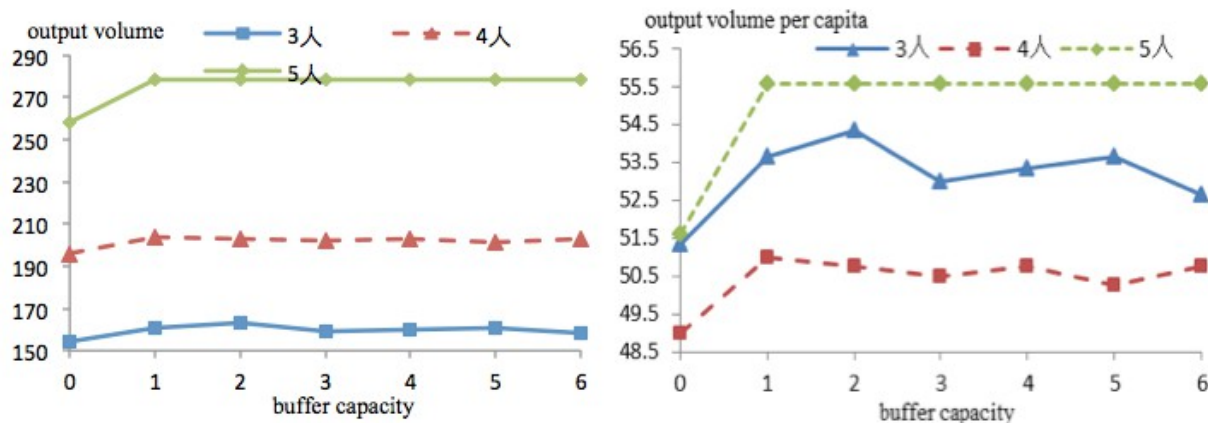


Figure 6. Impact of buffer capacity under SC model

From Figure 6, we can see that the buffer within the production cell plays a role in regulating the production equilibrium and obtaining higher output efficiency. When the buffer increases to a certain degree, there is no significant increase in the total output; output per capita has similar relationship with the buffer capacity. To minimize the number of articles being produced, we should set the buffer capacity as 1 or 2 under the SC model. Through the simulation analysis, we find that basically, there is no effect on output increase when the buffer capacity is more than 1 and that the optimal buffer capacity is 1.

6. Conclusion

To quantitatively compare performances of the four cellular manufacturing modes frequently adopted in the apparel industry, and analyze key indicators that impact overall production efficiencies of each particular mode, we established a simulation and found that different

operation modes and the number of buffers have impacts on the cellular production mode. For the apparel production line in this paper, to obtain the maximum output, we should prioritize the TSS or TC model when there are 3~4 operators and the TSS mode when there are 5 operators. Therefore, to obtain the highest output per capita, we should prioritize the TSS mode.

The research result of this paper indicates that in order to obtain higher total output and output per capita, some key indicators including the number of operators, operation modes and the number of buffers should be reasonably set for the particular apparel manufacturing line.

Acknowledgments

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