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A Study of Using Experiment to Test and Verify U-curve Management Thinking

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Abstract

The U-curve is the management thinking from Dr. Goldratt practical experience. The U-curve is a graph with extreme left and right sides, and it stands for the impact relationship between time buffer and management attention. Dr. Goldratt recommended buffer time from the both side move to the middle of U-curve, and manager could reduce the input of effort and time to manage the production line. However, the view of Dr. Goldratt is correct? First, this study will test and verify management thinking if the management attention is high at both ends of the U-curve. Then, this study will verify the adequate area of U-curve, and to understand the adjustment of time buffer is appropriate. There is no relevant literature to explore the U-curve management thinking, so this study explores U-curve management thinking by job shop game and records the management attention by observation. In this study, there are 24 data of machine tool research project and 11 groups of job shop game to verify U-curve management thinking, and there are three case studies of Theory of Constraints (TOC) to support the results of this study.

Keywords: Time buffer, Management attention, U-curve, Theory of constraints

1. Introduction

Dr. Goldratt mentioned the concept of the U-curve in the article entitled "Standing on the Shoulders of Giants" (Goldratt Consulting, 2008). U-curve stands for the impact relationship between time buffer and management attention. As shown in Figure 1, the horizontal axis represents time buffer and the longitudinal axis represents the strength of management attention. The left and right sides of the U-curve are very extreme cases. On the right side of the diagram, most of the traditional manufacturing industries are in this area. For the pursuit of more efficient production, materials are supplied in advance, resulting in more and more products. Managers must put more effort and time to deal with the chaos of the work site, but the production performance is still not good. Therefore, Dr. Goldratt suggested that time buffer should be slightly moved to the left side for improved performance. From the left side of the diagram, Toyota Production System (TPS) and lean production environment are in these areas. For the pursuit of zero stock and control the production buffer at the same length of production time, more accurate scheduling is required to avoid queuing.

However, any emergency such as delay in component transportation will push management attention to the height on the left (Baker, 1974; Wein, 1988; Tsai *et al*., 1997; Kim *et al*., *1998*; Schragenheim and Dettmer, 2001). Therefore, Dr. Goldratt suggested that time buffer should be added to move U-curve to the right side. He argued that mid-bottom of U-curve has sufficient horizontal area to adjust the excessively long time buffer (U-curve right end) or excessively short (U-curve left end) to the center instead of pushing time buffer from the high management attention area on the right or left side to another side. Is Dr. Goldratt's view correct? This study validated the U-curve management thinking in terms of the following points: (1) verify the existence of high management attention at the left and right ends of U-curve; if the settings of time buffer are changed to move the time buffer to the center of U-curve, whether the effort and time of managers will be significantly reduced; (2) verify whether there is sufficient horizontal area in the center of U-curve; (3) observe and explain management attention, which is used by Dr. Goldratt to represent U-curve longitudinal axis without giving clear definition; (4) design a job shop experiment to collect related data and validate U-curve.
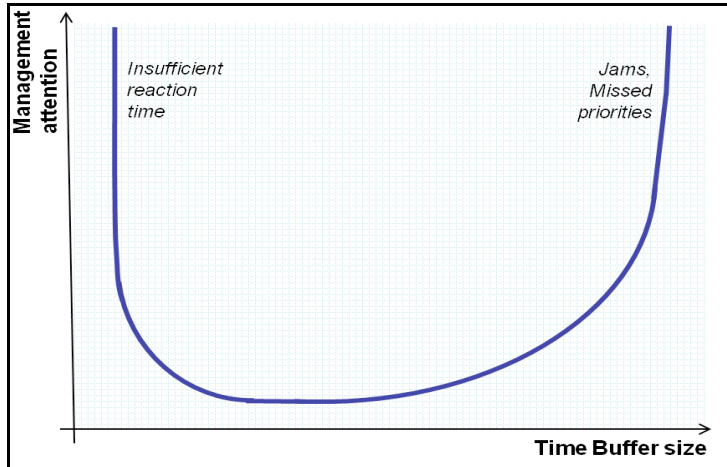
Figure 1: U-curve (Goldratt Consulting, 2008)

The purpose of this study is to verify the U-curve and discuss management attention. Simulated scenarios are used to understand U-curve. Wang (2008) established a job shop to explore the improvement of delivery performance. This study uses the Job Shop Game established by Wang (2008) in data collection as the simulated scenario is suitable for the environment of U-curve, in order to verify the U-curve management thinking by Job Shop Game and changes in production buffer settings.

2. Literature Review

2.1 Discussion of Time Buffer

Ford Motors mass-produced automobiles by using the flow line method, and successfully achieved balanced flow performance. With inventory management of limited space in work shop, it avoided excessive production (Goldratt Consulting, 2008). Similarly, Toyota Motors used its own Kanban management model to control its inventory (Lee, 2005; Science of Business, 2011). Differing from the space and inventory models of Ford Motors and Toyota Motors, Dr. Goldratt's management mechanism of production downtime is based on time. The proposed mechanism can be applied in unstable environment as compared with TPS, as expressed by using U-curve. Dr. Goldratt argued that the starting point of improving system smoothness is to use half of the current lead time as the production buffer time (Goldratt Consulting, 2008) and then determine the production priority along with the buffer management. Therefore, a set of complete TOC (Theory of Constraints) management method is extended closely following the U-curve thinking. As illustrated by the strategy and tactic diagrams of Dr. Goldratt (Davenport and Beck, 2002), there are several steps to achieve high level of delivery on time: (1) restriction of the order release; (2) order priority management; (3) Capacity Constrained Resource (CCR) Management.

The determination of product material feeding date, order date and delivery date according to the time buffer set by managers are steps of restriction of the order release. U-curve thinking

illustrates that time buffer can determine the optimal fall points in a short time (Goldratt Consulting, 2008; Chinese Goldratt Alliance Web, 2011). The Simplified Drum-Buffer-Rope (S-DBR) management method also applies the concept to determine the production buffer time (Wang, 2008).

2.2 Discussion of Management Attention

By observing the management behaviors during the game simulation process, we can learn how managers urge the operators or adjust in case of emergency, and see the leadership of the manager. An excellent manager knows that leadership is an art aimed to create an environment that can provide an incentive to inspire employees, so that employees can fully concentrate on the work to achieve the best performance. Through continuous learning and experience exchange, managers can accumulate the ability to achieve the best management performance (Chiou, 2004).

2.2.1   Definition of Attention

1. Attention is to devote mental activities to specific information items, which can draw attention before deciding whether to take action.

2. Attention is a psychological phenomenon we are very familiar with. In the awaken state, attention-related activities are regular. When people pay attention to certain things, psychological processes such as feeling, memory, imagination, and test will accompany and present significant differences, therefore, attention is able to reflect the mental activity status of people (Chiou, 2004).

The production line management attention generally refers to variations of machine, product, etc., namely, the times of problem occurrences. Therefore, in this study, the management attention is simply categorized as the times of processing notifications by managers and the management behavior of removing possible overdue orders.

2.3 Job Shop Production Process

As job shop production is commonly used in industries, such as semiconductor wafer fabrication, this study designs a factory of job shop production mode to conduct simulations from Game 1 to Game 5 to observe the decision-making of the manager in the case of different time buffers, collect data for analysis and draw the conclusions. The problem of job shop production is a relatively complex model. Job orders will be processed on different machines and each job order has its own route. The process production model is also one of such production methods. The basic job shop production has many assumptions (Chang, 2004), including: (1) each job order can only pass on the same machine for once at most; (2) one machine can only execute one job order at the same time; (3) one job order can only be processed on one machine at the same time; (4) machine processing order should have been specified in advance; (5) processing time and setup time are all known.

Chao and Pinedo (1999) proposed some basic evaluation principles and target functions regarding the problem of job shop production, as illustrated as below: (1) make-span: the make-span of the latest finished work piece of all, the target is the minimization of make-span; (2) flow time: workpiece residence time in the system, the target is the minimization of the average flow time; (3) tardiness: time difference between the workpiece make-span beyond the due date, the target is the minimization of the total tardiness; (4) lateness: difference between workpiece make-span and due date, the target is the minimization of the total lateness. The job order design in this study includes make-span and flow time. As out-of-stock complement and loss on sales are not considered in some cases, tardiness and lateness are not included in the job order design.

2.4 Determination of Delivery Date and Material Feeding Date by Using S-DBR

The job order designed using the job shop production is as shown in Table 1. Managers can push the delivery date and determine the order reception date according to Simplified Drum-Buffer-Rope (S-DBR) on the basis of production capacity load. For scenario with variation, changes in production buffer time can result in different decisions. What is S-DBR? It is the traditional Drum-Buffer-Rope (DBR), which is a type of TOC management concepts (Wu et al., 2010; Wu et al., 2011). It allows the production system to follow the pace of the bottlenecks. However, as the DBR is limited by the protection concept of three buffers including production capacity buffer, assembly buffer and delivery buffer, and requires more data for detailed scheduling, the application of DRB is complex. Therefore, Dr. Goldratt proposed the new concept of S-DBR to further simplify the production management. S-DBR focuses on the market, and requires only delivery buffer; hence, it is easier to implement as compared to DBR and S-DBR (Wang, 2008).

Table 1: Product data of job shop game (Wang, 2008)

Product	Product routes	Price (dollar)	Material cost (dollar)
Product 1	A→B→A→D	275	150
Product 2	C→D→B→B	375	110
Product 3	A→C→B→C	240	90
Product 4	A→B→D→B	305	95

This experimental study used S-DBR to determine the delivery date and material feeding date in order to improve delivery performance. With the situational example of this study, if the bottle machine load has reached 4 days, if there is a new order of A, can the order be taken? When should the materials be input into production? The practices are as follows: (1) As the bottle machine is highly likely to process Order A on the fifth day, if production buffer time is 8 days, by the practice of S-DBR, the company is likely to deliver the product to the customer on the eighth day. Can the second order be taken? (2) It is known that the bottleneck machine's days of load is 5, and the company is thus likely to deliver the product to the customer on the ninth

day. Therefore, the delivery of product to the customer on the 8th day is feasible. However, the industrial standard is 12 days, is it necessary to promise to deliver on the eighth date? Some studies have argued that reduction of lead time is important to enterprises as short lead time can reduce inventory and respond to customer demands rapidly, thus improving the competitiveness of the enterprise (Lo, 2005).

3. Research Method

3.1 Research Framework

The purpose of this study is to verify the U-curve and explore management attention, thus, the U-curve management thinking is explored by analyzing simulated scenarios. Wang (2008) established a job shop to enhance the delivery performance. Experiment 1 confirmed that variation is not the main cause. Experiment 2 used the S-DBR management method in production according to production capacity load. Experiment 3 proved that restriction of the order release is a good management method. This study used the Job Shop Game established by Wang (2008) for data collection because the simulated scenario is suitable for the environment of U-curve. Therefore, Job Shop Game and changes in production buffer settings were used to verify U-curve. The assumptions of the Job Shop Game are proposed, and data are collected and analyzed to draw the conclusions. The data analysis will be discussed in Section 4. The existence of high management attention at left and right ends of U-curve by is verified by 11 groups of data. However, the game scenarios are compared in left, right and center for comparison only, thus cannot verify whether the center of U-curve has sufficient horizontal area. Therefore, using the 24 samples collected by machine tool project, the second research problem is verified, and the successful TOC cases of three companies are used to support the findings of this study.

3.2 Experimental Scenario Design

This study designed a job shop with production variation. The main purpose is to observe how managers can make decisions to avoid job order delays for different production buffer time, and analyze the problem of failing to get the satisfactory results at both ends of U-curve despite the efforts and time of the managers. In the case of the experimental scenario without production variation proposed by Wang (2008), as long as production capacity load and material feeding control are done well, managers can easily manage the production line without delivery rate and the problem of WIP. As it is close to real production, we added variation factors such as machine downtime and product redo in our discussion.

3.3 Experimental Scenario Assumption

1. To get closer to the real factor production, this study designed production scenarios with variation, assuming there is a certain probability of each machine to have downtime in each day; therefore, it is assumed that 80% of the machines can work normally. The existence of downtime of machines was determined by dice.

2. It is assumed that market demand is infinite and factory should make full use of the capacity to produce the product.

3. Customers will not accept out-of-stock complement; therefore, if the time period from order to delivery time is overdue, it is regarded as a sales loss.

3.4 Job Shop Production Model

1. This study added the scenario design with production variation into the research model of Wang (2008) in the design of production model.

2. The job shop factory has machine A, machine B, machine C, and machine D.

3. Each product's processing time on each machine is 1 day and they cannot mutually support.

4. The factory model allows working overtime, and the factory leader can require working extra according to the operation of the factor, the number of products for each machine in each day is 1.

5. The touch time to produce each of the products is 4 days.

6. The production scenarios (games) with variation are set as:

Game 1 with 5% variation, the entire experimental process will have randomly 2 days of variation occurrence.

Game 2 with 10% variation, the entire experimental process will have randomly 4 days of variation occurrence.

Game 3 with 15% variation, the entire experimental process will have randomly 6 days of variation occurrence.

7. The factory produces four products including Product 1, Product 2, Product 3 and Product 4, each product is represented by a job order form as shown in Table 1.

8. In this experiment, the Quoted Lead Time (QLT) acceptable to customers is set. It differs in three games as it is 4, 8, 12 days for Game 1, Game 2, Game 3 respectively. With Game 3 as an example, if the order of Product 1 is accepted on the first date, the promised date of delivery to the customer is 1 + 12 = 13 days; the 13th day is the promised date of delivery. If it is beyond the 13th day, the time is not acceptable to customers.

9. Prior to the experiment, the factory had a Product 1 under production before machine B and Products 3 and 4 under production before machine A.

10. To get closer to the real situation, this study sets the rules: Product 1, Product 2, Product 3 and Product 4 should satisfy the production of at least four pieces and 12 pieces at most.

11. This study invited industrial personnel and students with industrial engineering and management background to test three times of Game 1 (time buffer is 4 days), Game 2 (time buffer is 8 days), and Game 3 (time buffer is 12 days) in 11 groups. Each group consists of 6 members playing roles of the director, production manager, operator A, operator B, operator C and operator D.

12. The number of testing days is 36 days. This study compared the results of the groups and the directors would discuss relevant problems after the tests.

4. Data Analysis

4.1 Machine Tool research project

The 24 samples collected from the machine tool research project are as shown in Table 2, which were used to explore whether the selection of time distance can significantly improve the production performance. This study tested the 24 samples in three times with results as shown below. Game 1: the longest production lead time is 12 days; Game 2: the longest production lead time is 9 days; Game 3: the longest production lead time is 6 days. Director at the end of the test will be conducted this study discussion.

Table 2: Data gathering of machine tool plan

	Finished order Qty				Finished but delayed				Delay order				DDP			
	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
31	21	22	23	23	11				2				0.43	1.00	1.00	1.00
34	21	22	23	22	9				1				0.55	1.00	1.00	1.00
38	21	22	23	23	9				1				0.55	1.00	1.00	1.00
19	21	22	23	23	4				2				0.74	1.00	1.00	1.00
20	21	22	23	23	8								0.62	1.00	1.00	1.00
18	21	21	23	23	3				2				0.78	1.00	1.00	1.00
ECE-29	22	22	23	23	7								0.68	1.00	1.00	1.00
22	22	22	23	23	7								0.68	1.00	1.00	1.00
APEC-21	21	22	23	23	8				2				0.57	1.00	1.00	1.00
V.-W.-44	23	22	23	23	8				6				0.52	1.00	1.00	1.00
51	21	21	22	23	5		1		2				0.70	1.00	0.95	1.00
Kuani-33	23	22	23	23	2								0.91	1.00	1.00	1.00
37	23	22	23	23	6								0.74	1.00	1.00	1.00
S.Y.-14	21	22	23	23	4								0.81	1.00	1.00	1.00
16	23	22	23	23	4	1							0.83	0.96	1.00	1.00

25	22	22	23	23	7								0.68	1.00	1.00	1.00
24	22	21	23	23	3				3				0.76	1.00	1.00	1.00
36	22	22	23	23	7								0.68	1.00	1.00	1.00
15	22	22	23	23	6								0.73	1.00	1.00	1.00
45	23	22	23	23	2								0.91	1.00	1.00	1.00
6	22	22	23	22	8								0.64	1.00	1.00	1.00
7	22	22	23	23				1					1.00	1.00	1.00	0.96
10	22	22	23	22	4	1		1	1				0.78	0.95	1.00	0.96
PMC-1	23	21	23	23	2				1				0.88	1.00	1.00	1.00

Average production time				NP				MAX-Q	Average WIP			
R1	R2	R3	R4	NP	R2	R3	R4	R1	R1	R2	R3	R4
14.71	7.61	5.61	7.11	545	660	820	820		11	6.8	6.9	7.2
12.32	8.21	6.16	7.94	465	660	820	665		9.5	6.9	6.9	7.6
12.29	8.44	6.16	7.11	520	660	820	820		10	7	6.9	7.2
12.00	8.17	5.58	7.33	545	685	820	820	4	9.2	6.4	6.9	7.2
11.06	8.12	5.58	6.50	505	660	820	820	4	9	6.5	6.9	7.6
10.88	7.41	5.58	7.11	490	475	820	820	7	9.8	6.6	7	7.6
10.63	8.50	5.58	6.42	670	685	820	820	19	9.3	7	6.9	7.2
10.61	7.56	5.63	7.32	615	615	820	820		7.8	7.7	6.9	7.2
10.59	8.30	5.84	7.00	520	660	820	820		11	6.7	6.9	7.2
10.47	8.06	5.58	7.11	765	660	820	820		13	6.7	6.9	7.2
10.35	8.24	6.56	7.32	490	475	665	820		9.3	7	7.2	7.2
10.33	8.28	5.89	7.11	795	660	820	820		7.4	6.9	6.9	7.2
10.32	8.11	5.58	7.32	720	685	820	820		8.3	6.8	6.9	7.2
10.28	7.67	5.59	7.11	450	660	820	820	4	8.3	8	6.9	7.2
10.19	8.72	5.58	7.11	725	660	820	820	4	8.3	7	6.9	7.2
9.98	8.63	5.67	6.95	615	660	820	820		8.7	7	6.9	7.2
9.94	8.50	5.63	6.89	655	475	820	820	14	9.6	7.2	6.9	7.2
9.79	8.22	5.58	7.32	670	660	820	820		9.1	7	6.9	7.2
9.78	8.61	5.58	6.58	615	660	820	820	4	7.5	6.6	6.9	7.2
9.74	7.44	5.74	7.11	795	685	820	820		7.9	6.7	7	7.2
9.72	8.56	5.74	7.33	710	685	820	665	24	8.5	6.5	7	7.5
9.72	6.78	5.58	7.63	610	685	820	820	9	5.3	6.8	6.5	7.7
9.61	8.56	5.64	7.67	645	660	820	665	8	8.9	7.4	7.1	7.7
9.56	8.88	5.58	7.05	685	530	820	820	30	8.9	6.6	6.9	8.5

4.1.1 Analysis of Due-Date Performance (DDP)

$$H_0 : P_a = P_b$$
$$H_1 : P_a \neq P_b$$

$\partial = 0.05$

At 5% significance level, p = 0.00000 < 0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$, hence, the research conclusions of this study are: at 5% significance level, Game 1 delivery rate and Game 2 delivery rate have significant differences. According to the average means, Game 2 delivery rate is significantly higher than Game 1 (Table 3).

Table 3: Game 1 and Game 2 verifications

| Variable | T-test for Dependent Samples (Spreadsheet1) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game1	0.714747	0.137801						
Game2	0.996042	0.013431	24	-0.281294	0.141068	-9.76873	23	0.000000

At 5% significance level, p= 0.55299 >0.05, therefore, it does not reject the assumption of $H_0 : P_a = P_b$, hence, the research conclusions of this study are: at 5% significance level, Game 2 delivery rate and Game 3 delivery rate have no significant differences. According to the average means, Game 3 delivery rate is higher than that of Game 2. Game 1is the production operation of long lead time (U-curve right end). The experimental results suggested that Game 1 delivery rate is significantly poorer than that of Game 2 and Game 2 and Game 3 have no significant differences. In other words, the improvement of performance can be immediately and significantly made by shortening the production lead time to move the production operations at the U-curve right end to the left side slightly (Table 4).

Table 4: Game 2 and Game 3 verifications

| Variable | T-test for Dependent Samples (Spreadsheet3) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game2	0.996042	0.013431						
Game3	0.998106	0.009278	24	-0.002064	0.016797	-0.602114	23	0.552988

4.1.2 Analysis of Net Profit (NP)

At 5% significance level, p= 0.42773 > 0.05, therefore, it does not reject the assumption of $H_0 : P_a = P_b$, hence, the research conclusions of this study are: at 5% significance level, Game 1 net profit and Game 2 net profit have no significant differences. According to the average means, Game 2 net profit is higher than that of Game 1. Therefore, reducing the lead time can increase net profit (Table 5).

Table 5: Game 1 and Game 2 verifications

| Variable | T-test for Dependent Samples (Spreadsheet5) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game1	617.5000	105.0259						
Game2	635.8333	69.5743	24	-18.3333	111.2446	-0.807362	23	0.427729

4.1.3 Analysis of Work-In-Process (WIP)

At 5% significance level, p= 0.00001 < 0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$, hence, the research conclusions of this study are: at 5% significance level, Game 1 work-in-process inventory and Game 2 work-in-process inventory have significant differences. According to the average means, Game 2 work-in-process inventory is significantly lower than that of Game 1 (Table 6).

Table 6: Game 1 and Game 2 verifications

| Variable | T-test for Dependent Samples (Spreadsheet7) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game1	8.983333	1.466337						
Game2	6.908333	0.375229	24	2.075000	1.567954	6.483217	23	0.000001

At 5% significance level, p = 0.91634 < 0.05, therefore, it does not reject the assumption of $H_0 : P_a = P_b$, hence, the research conclusions of this study are: at 5% significance level, Game 2 work-in-process inventory and Game 3 work-in-process inventory have no significant differences. According to the average means, Game 2 work-in-process inventory is lower than that of Game 3 (Table 7).

Table 7: Game 2 and Game 3 verifications

| Variable | T-test for Dependent Samples (Spreadsheet9) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game2	6.908333	0.375229						
Game3	6.916667	0.116718	24	-0.008333	0.384387	-0.106208	23	0.916339

According to the above results, work-in-process inventory can be immediately and significantly improved by shortening lead time. The production performance data suggested that shortening the lead time can achieve the effect of significant improvement as proved by the significant changes of Game 1 and Game 2. Game 2 and Game 3 have no significant changes. This suggests that the production performance of Game 2 and Game 3 are at a relatively good state, and

confirms that U-curve has sufficient horizontal area. The data analysis results of machine tool research project can verify the practice of Dr. Goldratt using half of the lead time as the production buffer time is correct. In other words, the analysis data have confirmed that the horizontal area at the center of U-curve has enough breadth. This study confirmed that the practice widely applied in S-DBR that has not been discussed in previous TOC literature before introducing the successful TOC cases to verify the U-curve management thinking.

4.2 Case Study and Analysis

4.2.1 Successful Case 1: a mechanics company

This mechanical company was found in 1962 with a capital of 200,000 NTD net to start the production of punching machine. In 2006~2008, the annual sales volume were approximately 40, 45, and 31 billion NTD. The problems included the poor delivery rate (approximately, 30~45%), long lead time (approximately 30~45 days), high overall inventory level (approximately 0.58 billion NTD), unsmooth production and sales procedures. It started the official introduction of TOC since September 2008. The production processing time is approximately 5~7 days, and the production lead time is up to 30~45 days. Apparently, the company is in the production environment of high management attention at the right end of the U-curve. After the introduction and implementation of TOC up to one year, the S-DBR production system, TOC distribution sales management (raw materials and inventory) are used to shorten the production lead time to 30 days to achieve the specific achievements including (Figure 2): (1) inventory reduced by 30% as compared to that of the first three quarters of last year; (2) the accurate delivery rate improved from 39% of the first three quarters to 80% of the same period in this year, it is expected that the performance can be stabilized at the level of 95%.
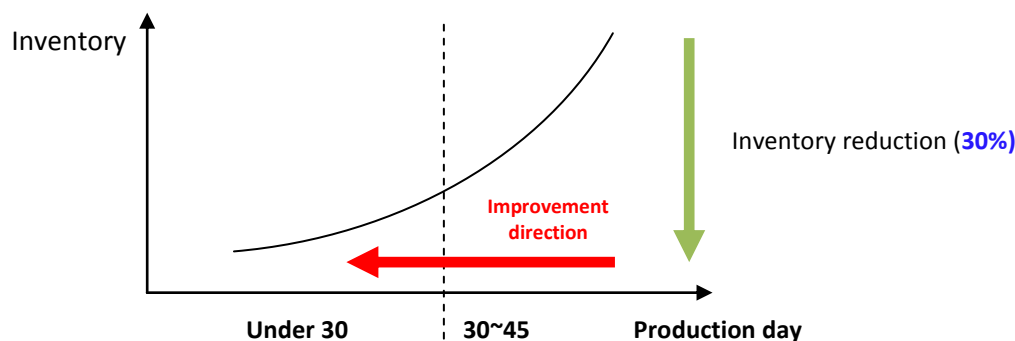

Figure 2: diagram descriptions

4.2.2 Successful Case 2: a furniture company and an aeronautics industry (Table 8)

The furniture company produces wooden furniture and has the processing time of about 3~5 days. The aeronautics company producing components for engine has the processing time of about 8~10 days. However, both companies' production lead time is longer than 2 months,

therefore, they are in a production environment of longer lead time and processing time at the right end of the U-curve. TOC improvement reduces production lead time. Similarly, WIP, sales performance and delivery rate have significant improvements (Figure 3).

Table 8: Case 2 Fundamentals

| Company	**** Furniture	** Aeronautics Industry
Location	Langfang, Hebei	Taiwan
Major Products	Wooden Furniture	Engine components
07 sales volume	0.45 billion RMB (approximately, 2 billion NTD)	5 billion NTD (approximately, 1,200 million RMB)
Number of employees	approximately, 5000 people (average annual output is approximately, 400,000 NTD)	approximately, 1000 people (average annual output is approximately 5 million NTD)
Quality of Operating Personnel	Mainly migrant workers on the site	Professional certified technicians with rich professional knowledge and expertise
Lead time before and after improvement	60->15 days	76->53 days
WIP before and after improvement	0.21 billion ->20 million RMB (reduced by 90%)	0.427->0.238 billion NTD (reduced by 44%)
Factory delivery rate before and after improvement	Below 50% ->99% (changed delivery model)	Below 75% ->95%
Sales improvement level	Increased by 36% (from 0.33~ 0.45 billion RMB)	------------
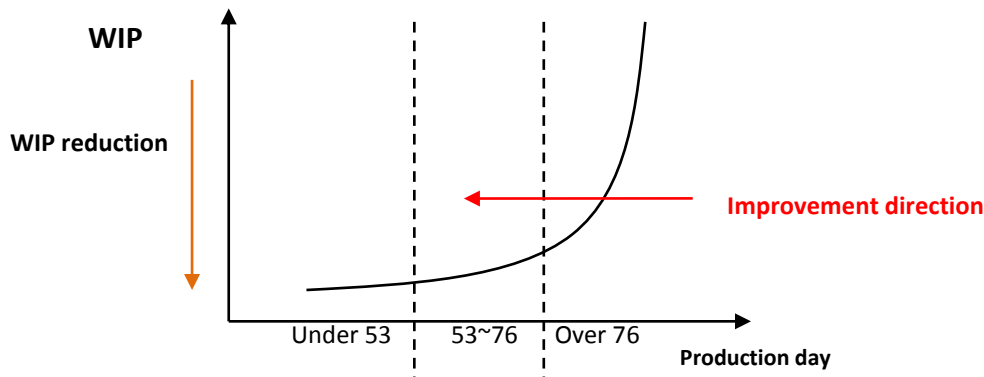
Figure 3: Improvement schematic descriptions

4.3 Discussion of U-curve Management Attention

The management attention indicators include the dispatching of operators, the notification of working extra hours, reminder, guiding employees, plan arrangement, material feeding date setting, and input of crashing cost, communication and coordination. This study collected from the experiments of job shop production the relevant data of production plan adjustment, delivery rate, and average WIP and production priority to further explain the changes of U-curve management attention. The research subjects are university students with industrial engineering background and they were divided into 11 groups to collect relevant data. This study observed and recorded the experimental results and obtained the data from interview.

4.3.1 Experiments

This study used the job shop game established by Wang (2008) to collect the data. The three games are as shown below, and the data collection is verified by Table 9:

Table 9: Data gathering of job shop game

| Group | Game 1 (Management attention) | | | |
	Replan times	DDP	Average WIP	Times of wrong priority
1	3	0.84	3.3	0
2	3	0.88	3.5	0
3	2	0.69	4	0
4	1	0.67	3.7	0
5	2	0.70	3.5	0
6	4	0.91	3.5	0
7	2	0.74	3.8	0
8	4	0.81	4.7	0

9	4	0.93	5.1	0
10	4	0.94	4.5	0
11	3	0.74	3.6	0

	Game 2 (Management attention)			
Group	Replan times	DDP	Average WIP	Times of wrong priority
1	0	1.00	5.9	0
2	0	1.00	5.6	0
3	0	1.00	5.6	0
4	1	1.00	5.4	0
5	1	1.00	5.6	0
6	0	1.00	5.6	0
7	0	1.00	6.1	0
8	2	1.00	4.9	0
9	1	1.00	5.2	0
10	0	1.00	5.6	0
11	0	1.00	5.6	0

	Game 3 (Management attention)			
Group	Replan times	DDP	Average WIP	Times of wrong priority
1	2	1.00	6.8	0
2	1	0.92	8.3	1
3	2	0.95	7.1	1
4	1	0.83	8.9	2
5	1	0.94	8.1	0
6	2	1.00	6.8	0
7	2	1.00	7.5	0
8	1	0.96	7.7	1
9	2	1.00	5.3	0
10	1	0.90	8.9	1
11	2	0.96	7.2	1

Game 1: production lead time is 4 days. In this case, managers should arrange the production process according to the concept of production management and deal with the emergency of the production line. In general, the director may delay the order and save time to re-plan the orders to prevent further delay. According to the interview results of the director, most management behaviors are expected to avoid job order delay by dispatching more employees to work extra hours. Game 2: production lead time is 8 days, as the product processing time is 4 days, therefore, it has sufficient response time to deal with variation, and there are not many products in progress on the production line. Therefore, there will be no wrong processing sequence of operators. Game 3: production lead time is 12 days, the production variation in such an environment is far greater than that of Games 1 and 2, most observed management behaviors are the cooperation with operators and managers in the work shop.

4.3.2 Indicator 1: production plan adjustment

The production plan adjustment means managers change the original order processing manner in an appropriate time. As Game 1 has no sufficient buffer time to deal with variation, even if the variation is very small, emergency can result in the failure of managers to deal with. Therefore, the strength of management attention can be understood by observing the times of the occurrence of the indicator. In this study, regarding times of production plan adjustments in three games, Game 1 has the most followed by Game 3 and Game 2, suggesting that the buffer of Game 1 is too small and thus more time buffer should be provided to reduce management attention. at 5% significance level, p = 0.00005 < 0.05. Therefore, it rejects the assumption of $H_0 : P_a = P_b$. The conclusions of this study are: at 5% significance level, Game 1 and Game 2 have significant differences in terms of production plan adjustment times. According to the average means, Game 1 times are significantly higher than that of Game 2 (Table 10).

Table 10: Game 1 and Game 2 production plan adjustment times verification

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
T-test for Dependent Samples (Spreadsheet5) Marked differences are significant at p < .05000								
Game 1	2.909091	1.044466						
Game 2	0.454545	0.687552	11	2.454545	1.213560	6.708204	10	0.000053

At 5% significance level, p= 0.00608 < 0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$. Hence, the conclusions of this study are: at 5% significance level, Game 2 and Game 3 have significant differences in terms of production plan adjustment times. According to the average means, the times of Game 3 are significantly higher than that of Game 2 (Table 11).

Table 11: Game 2 and Game 3 production plan adjustment times verification

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
T-test for Dependent Samples (Spreadsheet7) Marked differences are significant at p < .05000								
Game 2	0.454545	0.687552						
Game 3	1.545455	0.522233	11	-1.09091	1.044466	-3.46410	10	0.006081

4.3.5 Indicator 2: wrong product priority sequence

If the order priority sequence is not well processed, it may result in delay at any time. To avoid such situations, managers usually will actively help operators to pay attention to the gap between job order and delivery date. Therefore, it most probably occurs in the production

environment of too many products. Game 3 in this study belongs to such a situation, and the times of wrong product is the most.

At 5% significance level, p= 0.01068 < 0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$. Therefore, the conclusions of this study are: at 5% significance level, Game 2 and Game 3 have significant differences in terms of wrong Product priority sequence times. According to the average means, the times of Game 3 are significantly more than that of Game 2 (Table 12). As there is no wrong product priority sequence in the case of Game 1 and Game 2, therefore, it is unable to determine the strength of the indicator of management attention. It is mainly because that the WIP of Game 1 and Game 2 is very low. Compared with Game 3 with more than 6 products of WIP, it is almost unlikely for the operators to do the wrong product priority sequence.

Table 12: Game 2 and Game 3 wrong product priority sequence times verification

Variable	T-test for Dependent Samples (Spreadsheet9) Marked differences are significant at p < .05000							
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game 2	0.000000	0.000000						
Game 3	0.636364	0.674200	11	-0.636364	0.674200	-3.13050	10	0.010681

4.3.6 Indicator 3: Due-Date Performance

At 5% significance level, p= 0.00008< 0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$, therefore, the conclusions of this study are: at 5% significance level, Game 1 and Game 2 have significant differences in delivery rate. According to the average means, the times of Game 2 are significantly more than that of Game 1 (Table 13).

Table 13: Game 1 and Game 2 delivery rate verification

Variable	T-test for Dependent Samples (Spreadsheet27) Marked differences are significant at p < .05000							
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game 1	0.804545	0.101328						
Game 2	1.000000	0.000000	11	-0.195455	0.101328	-6.39756	10	0.000079

At 5% significance level, p= 0.01180 <0.05, therefore, it rejects the assumption of $H_0 : P_a = P_b$, therefore, the conclusion of this study are: at 5% significance level, Game 2 and Game 3 have significant differences in delivery rate. According to the average means, the times of Game 2 are significantly more than that of Game 3 (Table 14).

Table 14: Game 2 and Game 3 delivery rate verification

| Variable | T-test for Dependent Samples (Spreadsheet29) Marked differences are significant at p < .05000 | | | | | | | |
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
Game 2	1.000000	0.000000						
Game 3	0.950909	0.053001	11	0.049091	0.053001	3.071953	10	0.011801

4.3.7 Indicator 4: average WIP and profit relationship

Game 1 has lower level of WIP inventory as compared to Game 2. However, as the delivery rate is low, the production profits are worse accordingly. Therefore, regarding the overall assessment of performance, Game 1 is lower than that of Game 2. Game 3 is even poorer than Game 2 in terms of various performance evaluation items.

5. Conclusions

This study applied a job shop production system (Job Shop Game) for simulation to explore whether the relationship between changes in production buffer time and the strength of management attention is in line with the distribution trends of U-curve from Game 1 to Game 2. According to the differences of three indicators of management attention, Game 2 management attention strength is apparently lower than that of Game 1 or Game 3, confirming the distribution results of management attention of U-curve. In other words, too long production buffer time of the production line can push the management attention to the right end of the U-curve, and vice versa. It can result in the inability to improve the poor performance although the managers have the infinite management attention.

Acknowledgment

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