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MODELING AND SIMULATION OF A LEAN SYSTEM. CASE STUDY OF A PAINT LINE IN A FURNITURE COMPANY

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Abstract
Since they were first developed, lean methodologies have grown in importance and scope and have been applied in both manufacturing and service. However, determining how to transform a common manufacturing company into a lean one, as well as how to evaluate the future company, are challenges for both researchers and manufacturers. This paper presents a case study of a lean manufacturing implementation for the paint line system in a furniture company. A systematic method for execution is shown. In addition, a simulation model is constructed to evaluate the new system in comparison with the MRP system. The new system promises much improvement in terms of a resource's utility and the system's productivity.

Keywords: Lean Techniques, Simulation Model, Paint Line, Furniture Company

1. INTRODUCTION

Lean methodologies are not new technologies for the millennium, but are, in fact, a compilation of many techniques that companies have used in the past and are familiar with. The difference is the consolidation of these techniques into one set of powerful methodologies and their applications. Specifically, they are a series of techniques that allow a product to be produced one unit at a time, at a formulated rate, while eliminating non value-adding wait time, queue time, or other delays (Hobbs, 2004).

Since they were first developed, lean principles have been applied in many fields in both manufacturing and service. Applying lean principles is a systematic approach that focuses the entire enterprise on continuously improving quality, cost, delivery, and safety by seeking to eliminate wastes, create flow, and increase the velocity of the system's ability to meet customer demand (Plenert, 2007).

Lean techniques are growing in importance and scope because they help companies become more competitive and streamlined at a time when competitive and cost reduction pressures have intensified.

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Currently, 35.7% of plants and factories have adopted lean technologies, according to the Industry Week/MPI Census of Manufacturers, which collected responses from 967 plants (Arabe, 2004).

Management of the furniture company studied in this paper also intends to implement lean technologies for its shop-floor. Currently, the MRP (Material Requirements Planning) system is applied in this company. Although the company is able to meet the required productivity, it has many limitations such as an unbalanced shop floor which results in a large WIP inventory, a large amount of scrap, and so on. The company therefore demands a shop floor with balanced resources, less wastes, faster response time to customers and lower inventory.

This paper presents a way to transform the current system used in the furniture company to a lean system. As part of the shop floor, the paint line is used here as a case study. In addition, before applying any new system, it is essential to make an evaluation to determine its benefits. The aim of this step is to make a comparison between the current system and the suggested system. Although by using their knowledge and common sense, the management could recognize the advantages offered by the new lean workshop, more evidence to support the benefits of the lean system is needed to convince management to apply it in their factory. Quantifying alternatives is a useful way to make clear and explicit comparisons between the existing and the proposed systems. The simulation models are constructed with ARENA simulation software, because the simulation technique is a simplified representation of a complex system. The models provide predictions of the system's performance measures under an uncertain or statistical environment. In comparison with the trial and error technique on the real system, the simulation model is less expensive, safer, and is more rapid in evaluating the new system.

2. A SYSTEMATIC LEAN LINE DESIGN APPROACH

In order to identify opportunities for lean system implementation, it is necessary to determine the main products produced by the lean line. The main products must be representative of all the company's products to assure that all of the required processes used to produce these products are included. The number of major products should be neither too small nor too large so that the lean implementation project scale is manageable while still assuring a sufficient return on investment.

In the next step, the future demands of the factory are specified because these are important for determining both lean line capacity and the amount of resources required. Applicable quantitative and/or qualitative methods can be used, and this depends on many factors such as the amount of historic data available, intuitive knowledge, and marketing intelligence.

Consequently, data are collected, which play a very important role in lean implementation. For a successful lean implementation, all efforts in searching suitable methods, as well as time and money invested, are

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worthless without reliable and complete data. Therefore, a detailed data collection plan is required. A good data collection plan should include: a brief description of the project, the specific data that are needed, the rationale for collecting the data, and how the data will be used once it has been collected (Waddick, 2001).

One of the most important data required to design a lean line is the Process Flow Diagram (PFD). A PFD is a graphic illustration commonly used to indicate the sequence and the time input of processes required to manufacture a product. The required processes are combinations of resources such as people and machines necessary to produce a product. Therefore, PFDs should be created for all main products.

After collecting the required data, line balancing techniques are applied, in which the identified sequence of events (SOEs), labor and machine times are simply divided into parts equal to a Takt time, a time/volume relationship used by lean methodology. This is the required rate at each process, which commonly differs and is computed as equation (1),

$$\text{Takt} = \frac{\text{Work Minutes per Shift x \# of Shifts per Day}}{\text{Throughput Volume per Day}} \quad (1)$$

where: Takt is often designed as a “target” or “goal” rate of a process (minutes per unit); Work Minutes per Shift is the actual work time available, and is determined as the amount of time available for a manufacturing operator to perform work in each shift; # of Shifts per Day is the number of shifts per day per process (in minutes). The lean target is one shift per day (usually 8 hours a day); Throughput Volume per Day is the total of demand volume (including the impacts of any rework), scrap, and optional volume considerations (units a day).

Balancing Takt and physically linking manufacturing processes enable the complete output of one process to be directly consumed by another. This dramatically reduces inventories and cycle times. In the lean line, only the resources required to produce the demand are located. The amount of resources required to achieve the throughput volume of each process identified on the PFD is calculated as equation (2),

$$\#\,\text{Resource}_i = \frac{\text{SOE}_i}{\text{Takt}_i} \quad (2)$$

where: # Resource_i: the number of resources required of process i; SOE_i: Standard processing time of process i; Takt_i: Takt time of process i.

Since major products include many products rather than only one product, and the lean line is designed for a mixed product group, it would be better to determine the weighted standard processing time as the representative rather than use the standard processing time on its own. The weighted standard processing time is calculated as equation (3),

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$$ST_{wi} = \frac{\sum V_{ij} \text{ x } SOE_{ij}}{\sum V_{ij}} \qquad (3)$$

where, ST_{wi} is the weighted standard processing time of process i; SOE_{ij} is the standard processing time of product j at process i; and V_{ij} is the daily demand of product j at process i.

Therefore, the number of resources is now calculated by using equation (4) instead of equation (2).

$$\#\ Resource_i = \frac{ST_{wi}}{Takt_i} \qquad (4)$$

It is evident that Takt is a key factor in the design of lean lines. The required resources and the lean balance among processes are determined by the Takt. Each process commonly includes more than one workstation and each workstation includes more than one task, so to achieve the process's speed according to the Takt, balanced workstations are required as shown in Figure 1.

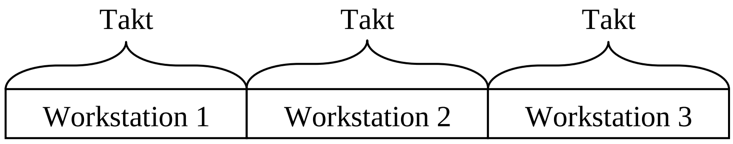

FIGURE 1 - AN ILLUSTRATION OF TAKT TIME

3. A SUGGESTED LEAN SYSTEM FOR PAINT LINE

The paint line is one of four main departments on the shop floor, which include machining, assembly, paint line and packing. The required processes for the machining, assembly and packing groups depend on the products, while those for the paint line are fixed. Every painted part must be processed on six sequential workstations and satisfy the required drying time after each workstation as shown in Figure 2. After processing on the paint line, the painted parts are transported to the packing department.

By applying the systematic approach mentioned in the previous section, a lean line is designed for the paint line. First, the Pareto or 80/20 rule is used to determine the primary products. Twenty-three main products are determined, in which some products include both painted and unpainted groups and others only include painted products. In addition, the new lean system is designed for the future production, so its capacity needs to meet the future demands that are used to determine the lean system's rate. The main products and demands are shown in the Table 1.

Sequentially, the rate or speed required for the lean system is calculated by using equation (1), in which the Work Minutes per Shift × # of Shift per Day equals 502.5 minutes.

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TABLE 1 - MAJOR PRODUCTS AND DEMAND

No.	Code	Demand 2009	Future demand		
			2010	2011	2012
1	1100AFGAC	1344	1344	1613	1747
	1100AUF	576	576	691	749
2	1101AFGAC	1536	1536	1843	1997
	1101AUF	576	576	691	749
3	1121AFGAC	288	288	346	374
	1121AUF	144	144	173	187
4	1126AFGC	288	288	346	374
	1126AUF	192	192	230	250
5	1127AFGAC	360	360	432	468
	1127AUF	240	240	288	312
6	1128AFGAC	360	360	432	468
	1128AUF	144	144	173	187
7	1180AFGAC	816	816	979	1061
	1180AUF	192	192	230	250
8	1181AFGAC	144	144	173	187
	1181AUF	144	144	173	187
9	1182AFGAC	144	144	173	187
	1182AUF	96	96	115	125
10	1318AFGAC	2304	2304	2765	2995
	1318AUF	960	960	1152	1248
11	1319AFGAC	1296	1296	1555	1685
	1319AUF	216	216	259	281
12	1327AFGAC	432	432	518	562
	1327AUF	144	144	173	187
13	1347AFGAC	144	144	173	187
14	2068AFGAC	336	336	403	437
	2068AUF	240	240	288	312
15	2069AFGAC	240	240	288	312
	2069AUF	192	192	230	250
16	2070AFGAC	144	144	173	187
	2070AUF	120	120	144	156
17	2071AFGAC	240	240	288	312
	2071AUF	120	120	144	156
18	1103	360	360	432	468
19	1107	360	360	432	468
20	1136	480	480	576	624
21	1140	480	480	576	624
22	1449	480	480	576	624
23	1451	240	240	288	312

Note: Code: AUF: No paint (natural color), GAC: Paint, number only: Paint

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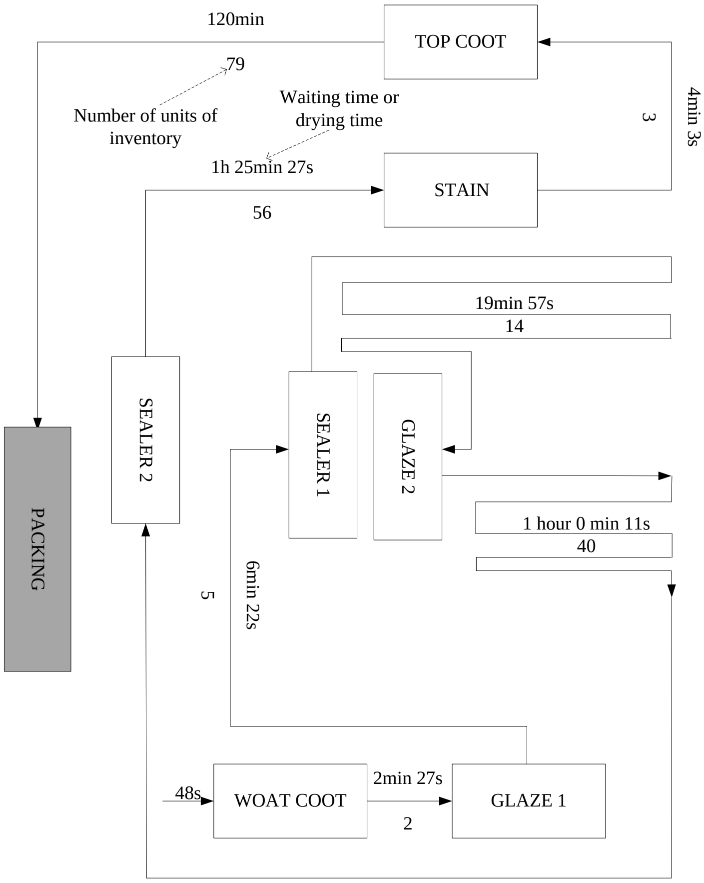

FIGURE 2 - PAINT LINE PROCESS

On the paint line, only products with the characters of AFGAC and that are number coded are processed. Once it enters the paint line, each product must go through all included processes. Therefore, the throughput volume is the same for all processes as follows,

$$\text{Throughput Volume}_{\text{paint line}} = \sum_{i=1}^{23} \text{Demand}_{i(\text{AFGAC})} = 54.81 \text{ (units/day)}$$

The Takt value is therefore the same for all processes on the paint line. In other words, the required rate would be set up at stable conditions for the system.

$$\text{Takt}_{\text{Paint line}} = \frac{502.5}{54.81} = 9.17 \text{ (Minutes/unit)}$$

Balancing Takt and physically linking manufacturing processes enable the complete output of one process to be directly consumed by another. This dramatically reduces inventories and cycle times. In the lean line, only the resources required to produce the demand are located.

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The average weighted standard processing times, and the number of resources required are calculated. Based on these, resources are allocated as shown in the allocated resources row for each work station in Table 2. The work content time i is also then computed as shown in Table 2.

TABLE 2 - RESOURCES ALLOCATION AND WORK CONTENT TIME I

Factors	Woat coat			Sealer 1		Glaze 2		Sealer 2		Stain color			
	Load	Woat coat	Glaze 1	Wiping by clothes	Sealer 1	Sanding 320	Glaze 2	Wiping by clothes	Sealer 2	Sanding 320	Stain color	Top Coat	Unload
Average of STw (seconds/unit)	173.73	127.42	105.16	161.20	99.01	225.84	105.43	370.20	228.97	338.23	180.75	197.20	180.69
Number of Resources (unit)	0.32	0.23	0.19	0.29	0.18	0.41	0.19	0.67	0.42	0.61	0.33	0.36	0.33
Allocated resources (unit)	2			1		1		2		2		1	1
Work content time i (seconds)	203.15			260.21		331.27		299.59		259.49		197.2	180.69

Increasing the streamlining of the production line reduces the chances of having any wasted time. Waste time can include motion, which is one of the original wastes of manufacturing. To avoid unnecessary movement of employees, implementing a lean layout should be a major priority. A lean layout is where all the processes necessary to produce a product are physically linked together. It allows standard work tasks to be accomplished in a sequence and in a progressive manner. However, the physical structure of material handling system of a paint line should not change because of costs and unnecessary items. The locations of workstations on the paint line are re-allocated based on the number of units of inventory. Because differences between the Takt time and the cycle time of required drying times commonly occur, additional inventory is necessary to achieve the balance.

Since the drying time is the required time for continuous movement on the paint line at each workstation, the number of inventories is calculated by applying equation (5),

$$\text{Number of inventory} = \frac{\text{Cycle time of machine}}{\text{Process Takt time}} \qquad (5)$$

where the cycle time of the machine is the drying time after each workstation as shown in Figure 1.

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As mentioned above, the daily throughput volume is 54.81 (units/day) and the Takt time is 9.17 (minutes/unit), which is the same for all processes. Each product has 6 main parts groups, so the Takt required for each part is 1.53 (minutes/part), obtained by dividing 9.17 by 6. The required inventory units are summarized in Table 3.

TABLE 3 - REQUIRED INVENTORY UNITS FOR THE PAINT LINE

Main processes	Woat coat	Glaze 1	Sealer 1	Glaze 2	Sealer 2	Stain color	Top Coat
Waiting time (seconds)	147	382	1197	3611	5127	243	7200
Number of products of inventory (units)	0.27	0.69	2.18	6.56	9.32	0.44	13.09
Number of parts of inventory (units)	1.60	4.17	13.06	39.38	55.92	2.65	78.53
	2	5	14	40	56	3	79

A lean paint line could produce an average of 54.81 units a day. It requires the system rate to be stable at 9.17 minutes per unit. To insure that rate, the number of resources is determined and allocated and the work content times of these resources are calculated as summarized in Table 2. In addition, the re-allocation of physical links among workstations of the lean paint line is suggested following the required inventory units as shown in the Table 3. The new system promises to be significantly superior if implemented.

4. EVALUATION

By using qualitative evaluations, the suggested system promises to become more comfortable when Takt is sufficiently stable and flexible to adapt to changes of products by changing the system's rate at workstations. If the quality system is completely executed by assigning detail responsibility to each worker who is responsible for his/her process and for checking the immediately previous process, the system becomes self-quality controlled. Besides, a fair environment among workers or workstations is created because the employees all work at the same rate. Teamwork skill is actually improved by their co-operation to maintain the system's rate. It is easy for managers to manage by walking around and modifying a process if necessary, because by working on the lean line they know what to do and when to do it. Moreover, once the lean system is applied, the Kanban signals are activated to control the Takt rate; therefore WIPs are controlled.

Quantifying alternatives is another way to make clear and explicit comparisons between alternatives. An Arena model is constructed for the paint line described in the previous section. The model is considered under the following assumptions:

- The semi-products that will be processed on the paint line arrive in a batch including 6 main parts groups per semi-product and follow the exponential distribution.

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- Parts group processing time is fixed into the best distribution with supporting Arena input analysis tool.
- There are only 23 main products considered.
- The unstudied issues such as down time of machine, lack of material or supporting resource, unexpected rest time and so on are not mentioned.

The stable stages of a resource utility and a system productivity are the performance measures in this research. System's information flows are as shown in Figure 3. Two signal systems including Kanban signals and the paint line rate control are used to control the paint line. The former is only designed for a lean system, and the latter is used to modify the speed of the line by creating the number of hooks. The arrival parts are hung up and processed in order through all workstations. An overview of the Arena model is shown in Figure 4, which includes a logic model and an animation view.

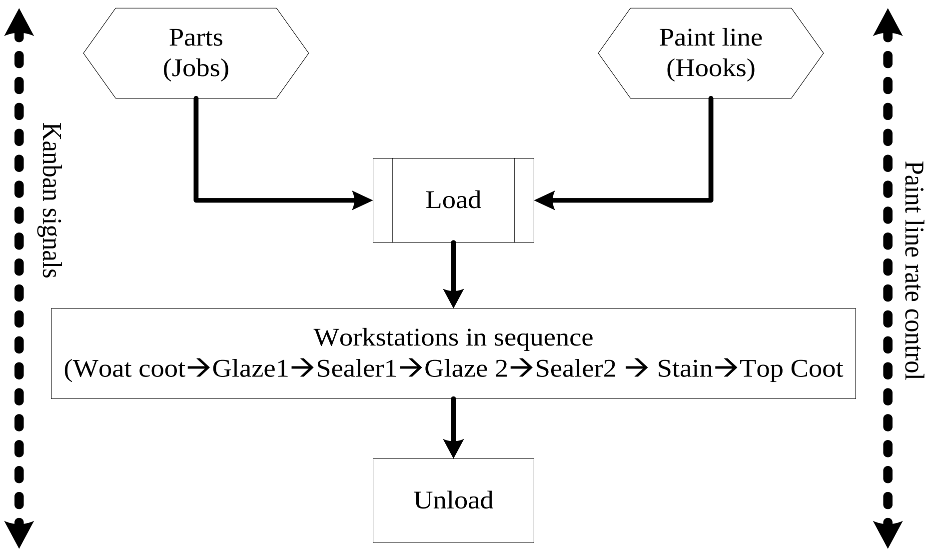

FIGURE 3 - SYSTEM'S INFORMATION FLOWS

Two scenarios are modeled to verify and validate the simulation model by changing the arrival rate. In the first scenario, the arrival rate is equal to the Takt's value of 91.7 seconds per part. At that value, the expected throughput volume is 54.81 products per day or 328.86 parts per day. In the second scenario, the arrival rate is 200 seconds/part, at which it is expected to process 33.33 products per day or 150.75 parts a day. Two hypotheses are created for the two scenarios as follows.

First hypothesis: The throughput volume is 328.86 if the Takt is 91.7

Second hypothesis: The throughput volume is 150.75 if the Takt is 200

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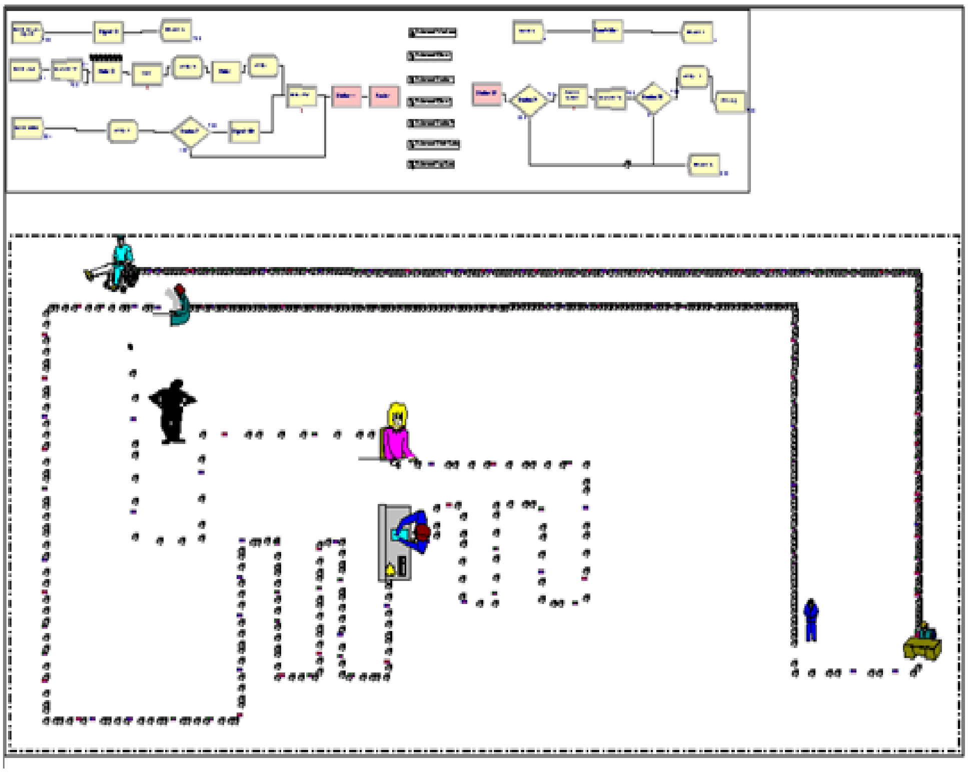

FIGURE 4 - OVERVIEW OF ARENA MODEL

In order to test these hypotheses, simulation results were used. Testing results are summarized in Table 4.

TABLE 4 - HYPOTHESIS TESTING (A = 0.05)

	Scenarios 1	Scenarios 1
Hypothesis	H_0: $\mu = 328.86$ H_1: $\mu \neq 328.86$	H_0: $\mu = 150.75$ H_1: $\mu \neq 150.75$
Test statistic	$t_t = \frac{\overline{X} - \mu_0}{S/\sqrt{n}} = -1.8974$	$t_t = \frac{\overline{X} - \mu_0}{S/\sqrt{n}} = 1.7185$
p-value	0.0637	0.092
Conclusion	Do not reject H_0.	Do not reject H_0.

From the two tests, it is believed that the constructed simulation model can stimulate the current system. It is therefore used to evaluate the suggested lean system.

Two experiments are constructed by changing the input parameters. In the first experiment, denoted S1, the paint line is controlled by the Kanban system, which makes a signal for arrival parts at each Takt value. In the other experiment, S2, arrival products are processed on the system immediately when they enter the paint line system.

To attain sufficient statistical reliability of scenario-related performance measures, each scenario is replicated or run many times subject to different sequences of random numbers, and the results are averaged to reduce statistical variability. In this study, for the resource utility, each scenario is run 50 times, in which each run time is considered as a working day of 8.37 hours; while the throughput volume is run for 304 working days. In addition, to assure that the system is simulated at stable conditions, the warm-up time is set at 8 hours.

From the simulation outputs, comparisons between the scenarios were carried out on the system productivity and resource utility factors.

Throughput comparison

In order to compare whether the suggested lean system provides a better performance for the company once applied, the simulation results were analyzed and compared in terms of the system's expected throughput of 328.86 (parts/day).

Throughputs of the two scenarios were recorded and displayed as shown in Figure 5. The means and standard deviations are calculated as shown in Table 5. From Table 5, it can be seen that the difference between the expected value (mean) of S1 and the system's expected throughput is less than that between S2 and the system's expected throughput. Furthermore, the standard deviation of S1 is less than that of S2; or the data in the S2 case fluctuate more than that in S1 (see also Figure 5). This means that the performance in the S1 case is more stable than that in S2. In other words, the performance of the suggested lean system is superior to that of the company's existing system in terms of throughput volume.

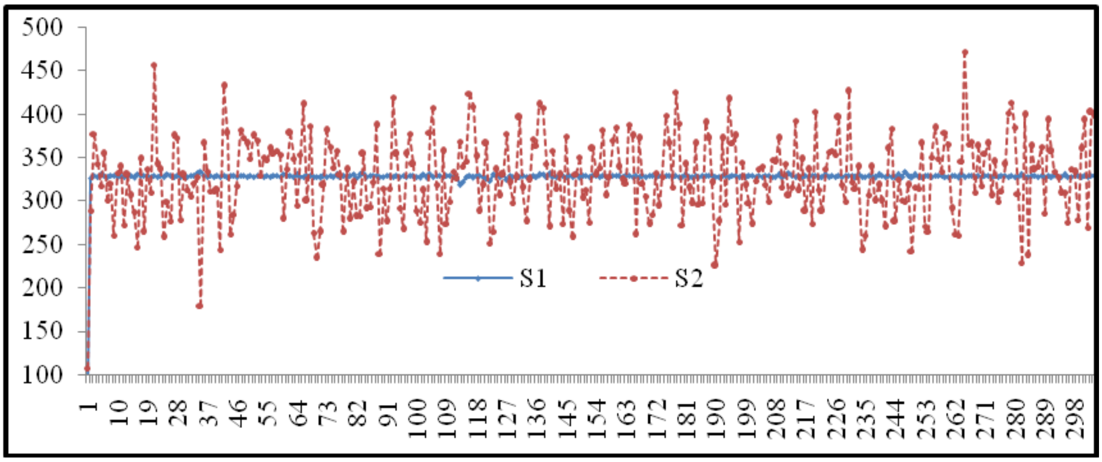

FIGURE 5- OUTPUTS OF S1 VS. S2

TABLE 5 - BASIC STATISTICS

	S1	S2
Mean	328.60	328.45
Standard deviation	1.25635	45.5755

Utility comparison

The utilities are also compared and it was determined that a better system results from more stable utilities and less resources used to produce the same throughput. From corresponding simulation outputs, the stability of utilities is drawn as shown in the following figures (Figure 6 – Figure 12).

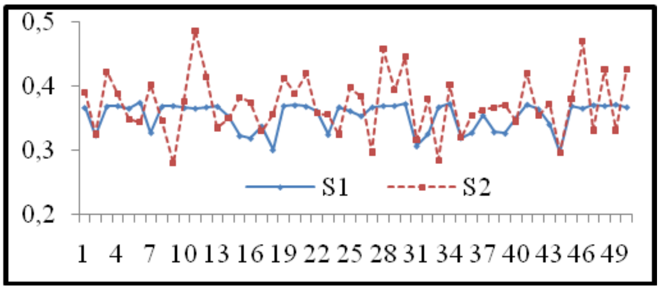

FIGURE 6 – OPERATOR GLAZE 1'S UTILITY

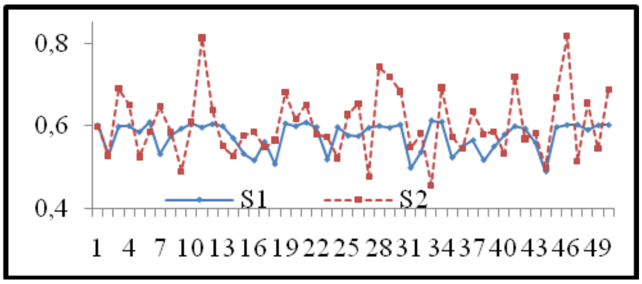

FIGURE 7 - OPERATOR GLAZE 2'S UTILITY

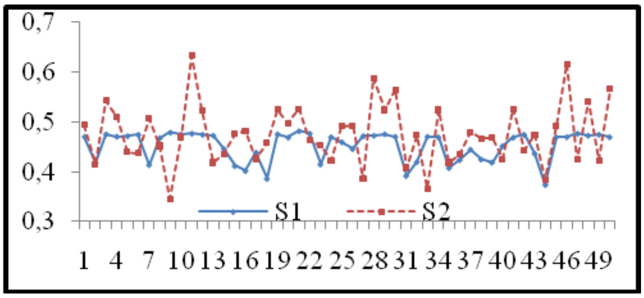

FIGURE 8 - OPERATOR SEALER 1'S UTILITY

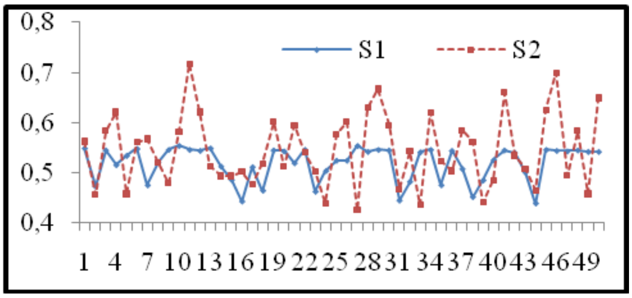

FIGURE 9 - OPERATOR SEALER 2'S UTILITY

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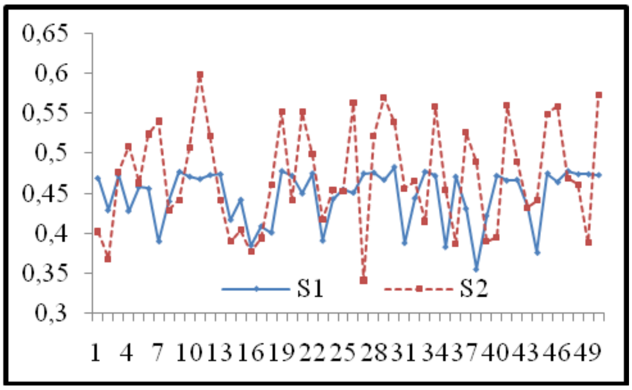

FIGURE 10 - OPERATOR STAIN COLOR'S UTILITY

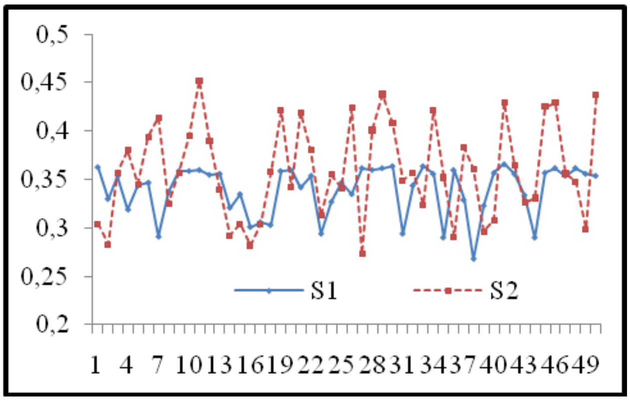

FIGURE 11 - OPERATOR TOP COOT'S UTILITY

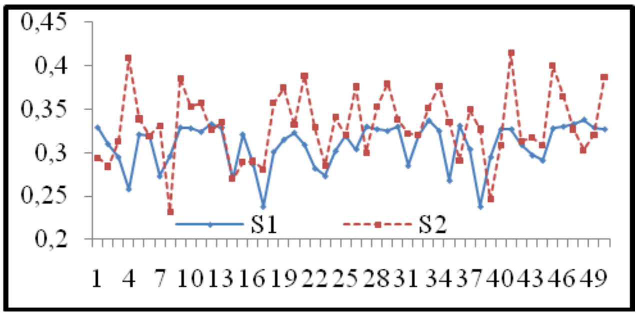

FIGURE 12 - OPERATOR UNLOAD'S UTILITY

Although the operators' utilities fluctuate at every workstation, the fluctuation levels when the suggested lean system is applied (S1) are less than that when the lean system is not applied. In other word, the lean system shows better performance.

For the resource used level, seven hypotheses are conducted to test the resources used level as follows.

Hypothesis i (i = 1..7): *At workstation i, resources used level when suggested lean system is applied is less than that when it is not applied.*

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The test results are summarized as shown in Table 6. It is assumed that population variances are unequal and that the tests are conducted at the significant level of 0.05 (α = 0.05).

TABLE 6 - TEST RESULTS

Operator	Hypothesis	Statistics	p-value	Conclusion
Woat Coot and Glaze 1	H_0: $\mu_1 - \mu_2 \geq 0$ H_1: $\mu_1 - \mu_2 < 0$	- 2.5408	0.0066	Reject H_0
Glaze 2	H_0: $\mu_1 - \mu_2 \geq 0$ H_2: $\mu_1 - \mu_2 < 0$	-2.3685	0.0104	Reject H_0
Sealer 1	H_0: $\mu_1 - \mu_2 \geq 0$ H_3: $\mu_1 - \mu_2 < 0$	-2.3324	0.0113	Reject H_0
Sealer 2	H_0: $\mu_1 - \mu_2 \geq 0$ H_4: $\mu_1 - \mu_2 < 0$	-2.2552	0.0136	Reject H_0
Stain Color	H_0: $\mu_1 - \mu_2 \geq 0$ H_5: $\mu_1 - \mu_2 < 0$	-2.3768	0.0100	Reject H_0
Top Coot	H_0: $\mu_1 - \mu_2 \geq 0$ H_6: $\mu_1 - \mu_2 < 0$	-2.5465	0.0065	Reject H_0
Unload	H_0: $\mu_1 - \mu_2 \geq 0$ H_7: $\mu_1 - \mu_2 < 0$	-3.3755	0.0006	Reject H_0

Note: H_0: Null hypothesis corresponding to each H_i, i = 1,..7; H_1… H_7: the seven testing hypotheses; μ_1 Population mean when suggested lean is applied; μ_2: population mean when suggested lean is not applied.

From Table 6, there is enough evidence to conclude that when the suggested lean system is applied, the level of resources used to produce the same required throughput is reduced. In other words, the lean system provides better performance.

5. CONCLUSIONS AND SUGGESTIONS

From comparisons with the current system, the new lean system promises considerable improvement. The new lean system was evaluated by both qualitative and quantitative techniques. The former technique is mainly based on common sense and depends significantly on the managers' experience and approach. The latter technique is more involved with convincing management to apply the new system. The resource assignment in the new system has proven to be more useful than that in the current system which has two output factors; resources' utility and system's productivity.

The expected rate of the lean system was calculated for every process in the system. Generally, the rates of each process slightly differ, so the Kanban system was designed to control the rate. In addition, necessary resources were determined by Takt to achieve a balance in the lean lines.

Other supporting systems such as 5S, Kanban and Kaizen were proposed to assist the new system. They were designed and implemented to co-operate with the lean lines.

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This paper presented the implementation of a lean system only for a paint line. Therefore, other research needs to be carried out to transform the whole furniture company into a lean system.

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