Using Computer Simulation in Lean Manufacturing Implementation

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ABSTRACT

Lean manufacturing is a systematic approach to identify and eliminate wastes. Adopting the lean manufacturing concepts has become inevitable. It can lead to many advantages including higher efficiency, better responsiveness and flexibility, shorter lead times, and lower rework and defect rates. This ultimately reduces the production costs, and is appropriate for current business environment where it is required to produce a portfolio of products with suitable production capacity.

This paper describes the process of transforming an assembly line to work with lean concepts. A methodology has been developed and used as a framework to utilize various lean manufacturing tools in analyzing the configuration and performance of the assembly line and identify the present forms of waste and their causes. Wastes included high levels of work-in-process that led to high defect rates, frequent inability to meet production targets within regular capacity, lack of flexibility and expensive change over between models were identified. Simulation models of the modified (lean) assembly lines were built and used as management decision support tools to investigate further modifications to the lean system.

Converting the assembly line into a lean production system led to cutting off work-in-process by about 82%, reducing the cycle time by 30%, and decreasing the model changeover time from 127.5 min to 11.5 min, in addition, splitting the assembly line into two parallel assembly lines to produce two models concurrently.

KEYWORDS

Lean Manufacturing, Value Stream Map, Assembly Line, TAKT time, Multi-Skilled operator, Work in Process, Model changeover time, Simulation

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1. INTRODUCTION

Lean is the way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption, and perform them more and more effectively, Womack and Jones [1]. Principles for practical implementation of the lean manufacturing were described in Womack and Jones [2] as outlined in the following sections:

- **Specify Value**
  Value can only be defined by the ultimate customer and is only meaningful when determined in terms of a specific product that meets the customer's needs at a specific price at a specific time. It is important for companies to understand what customer particular needs are at a certain time and what they are ready to pay for
- **Identify the Value Stream**
  The next Lean principle is to identify the actual value stream, i.e. the whole set of activities or services required to produce the specific product
- **Flow**
  After specifying the value, mapping the value stream and eliminating no value adding activities, the next principle in lean thinking consists of making the value-creating activities flow. This is a very critical step as it requires a change in thinking, away from the traditional batch production approach thinking in the direction of the continuous flow thinking.
- **Pull Approach**
  Lean thinking however is not only concerned with the question of how to provide the exact goods and services the customer really wants, but also how to provide it when the customer really wants it. The strategy behind that is the pull principle, which means that you let the customer pull the product from your company as needed instead of pushing products onto the customer and so accumulating huge stocks of products that no one wants
- **Striving for Perfection**
  The final principle is striving for perfection which is some kind of reminder that there is no end in reducing effort, time, space, cost and mistakes while simultaneously producing more and more products which the customer really wants Womack and Jones [1].

The elimination of waste is the goal of Lean philosophy. While the elimination of waste may seem like a simple and clear subject it is noticeable that waste is often very conservatively identified. According to Naval [3], Toyota defined three types of waste:

- **MURI** (or overburden). It is focused on the preparation and planning of the process, or what work can be avoided by design
- **MURA** (or unevenness).It focuses on implementation and the elimination of fluctuations at the scheduling or operations level, such as quality and volume. Mura is traditional general Japanese term for unevenness. Mura is avoided through the Just-in-Time systems.
- **MUDA** (or non-value-added work). It is discovered after the process is in place and is dealt with reactively. The following Seven Wastes identify and classify resources which are commonly wasted Hirano [4]:
  1. Production ahead of demand (excess production)

2. Transportation: To move product that is not actually required to perform the processing.
3. Waiting: Waiting for the next production step or for tools.
4. Inventory: All components, work-in-progress and finished product not being processed.
5. Motion: People or equipment moving or walking more than is required to perform the processing.
6. Over-Processing: Due to poor tool or product design creating activity.
7. Defects: The effort involved in inspecting for and fixing defects.

Once the sources of the waste are identified it is easy to use the suitable lean tool to reduce or eliminate them and make waste free systems. Lean tools, like Value Stream Map, production smoothing, continuous improvement, 5S, single-minute die exchange, total quality management, just-in-time, etc., have been conceived by Toyota production system, Liker [5].
Implementing lean manufacturing principles will involve many changes to the current manufacturing system to make the system lean. Because every company is different and has different needs, the changes made to each company will be different to suit their specific situation. Also creativity is a big part of implementing lean manufacturing principles; people have to fine tune the ways lean principle are implemented and this is done by trial and error most of the time, McClellan [6].Lean principles can be implemented without simulation, but it will require a trial-and-error period to make sure the changes were optimally implemented. The point of this research is not to use simulation to decide if lean principles should or should not be implemented, but work to benefit from the capabilities of simulation to support lean implementation. If simulation were used to help with lean implementation, the optimum solutions to each lean principle could be implemented without it being expensive, time consuming and disruptive. In today's competitive business environment it is essential that everything is done as effective as possible and simulation would help that happen.

2. CASE STUDY

A methodology has been designed to deal with the assembly line problems indicated after waste assessment; the four legs of work methodology are:
Developing Value Stream Map (VSM) and assessing current assembly line status - Preparing Multi-skilled operators – Using Industrial Engineering tools - Utilizing Simulation.

2.1 Developing Value Stream Map, Assessing Current Assembly Line Status

A value stream map (Figure 1) which visually presents all processes flow in the company was constructed. Lean concepts can be implemented anywhere, it depends on company needs or assessments which help in finding the gap between lean and non-lean systems. The big problem at the current VSM is the delay of achieving customers' demand. Usually customers need mix of models during shipping process. Current line can't achieve this easily due to relatively long models changeover time which equal 127.5 minutes, on average, because of that assembly line produce only one model per day, so the researcher select assembly line number one to increase its flexibility and reduce models changeover time, by applying Lean manufacturing principles on it. YAMAZUMI chart as in Figure 2 was constructed. The chart illustrates operations average cycle times and the TAKT time which equals 30 seconds, for the selected product. Figure 2 shows that operations are not balanced with each other. As a result of unbalanced operations cycle times, the assembly line is suffering from 2 types of wastes:

- Waiting Time, equation (1) - Waldemar [7], was used to quantify the unbalance between operations cycle time,

$$\text{Unbalance Index} = \frac{\sum_{i=1}^{n}[(CT)_{longest} - (CT)_i]}{(CT)_{longest}.(n)} = 60\% \qquad (1)$$

  Where:

  - (n) is the number of operations which equal 42,
  - (CT) longest, is operation number 5 which equal 40 seconds.
  - $(CT)_i$ is operation i cycle time, from i=1 to i=42
    (See Figure 3, the 60% is indicated by the black column areas)

- Work in Process, which increases model change time, it was observed that total WIP is equal 255 units per line, also model changeover is 127.5 minutes.

2.2 Preparing Multi-Skilled operators

It was observed that each operator can perform one operation only. Achieving balance between operations cycle time requires rearranging those operations. And this can't occur without improving each operator skills to be capable to perform multi tasks. Training programs were designed and implemented by manufacturing, quality, and human resource departments in four phases:

- Outside assembly line training, in a training room which is equipped with jigs, fixtures, tools, and components used in real assembly line. Also charts and printed work instructions that describe in details all operations within the assembly line. Based on assessment done by manufacturing engineers after this training phase, the researcher classifies operators into two groups, group (A) and group (B). Group A - 24 operators, was selected to continue the second training phase.
- Group (A) are splitted into two equally sub-groups, subgroup (AI), and subgroup (AII).Both subgroups operators are trained in training room again to be multi-skilled. Manufacturing and engineering departments determined the needed skills and set skills priority as shown in Table 1, The researcher constructed a before training skill matrix, based on assessment done by manufacturing supervisors before starting training program inside training room. Table 2 shows subgroup (AI) Skill Matrix before implementing training program. An index was used to assess the total skills of the group. It is shown that subgroup (AI) total skills were 566; also Table 3 shows subgroup (AII) total skills before implementing training program.
- Off-Line Training, training done without running assembly line. Subgroup (AI) and subgroup (AII) operators are positioned on real assembly line, line conveyor was stopped. They perform assembly operations under supervisions and coaching of manufacturing engineers and quality supervisors.
- On Job Training, training done while assembly line running in normal speed. This, to finally evaluate operators of group (A) and make corrective actions concurrently. The researcher construct after training skill matrix (Table 4 and

5), based on assessment done by manufacturing supervisors after finalizing training program phases, total training duration is 85 days.

Skills and knowledge was improved by 114.5% for group (AI), and 97.2% for group (AII) after applying the four phases of training program.

2.3 Using Industrial Engineering Tools

The Activities in each operation were classified, and improvement plan was decided as shown in Figure 4. YAMAZUMI chart after considering this classification was constructed as shown in Figure 5. The following five steps were implemented to achieve balancing between operations cycle time, and to reduce identified type of wastes.

2.3.1 Eliminating Abnormal and UNVA activities

Inspection Process which performed within operations 28, 30, and 31 were considered as abnormal activities and UNVA activities, because suppliers of liquid crystal panels perform this test before panel shipping. That operation (shown in Figure 5) was eliminated directly after a discussion with the engineering department manager. Also in operation number 42 there is an abnormal activity, which is fixing labels that add no value to customer. This activity was eliminated. Table 6 shows the reduction in process cycle time due to eliminating the abnormal activities. Actually 33 Seconds on average were reduced from total cycle time by eliminating abnormal activities, which means 5%reduction in the total cycle time.

The Unnecessary non-value added activates, such as extra cleaning by operators were observed in that all operators clean the units and in particular the glossy front cabinet. Of course all units should be clean, but why should all workers do cleaning! After a discussion, the quality manager agreed to use front cabinet with protection plastic film on its glossy surface, and removes it just before packing the unit. Thus there becomes no need for cleaning this glossy surface in all steps. This eliminated 109 seconds of the total cycle time, which means 16.2% reduction in the total cycle time.

2.3.2 Reducing Bottleneck NNVA Activities

After eliminating both abnormal and unnecessary non value added activities, operations 5 and 33 remained greater than the TAKT time (30 seconds). As shown in Figure 6. Both operations 5 and 33 were considered as bottlenecks processes at that time. Those activities cannot be eliminated directly. Efforts should be done to reduce them, then identify their root causes and eliminate those root causes.

1) In operation number 5, the operator has to cut burrs from front cabinet before assembly. Those burrs come from bad injection mold surface that need to be grinded in the die and mold repair workshop. Repairing the mold surface eliminate burrs then no need to perform such activity.
2) In operation number 33, remote control inspection cycle time was reduced by using special fixture, which reduces excessive operator motion that was the only inspection that was treated.

Figure 7 shows the YAMAZUMI chart after reducing necessary non value added activities in operations number 5 and 33.

2.3.3 Grouping Processes, Reducing Work-In-Process (WIP) Inventory

After preparing multi-skilled operators, operations were combined together as shown in Figure 8. Instead of 42 operators only 9 multi-skilled operators are required to perform the same tasks. For example, operations from one to five are grouped and performed by only one operator, (Figure 9), 12 activities which performed by 5 operators in 62.5 seconds now performed by one multi-skilled operator nearly in the same time, also operations from six to 11 are grouped and performed by one operator. Operators now are capable to perform multiple operations. Figure 10 shows the new operations cycle time in case of utilizing nine multi-skilled operators. As a result WIP between operators was reduced, because there is no significant difference between cycle times, so no relatively high WIP was piled up.

2.3.4 Splitting Assembly Line, Increasing Line Flexibility

The assembly line targeted cycle time after utilizing the nine multi-skilled operators is 60 Seconds, as shown in Figure 10, which is twice the original TAKT time. This did not meet customer demand or production plans. As calculated at the beginning TAKT time must be 30 Seconds. To overcome that, the researcher suggested dividing the assembly line into two parallels lines. This led to changing the layout of the working area from one long assembly line with TAKT time = 30 seconds, to be two short assembly line with cycle time equal 60 Seconds. Instead of 42 operators on the lengthy assembly line only 18 operators in two groups are needed to perform the same tasks, those 18 operators are multi-skilled operators. The benefits achieved out of this are:

- Increasing the ability of producing two models at the same time
- Reducing WIP inventories
- Reducing setup time
- Reducing total usage area

2.3.5 Improving Performance

Figure 10 shows that cycle times of operations number 1, 4, 7, and 8 are greater than 60 seconds. Thus the NNVA activities had to be eliminated in those processes to achieve daily planned production. The researcher observed that each operator had to transport materials and components needed for assembly process every 90 minutes. It was suggested adding two additional operators; one of them for supporting assembly processes operators before furnace area, and the other for supporting testing and packing operators after furnace area. Both of them were for supporting transporting and arrange parts and components during assembly and packing operations. The following list indicates some performed tasks to be done by the two additional operators:

1. Removing front cabinet from cartons and arranging them on table
2. Removing speakers from cartons and arranging them on carriage
3. Removing PCB from cartons and arranging them on table
4. Preparing Cables and arranging them in order on table
5. Assembly power cable, signal cable, and USB to TV before testing
6. Maintaining, checking, and self-calibration of test equipment's.

The Spagitti diagram in Figure 11 explains the motion done by the additional operator to prepare components, release them from packing carton, and supply line operators regularly by needed components. With the two additional operators, the line operators did not waste their time in handling and bringing components any more. By assigning the additional operators the total cycle time of each assembly process was reduced. The additional two operators who handle and arrange parts and components to be ready for assembly directly by multi-skilled operators actually reduced total cycle time for all nine processes. Total reduction in Necessary-Non value added activities was 46 seconds (299seconds before less 253 after the two operators) Figure 12 shows processes cycle time after introducing additional two operators.

However, it was observed that when one of a multi-skilled operator is absent, troubles occur and the cycle time exceeds the 60seconds in addition to more defects. The researcher suggested training the two additional operators on the assembly operations to be multi-skilled operators also. Refresher training programs were implemented, and the two additional operators for handling and arranging parts or components became qualified to make up for any of the nine basic operators after this training. Normally the additional operators perform all supervisions tasks and write all needed reports related to production quantity, produced models, and quality.

The new level of unbalance is shown in Figure 13. The maximum operation cycle time, (CT) longest, is 58 seconds for operation number 7. By adding up the differences between (CT) longest and each operation cycle time (CT) i, the unbalance index value calculated as following:

$$\text{Unbalance Index} = \frac{\sum_{i=1}^{n}[(CT)_{Longest} - (CT)_i]}{((CT)_{Longest}).(n)} = 10.3\%$$

Where: n is the number of operations which equal 9
The 10.3% are indicated by the black columns areas in Figure 13 below.

2.4 Utilizing Simulation

Simulation was used to handle the uncertainty and dynamic factors that could not be captured using the VSM, Detty and Yingling [8]. Also it was used to establish specific parameters of a lean manufacturing system (i.e. the number of kanban, container size, batch size, and mixed-model sequencing approaches).

2.4.1 Why Using Simulation

It was observed that modified assembly line throughput is often below target. The researcher collected data on daily throughput and the average short line output was 428 units, with standard deviation of two. Given that the planned production rate was 450 units. Throughput problem resulted from variation in operations cycle times. In YAMAZUMI chart one draws the average cycle time but variation is not considered. Thus a new YAMAZUMI chart (Figure 14) was prepared to present variation in each operation cycle time, this variation in each operation was not considered before, as shown in Figure 14, maximum value of cycle time in most operations are greater than TAKT time. This is the reason of daily production shortage. The objective of using simulation in this paper is to consider variation in operations cycle time while quantifying and estimating results of new improvement suggestion.

2.4.2 Modeling of Current Assembly Line

Operations within assembly and testing area were simulated. 40 readings were collected in stable and normal conditions of performance; data was fitted in Arena input analyzer, triangular distribution was used. Figure 15 shows the result of operation number one distribution. The researcher accepted that triangular distribution is accurately describes operations cycle time distribution, as corresponding P-value is greater than 0.05 for obtained triangular distributions for all operations, Table 7 describes triangular distribution parameters in seconds for all current processes. Based on actual processes cycle time distribution shown in Table 7, the researcher constructed Arena model presented in Figure 16, with the following assumptions:

1. Working hours per day = 7.5 hours
2. Assembly line failure rate = zero, "where actual assembly line failure rate = 0.00152".

2.4.3 Model Validation

The model shown in Figure 16 was run for 35 replications, and the results for level of output were compared to the output of actual system. Figure 17 "2-sample t test results" indicates that the model is valid, and can be used to experiment with the system. Since the P-value is greater than 0.05, there is no evidence for a difference between simulation model output and actual line output. Figure 17 "2-sample t test results" showed that there is no significant change between actual collected data for current assembly line output and the output obtained from Arena model which simulates current assembly line. The results for level of WIP also compared to the actual system as shown in Figure 18, the comparison indicates that the model is valid, and can be used to experiment the system.

2.4.4 First Proposal for Optimizing Current Assembly Line

Each operation was splitted into small components. The researcher then suggested adding two others operators one of them in assembly area and the other in the final testing and packing area, Figure 19 shows the location of additional two operators. Figure 20 presents the 11 operators cycle time, after rearranging activities. Figure 21 presents common variation in operations cycle time, after adding two operators, also Table 8 shows the triangular distribution of operations cycle time. The researcher modified the valid Arena model to simulate his new suggestion. After running modified model the following results were obtained:

1. WIP = 10±2 Units
2. Line Output = 515±2 Units/day

However, the simulation results in previous model show that operator's utilizations will be as shown in Figure 22.

As can be seen operators number 1, 2, 3, and 5 will be extremely utilized during the working hours. Estimated utilizations can be more than 90%. Although it is estimated that the researcher suggestion can increase the daily production rate, it is not recommended to accept it, as utilizations of some operators can be more than 90%.

2.4.5 Second Proposal for improving Assembly Line performance

In order to reduce utilizations of assembly operators the researcher suggested adding another operator in the assembly area, before furnace, and rearranged activities between operators in previous model (See first proposal), to allocate job for the additional operator as shown in Figure 23. Variation in operations cycle time is considered as shown in Figure 24 and triangular distribution is used to present operations cycle time distribution (see Table 9). The following Arena model (Figure

25) is constructed to simulate the effect of introducing seven operators in assembly area instead of six operators. After running model shown in Figure 25, (35-Replications), the new estimate for utilization of operators, if 515 units were produced per day is shown in Figure 26. Maximum estimated utilization is 87%, which is below 90%. The previous steps indicate the benefits of using simulation to investigate current problem causes and to examine any proposed suggestions before implementation. This leads to saving cost as a result of reducing number of trails.

3. CONCLUSION

A methodology to implement lean concepts in legacy assembly lines, have been developed that is based on:

- Using the VSM to capture the current system status and identify the opportunities for improvements
- Using the traditional IE tools of job and method design, time study, and assembly line balancing, in addition to the other lean manufacturing tools
- Directing the use of simulation modeling to where other lean and IE tools are not feasible
- Developing tailored periodic training programs on using the manufacturing lean tools and to develop multi-skilled operators

A successful implementation of the lean manufacturing concepts has been accomplished by which an assembly line in a leading Egyptian manufacturing firm has been converted into a lean system with remarkably improved performance and productivity. The Firm’s management had a strategic plan of increasing productivity by 2014 and the directions in considerations were building a new assembly line or increasing the current workforce. Both options were not feasible on time due to lack of investments as well as lack of available floor space. The line is still suffers of major forms of waste due to high levels of WIP, long model changeover times, and unbalanced loadings.

As a lean production system, the assembly line was divided into two typical assembly lines that shared the same Furnace operations with the same capacity of the original line but without its associated problems and using about half of the workforce. Converting the assembly line into a lean production system led to:

- Cutting WIP by about 82%; from 510,000 LE to 90,000 LE
- Cutting the cycle time by about 30% (from 6.72 min to 4.68 min)
- Cutting model changeover time by about 91%; from 127.5 min to 11.5 min.
- Producing two different models concurrently.
- Cutting the unbalance level by about 83%; from 60% to about 10.3%
- Cutting the number of operators on the assembly line by 52%, from 42 to 20. Remaining workers were assigned to the other assembly lines that led to enhancing their production rate and eliminating the need for overtime on them
- Cutting the opportunities for defects from 30,000 PPM to 1,100 PPM for the TV panel; 23,000 PPM to 18,500 PPM for the PCB; and from 45,000 PPM to zero for the plastic front cabinet

Simulation models have been built for the modified assembly line to account for the variation in performance that could not be accounted for using the other Industrial Engineering and lean tools. The simulation models offered efficient management decision support tool for the analysis of the system response to suggested changes in task designs and worker assignments. Although proven an effective manufacturing system analysis tool, simulation is expensive and time consuming to build, which supports our dissertation that simulations should be used for systems that have the lean tools applied in order to experiment for further improvement. The common lean manufacturing tools are relatively easy to learn by workers while simulation requires highly skilled experts to develop and use. It can be stated that using simulation in lean manufacturing is most suitable for studying the system after having applied the other common lean manufacturing tools. The use of simulation model revealed the potential of planning further increase in productivity for the targeted 480 units per hour to 550 units per hour and virtually no new investments.

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5. LIST OF TABLES

Table1 : Assembly Skills Priority

No.	Skill definition	Priority number
1	Plastic parts inspections and assembly	1
2	Panel assembly and handling	4
3	Cables and wires assembly and inspections	2
4	Printed Circuit Board (PCB) assembly and handling	3
5	PCB and panel inspections	5
6	TV unit adjusting and testing	5

Table2 : Group A (I) - Before Training Skill Matrix

Subgroup(AI)	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Total
Priority	**1**	**4**	**2**	**3**	**5**	**5**	
Operator 1	9	3	1	0	0	3	38
Operator2	3	0	3	1	9	0	57
Operator3	1	3	0	3	1	0	27
Operator4	1	9	3	0	3	1	63
Operator5	1	1	0	3	9	3	74
Operator6	1	1	0	0	0	9	50
Operator7	9	3	1	0	0	3	38
Operator8	0	9	3	1	0	0	45
Operator9	0	0	9	3	1	0	32
Operator10	0	0	3	9	0	1	38
Operator11	0	0	0	3	9	0	54
Operator12	1	1	0	0	0	9	50
Total							**566**

Table3 : Group A (II) - Before Training Skill Matrix

Subgroup(AI)	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Total
Priority	1	4	2	3	5	5	
Operator 1	3	3	1	0	0	3	32
Operator 2	3	0	3	0	9	0	54
Operator 3	1	3	1	3	1	0	29
Operator 4	1	3	3	0	3	1	39
Operator 5	1	1	0	3	9	3	74
Operator 6	1	1	0	0	0	9	50
Operator 7	9	3	1	0	0	3	38
Operator 8	0	9	3	1	0	0	45
Operator 9	1	1	3	3	1	0	25
Operator 10	0	1	3	3	1	1	29
Operator 11	0	1	0	3	3	0	28
Operator 12	1	1	0	0	0	9	50
Total							493

Table4 : Group A (I) - After Training Skill Matrix

Subgroup(AI)	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Total
Priority	**1**	**4**	**2**	**3**	**5**	**5**	
Operator 1	9	9	3	1	1	9	104
Operator2	9	1	9	3	9	1	90
Operator3	3	9	1	9	3	1	88
Operator4	3	9	9	1	9	3	120
Operator5	3	3	1	9	9	9	134
Operator6	3	9	1	1	1	9	94
Operator7	9	9	3	1	1	9	104
Operator8	3	9	9	3	3	3	96
Operator9	3	3	9	9	3	1	80
Operator10	1	3	9	9	1	3	78
Operator11	1	3	3	9	9	3	106
Operator12	9	9	3	3	3	9	120
Total							**1214**

Table5 : Group A (II) - After Training Skill Matrix

Subgroup(AII)	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Total
Priority	1	4	2	3	5	5	
Operator 1	9	9	1	1	1	3	70
Operator 2	9	1	9	1	9	0	79
Operator 3	1	9	1	9	1	0	71
Operator 4	1	9	9	1	3	1	78
Operator 5	1	1	9	9	9	3	110
Operator 6	1	9	9	3	1	9	114
Operator 7	9	3	3	9	1	3	74
Operator 8	1	9	3	1	1	0	51
Operator 9	1	1	9	9	1	0	55
Operator 10	3	1	3	9	1	1	50
Operator 11	3	1	1	9	9	0	81
Operator 12	1	1	9	9	9	9	140
Total							973

Table6 : Reduction in Operation Cycle Times after Eliminating Abnormal Activities

Operation number	Reduction in cycle time, seconds
28	8
30	6
31	11
42	8.1

Table7 : Triangular Distribution Parameters of Current Operations

Operations	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8	Operation 9
Minimum	50	46	45	47	49	46	51	57	31
Mode	55	52	52	56	51	50	58	58	36
Maximum	65	61	64	70	64	62	71	70	47

Table8 : Triangular Distribution Parameters of First Proposal

Operators	Operator 1	Operator 2	Operator 3	Operator 4	Operator 5	Additional Operator	Operator 6	Operator 7	Operator 8	Additional Operator	Operator 9
Cycle Time (Mode)	50	50.5	47	43.5	43.5	42	43	42	40	36	30.8
min	5	6	7	9	2	4	7	1	5	4	7
max	9.5	9	12	14	13	12	13	12	11	11	11

Table9 : Triangular Distribution Parameters of Second Proposal

Operators	Operator 1	Operator 2	Operator 3	Operator 4	Operator 5	Operator 6	Operator 7	Operator 8	Operator 9	Operator 10	Operator 11	Operator 12
Cycle Time (Mode)	44	41	38.5	37.5	38.5	37	40	43	42	40	36	30.8
Min	39	35	31.5	28.5	36.5	33	36	36	41	35	32	23.8
Max	53.5	50	50.5	51.5	51.5	49	52	56	54	51	47	41.8

6. LIST OF FIGURES

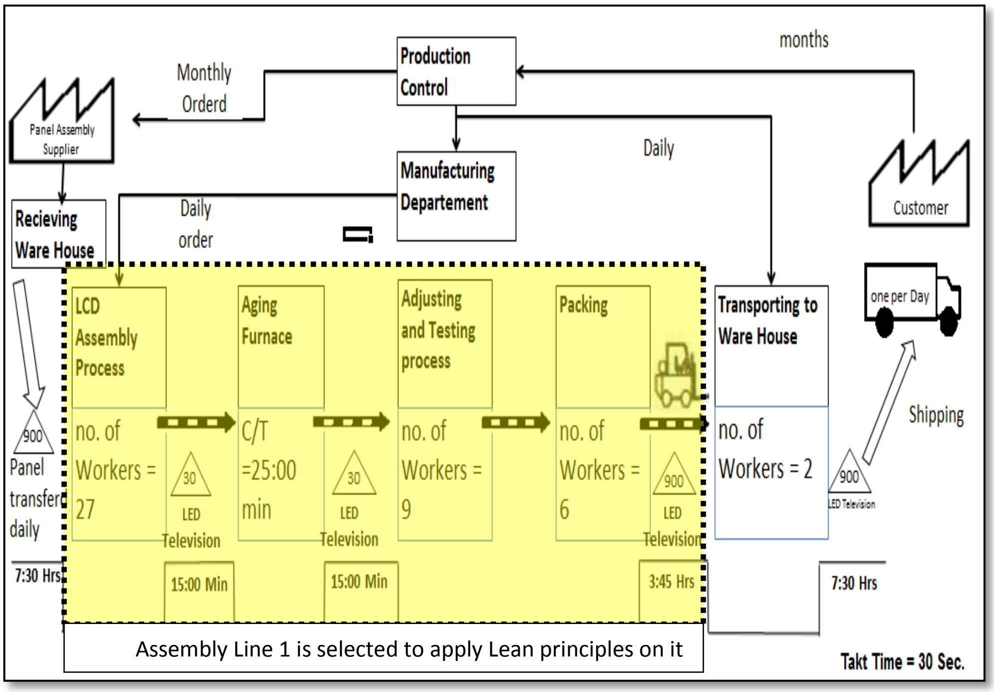

Figure 1: Current Value Stream Map

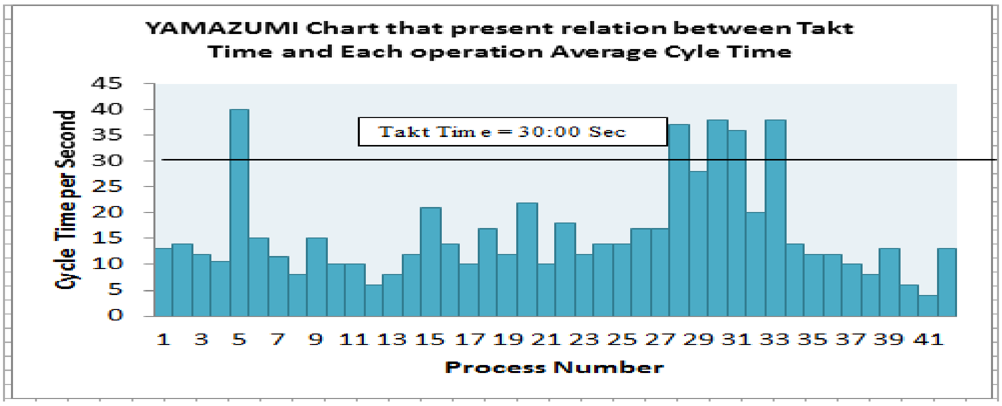

Figure 2: YAMAZUMI Chart

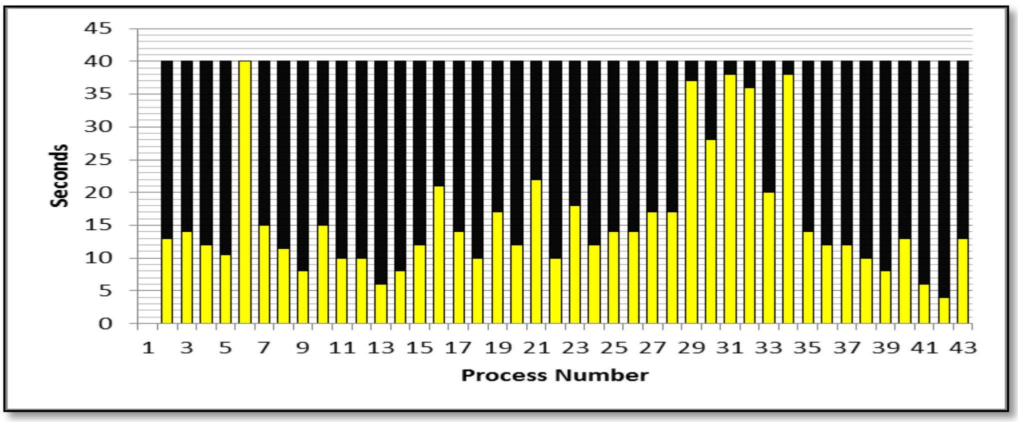

Figure 3: Quantifying of Unbalanced Operations

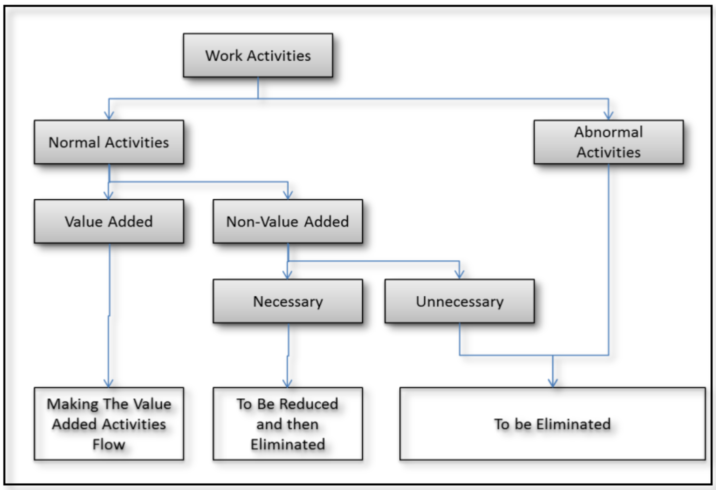

Figure 4: Work Activities Classification

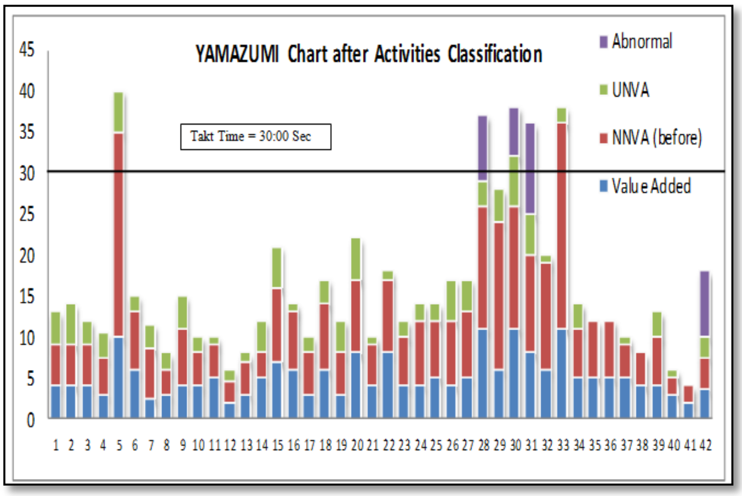

Figure 5: Yamazumi Chart after Work Activities Classification

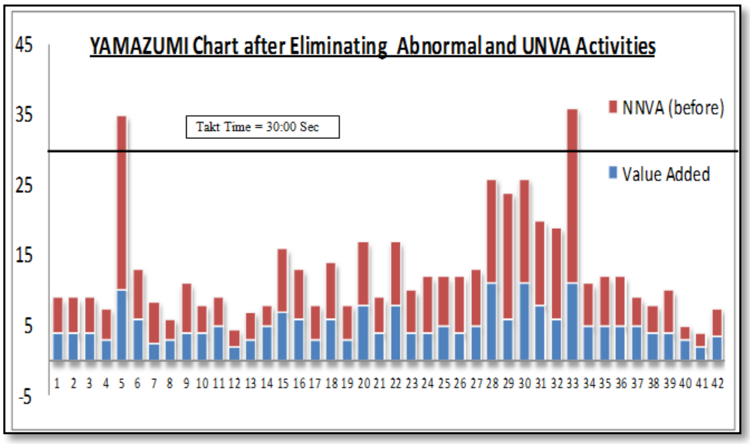

Figure 6: Yamazumi Chart after Eliminating Abnormal and UNVA Activities

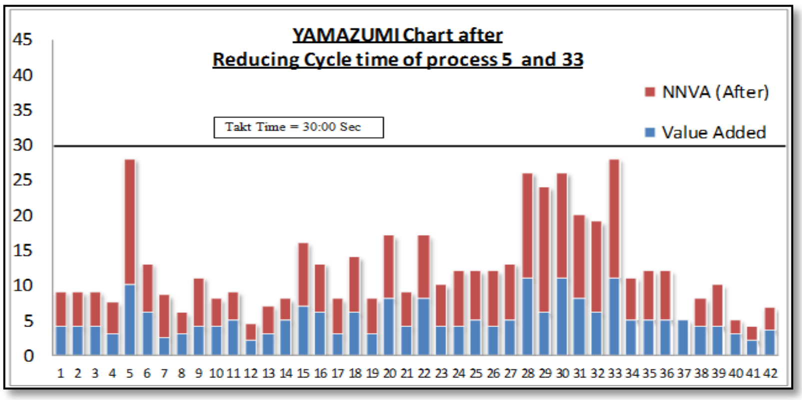

Figure 7: Yamazumi Chart after Bottleneck NNVA Activities

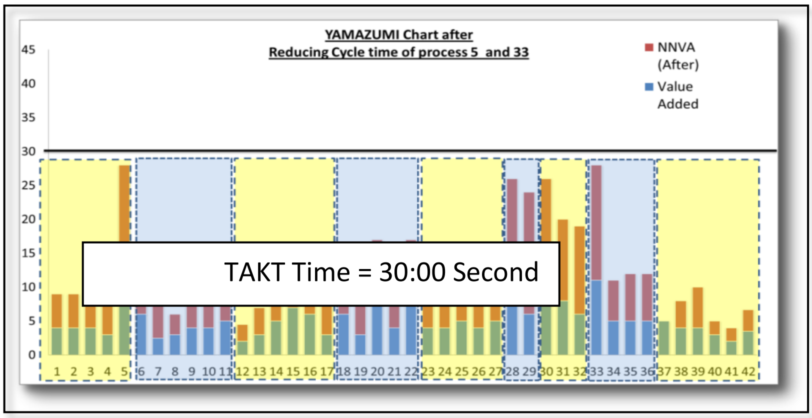

Figure 8: Grouping Operations

no.	Operation Descriptions on LED Assembly - 32 inch size family	number of Operators Before Grouping	number of Operators After Grouping	Operation Time before Grouping Seconds	Operation Time After Grouping Seconds
1	Removing Front Bezel From Back Light Unit	1		9	
2	Removing Plastic From Back Light Unit				
3	Removing Cables over Back Light Unit				
4	Put Insulation Sheet	2		9	
5	Power Board Assembly				
6	Screwing	3	1	9	62.5
7	Barcode of Back Light Unit				
8	Fixed Power On Board				
9	Fixed The Power Cable	4		7.5	
10	Put Back Light Unit On Pallet				
11	Barcode of Inspection Card	5		28	
12	Back Light Unit Inspection				

Figure 9: Grouping of Activities Example

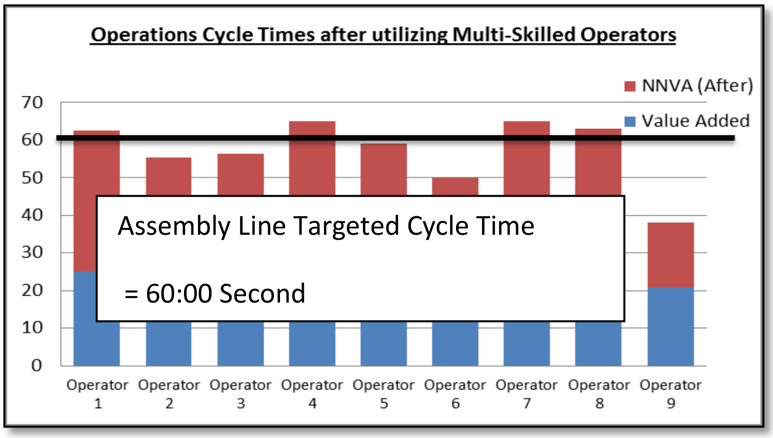

Figure 10: After Grouping Operations

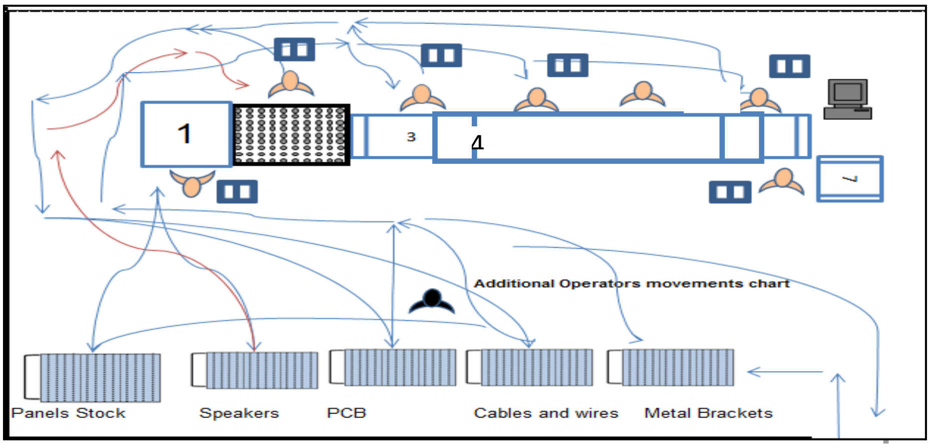

Figure11 : Spagitti Diagram Explains Motion to Handle Materials

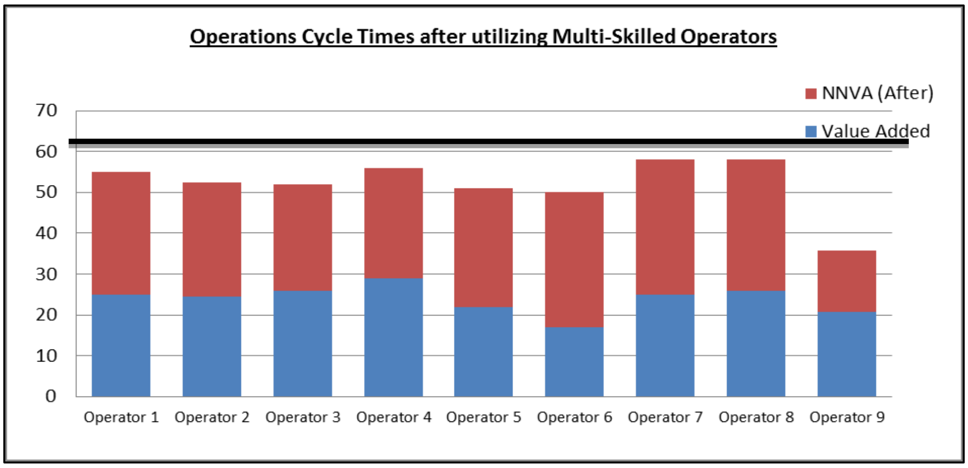

Figure 12: Yamazumi Chart after Introducing Handling Material Operator

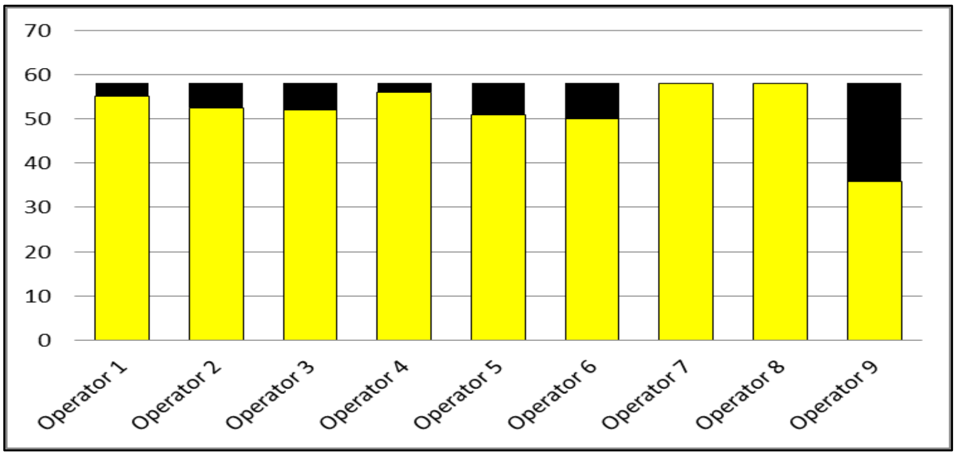

Figure 13: New Level of Unbalance in Line 1

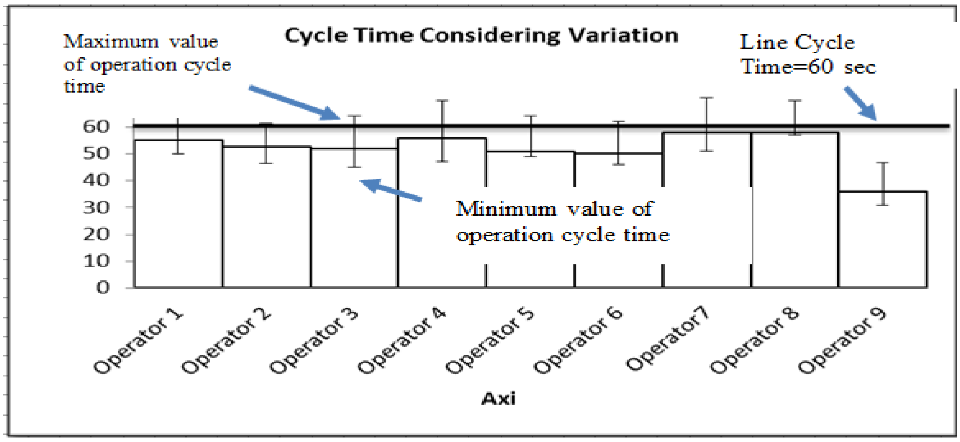

Figure 14: Yamazumi Chart after Considering of Cycle Time Variation

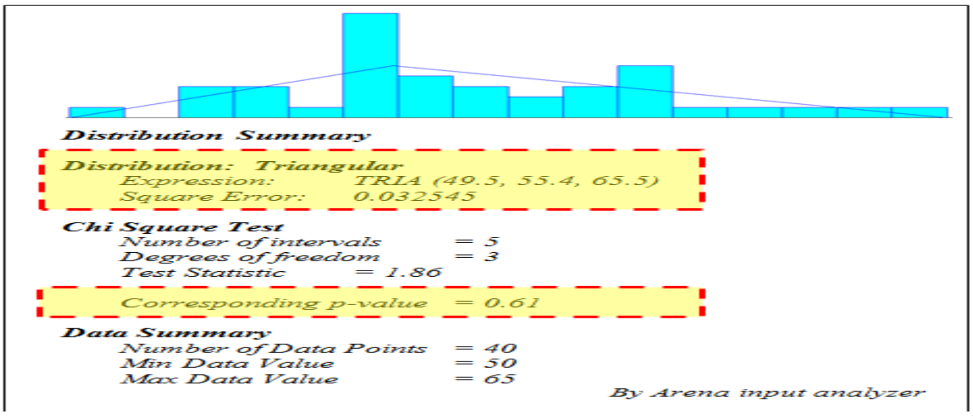

Figure 14: Triangular Distribution of Operation 1

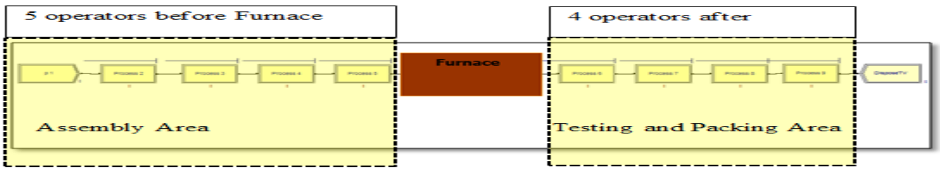

Figure 15: Arena Model which Describe Assembly line

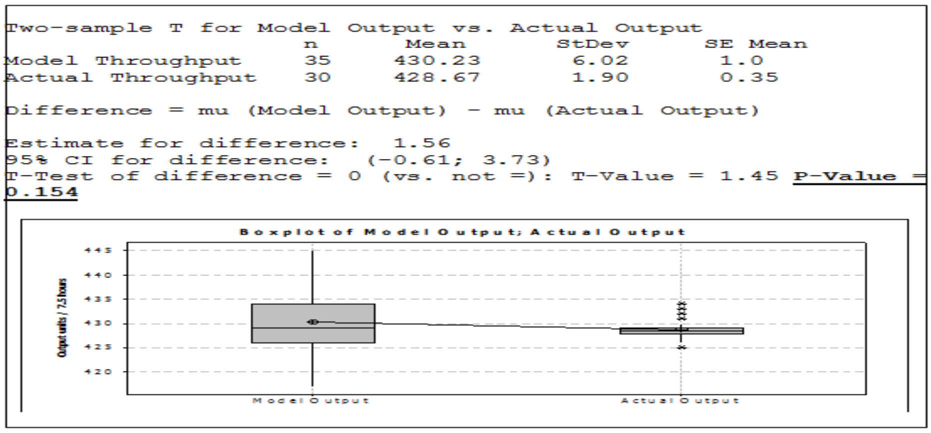

Figure 16: two-Sample t Test of Level of Output

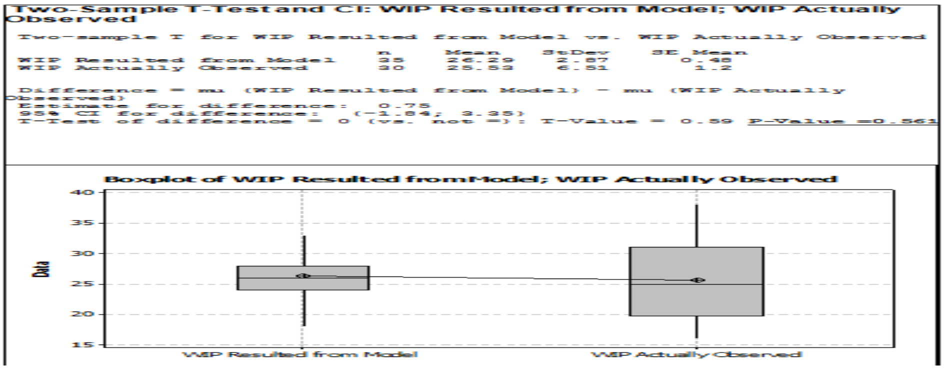

Figure 18: two-Sample t Test of WIP

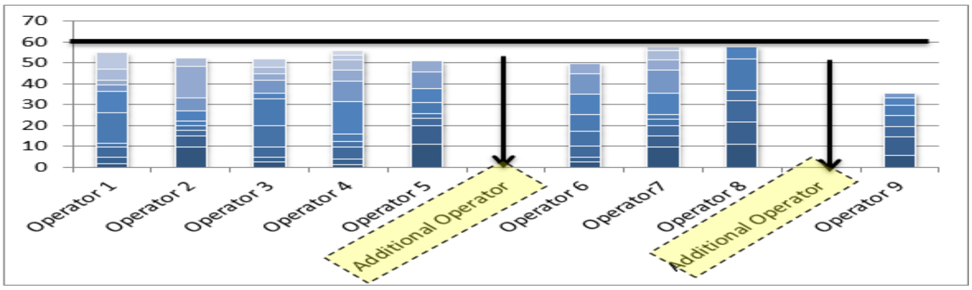

Figure 17: Location of Additional Operators

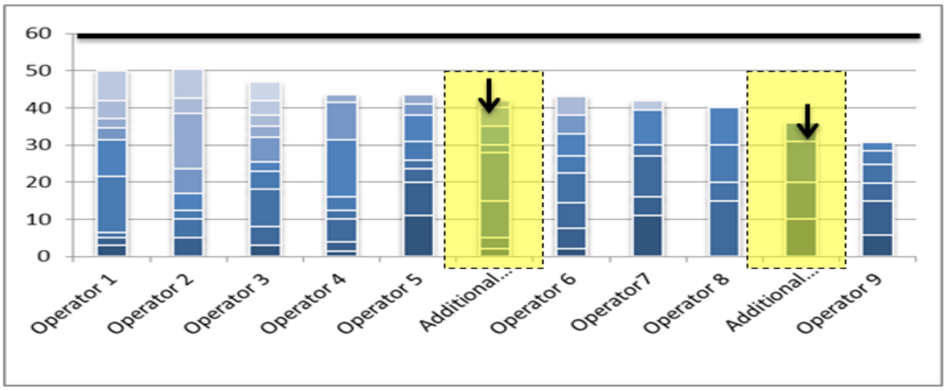

Figure 180: Yamazumi Chart of 11-Operators

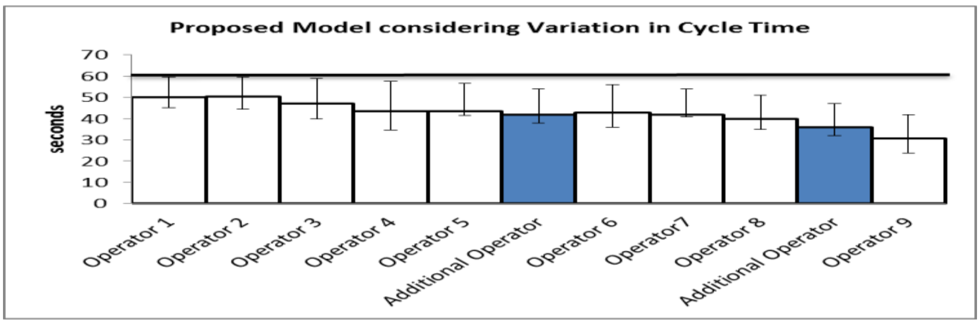

Figure 19: Yamazumi Chart Considering Variations

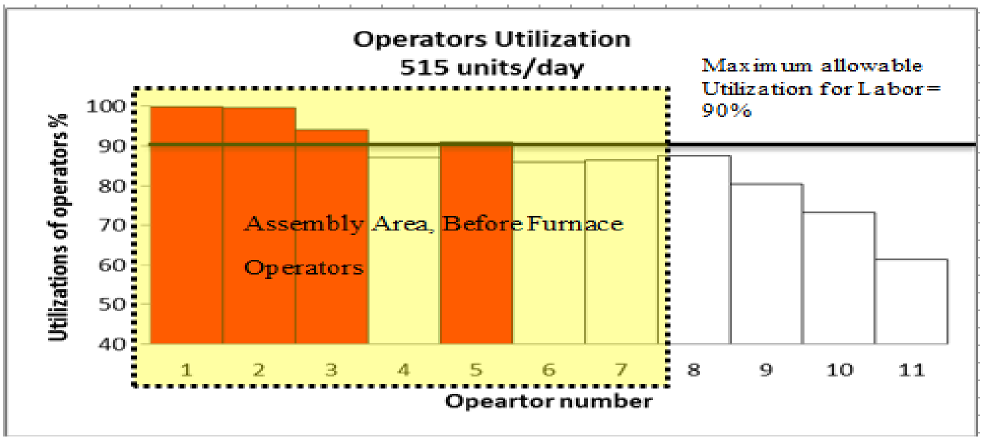

Figure 20: Second Proposal - Seven Operators in Assembly Area

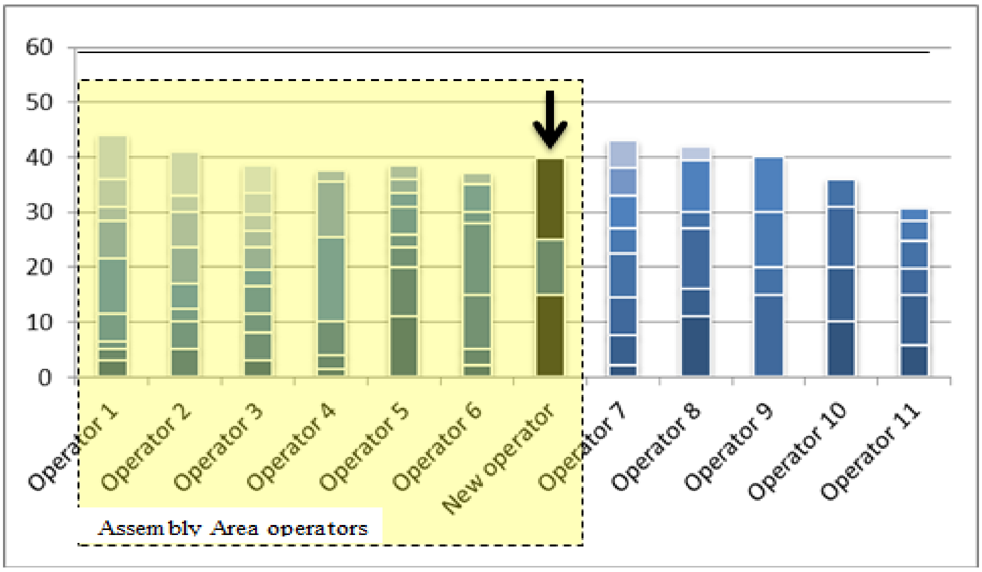

Figure 21: Operators Utilization in first Proposal

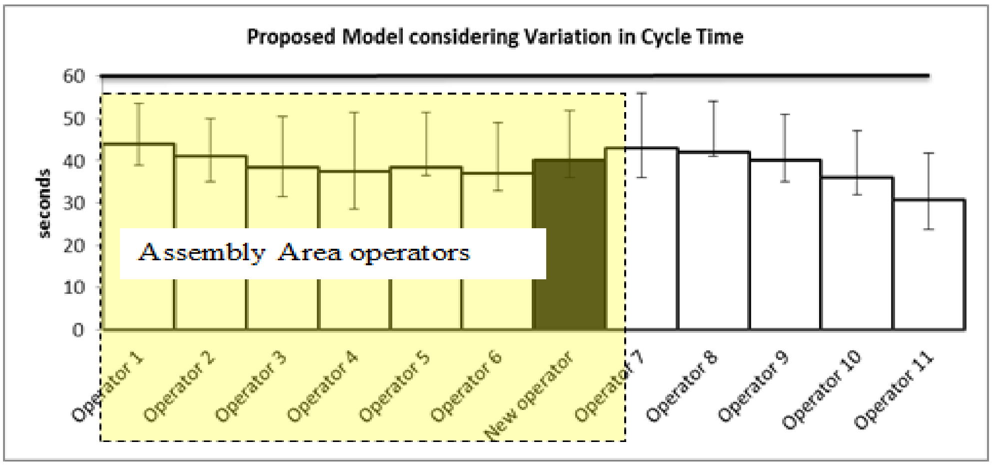

Figure 22: Second Proposal Cycle Time

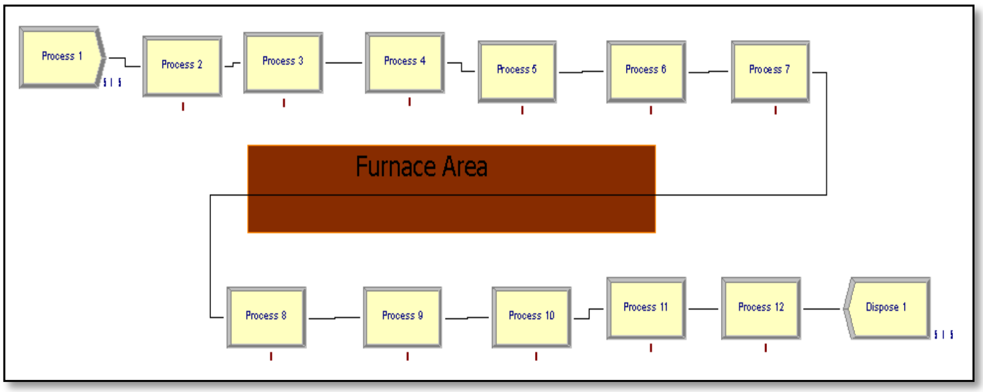

Figure 23: Second Proposal Arena Model

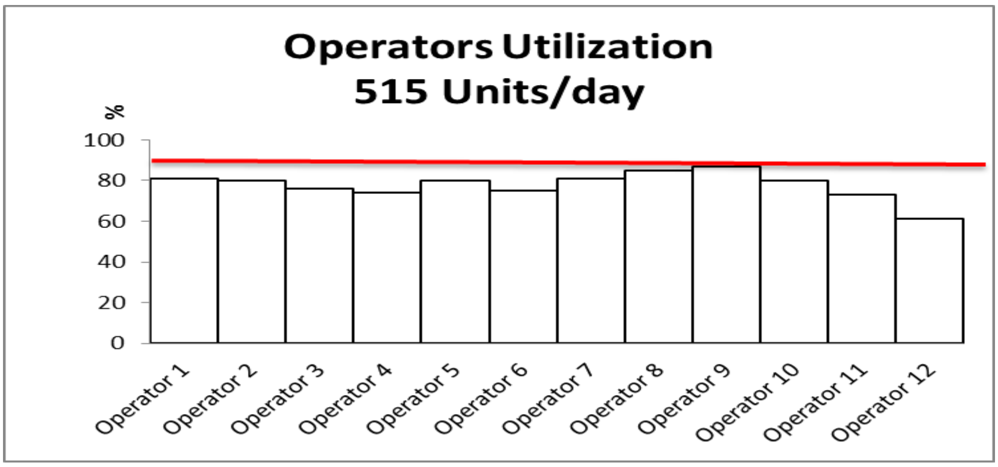

Figure 24: Operators Utilization in Second Proposal