Cycle Time Reduction and Design Improvement of Facility Layout Using Lean Six Sigma with Production Simulation Forecast in Arena

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Synopsis: An industry's ability to survive depends on how well the organization adapts to demands imposed by a changing environment. The industry faces many challenges when the customer demand increases for a fast moving consumer good. To overcome this, necessary steps have to be taken to improve the manufacturing system, with the available facility. This action could be conducted under existing resources such as labour, machines, and other facilities. It is essential to choose a method which is cost effective to reduce the cycle time for the component. In order to reduce the cycle time for the component in an existing plant, the various operations along with the value added and non-value added time were recorded using a flow process chart and studied by using Lean Six Sigma methodology, through lean tools like Takt time and Value Stream Mapping which provide a novel cost-effective method for monitoring and identifying the possible causes for wastage in time. This analysis aims to reduce the non-value added time for the various components manufactured in the plant by using CRAFT algorithm which is one of the primary methods currently used for optimization of facility layouts. The various proposed layouts were analyzed and evaluated through the algorithm and the various performance metrics of the layout were forecasted and evaluated with Arena, simulation software.

I. INTRODUCTION

In today's business circumstances, the old saying "time is money" has been expanded to mean that time is a competitive weapon. By reducing the cycle time in manufacturing and administrative processes, organizations are finding that they can respond faster to customers and become more flexible in dealing with marketplace changes [1]. With rapid increasing of demand in production, industrial factories need to increase their potentials in production and effectiveness to compete against their market rivals. At the same time, the production process needs to be equipped with the ability to have lower cost with higher effectiveness. Therefore, the way to solve the problem about the production is very important [2].

Cycle time reduction is an under-used and valuable addition to any company's business improvement toolbox. It provides a different perspective that may open up significant new working capital and cost reduction opportunities in areas of a company's operations that are often missed using other cost incurring approaches. The cycle time reduction is an approach to business profitability improvement that enhances a company's capability to use time as a strategic weapon to compete and win in intensely competitive global markets [3].

1.1. Value of Cycle Time Reduction:

In this new environment, cycle time reduction provides a key competitive advantage. Reduced cycle time can translate into increased customer satisfaction. Quick response companies can launch new products earlier, penetrate new markets faster, meet changing demand, and can deliver rapidly and on time. They can also offer their customers lower costs because quick response companies have streamlined processes with low inventory and less obsolete stock. With reduced cycle times, quality improves too. Faster processes allow lower inventories, which, in turn, expose weaknesses and increase the rate of improvement [11].

1.2 The Cycle Time Reduction Approach:

Cycle time reduction is inherently different from traditional cost cutting approaches to profit improvement. It enables rather than diminishes an organization's ability to compete, by strengthening a company's core capabilities and by developing the dimension of time as a new strategic weapon. Slashing cycle time is the fastest and most powerful approach to profitability improvement, especially for companies who have already realized most of their core manufacturing. When cycle time reduces, investment in finished goods, WIP inventory and financing of receivables decreases. New market opportunities based upon order fulfilment speed and flexibility are enabled, pricing can be strengthened, and customer loyalty enhanced in existing segments through improved service capabilities .Fewer changes to orders and production schedules mean achieving higher manufacturing efficiency levels. Operating costs decrease, and expediting, overtime, and other costs associated with "rush" orders are eliminated. Write-offs on raw materials, WIP or finished goods inventories are reduced, as there is less damage during storage, and less risk of obsolescence [3].

1.3 The Facility Layout Problem

The facility layout problem is concerned with finding the most efficient arrangement of m indivisible departments with unequal area requirements within a facility. The objective of the facility layout problem is to minimize the material handling costs inside a facility subject to two sets of constraints as department and floor area requirements and department locational restrictions [4].

1.4 Facility Layout Planning

Facility layout is where the pen meets the paper in the design and operation of a production system. A good factory layout can provide real competitive advantage by facilitating material and information flow processes. It can also enhance employees' work life and improved productivity can be achieved. The key innovative practices in facility layout planning includes few of the modern Facility Layout Planning designs viz. CRAFT(Computerized Relative Allocation of Facilities Technique),SLP(systematic layout planning),QAP(Quadratic Assignment Problem), and Basic models like Assembly line balancing, Mixed model line balancing, Group technology layouts, Material handling cost method, Flexible manufacturing system(FMS) too [10].

II. METHODOLOGY

2.1 LEAN SIX SIGMA

Lean Six Sigma is an integration of two World Class Manufacturing improvement philosophies that help organizations improves their performance and competitiveness. Lean causes products to move through processes faster, and Six Sigma improves Quality. It is about relentless, sustained improvement that takes the implementers through analysis, metrics and improvement projects [8]. However, different individual and companies view Lean Six Sigma in different ways. Some would perceive it as a fully integrated system between Lean Manufacturing and Six Sigma while others would perceive as two different concepts which is adapted in parallel. Moreover, the integration between the two quality management concepts varies between each integration as points out that each integration may involve transferring of different tools, ideas and philosophies. This leads to many theories on how Lean and Six Sigma could be integrated. Some authors recommended that Six Sigma should lead the initiatives, with Lean tools added during the analysis phase of the initiatives while other authors recommend that Lean should be the backbone of the framework and Six Sigma is used to reduce and then eliminate the variation found [9].

2.1.1 LEAN SIX SIGMA DMAIC PROCEDURE [13]

The sequence of steps of LEAN SIX SIGMA DMAIC is summarized below.

Step 1: DEFINE

This phase is concerned with the definition of project goals and boundaries, and the identification of issues that need to be measured and analysed by process mapping, where Process mapping is a workflow diagram to bring forth a clearer understanding of a process.

Step 2: MEASURE

The goal of the measure phase is to gather information about the current situation, to obtain the baseline data on the current process performance, and to identify problem areas.

Step 3: ANALYZE

The goal of the analysis phase is to identify the problems and to confirm those causes using the appropriate data analysis tools.

Step 4: IMPROVE

The goal of the improve phase is to implement lean solutions that address the problems identified during the Analyze phase.

Step 5: CONTROL

The goal of the control phase is to evaluate, monitor and maintain the results of the Improve phase.

2.2 PROCESS CHART

A process chart is setting out the sequence of flow of a product or a procedure by recording all events under review using appropriate process chart symbols. This chart gives a record of all events associated with workers.

2.2.1 PROCESS CHART SYMBOL

Process charts use five common symbols like operation, inspection, delay, transport and storage for recording nature of events. These were developed by American Society of Mechanical Engineers (ASME) in 1947 [5].

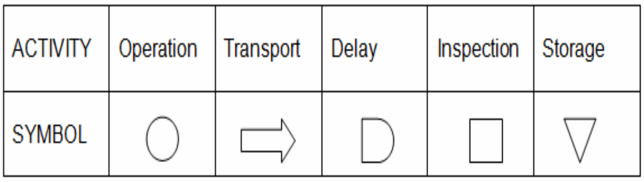

Fig 2.1 Process chart symbols

Lean tools used

The various lean tools used are:

- Takt time
- Value Stream Mapping

2.3.1 TAKT TIME:

Takt time, derived from the German word Taktzeit, translated best as meter, is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand.

Takt time is a management tool to indicate at a glance whether production is ahead or behind it. In fact, its first use (in 1930s Germany) was in the aerospace industry, where product flow was extremely slow and repetitive activities are difficult to discern. Integration of Takt time into manufacturing operation is helpful to set real-time targets for production to show operators exactly where their work output should be at any point of time. Concept of Takt time is also responsible in reminding the process owner so that to keep their own equipment to operate in-aligned with the heartbeat of overall production line in order to achieve the customer demand. It’s important to obtain the total time available to get an accurate Takt time as the heartbeat of production line. In achieving this, the availability of the equipment should be incorporated in the computation of time available [12].

The formula for Takt time is:

Takt time = Available time per week / customer demand per week

Where

Available time per week = total production time per week – breaks

Customer demand = amount of Units required by customer / time period

Takt time is impacted only by customer demand and the amount of time available for production. When demand rises, Takt time drops. When available production time increases, Takt time increases as well.

2.3.2 VALUE STREAM MAPPING

A value stream is defined as all the value-added and non-value-added actions required to bring a specific product, service, or combination of products and services, to a customer, including those in the overall supply chain as well as those in internal operations. Value stream mapping is an enterprise improvement technique to visualize an entire production process, representing information and material flow, to improve the production process by identifying waste and its sources. Value Stream mapping, both current and future state, is created using a pre-defined set of icons. Value stream mapping creates a common language about a production process, enabling more purposeful decisions to improve the value stream. A value stream map provides a blueprint for implementing lean manufacturing concepts by illustrating how the flow of information and materials should operate [7].

2.4 CRAFT- ALGORITHMS

CRAFT is the archetypal improvement-type approach and was developed by Armour and Buffa in 1963. CRAFT begins by determining the centroids of each department in the initial layout, then performs two-way or three-way exchanges of the centroids of non fixed departments that are also equal in area or adjacent in the current layout. For each exchange, CRAFT will calculate an estimated reduction in cost and chooses the exchange with the largest estimated reduction. It then exchanges the departments exactly and continues until there exists no estimated reduction due to two-way or three-way exchanges [4].The CRAFT requirements include Initial layout, Cost per Unit distance, Total number of departments, fixed departments -Number of such departments and location of those departments and area of departments.

III. PROBLEM DESCRIPTION

The company considered for analysis is a leading manufacturer in Pump Industry and utilizes two plants, one for manufacturing main pump components like stator, rotor stamping, rotor brazing, spline coupling, S.S bowls and S.S impeller and the other for manufacturing engineering plastic components like diffuser, venturi tubes and nozzles. The existing cycle time of the pump components results in longer lead time when the customer demand fluctuates, which is the burning problem in the industry. The main reasons of increased cycle time in the company are due to non value adding activities and irregular arrangement of layout, these main reasons should be reduced and solved for the increasing customer demand for a fast moving product. An attempt has been made to reduce the cycle time by using the Lean Six Sigma DMAIC methodology.

3.1 LEAN SIX SIGMA DMAIC

Lean Six Sigma program is a structured procedure for problem solving, represented by the Define – Measure – Analyze – Improve – Control (DMAIC) stages for reducing the cycle time.

The DMAIC sequences of steps are as follows:

DEFINE:

Identification of issues that need to be measured and analysed by process mapping, where Process mapping is a workflow diagram to bring forth a clearer understanding of the manufacturing process.

PROCESS MAPPING

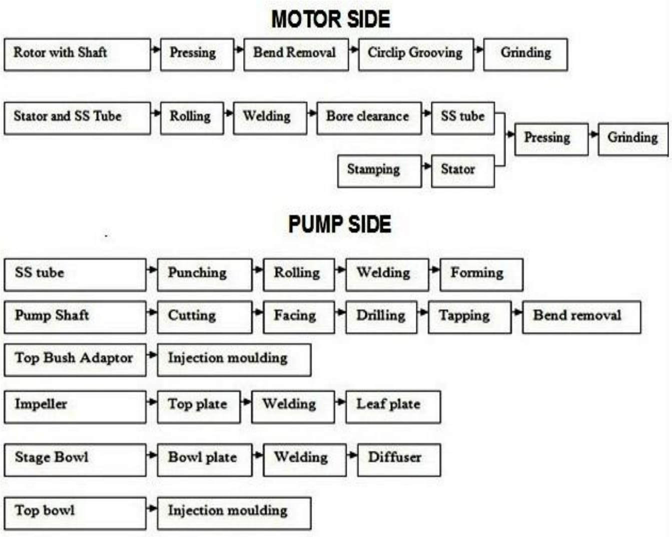

Fig 3.1 Process mapping of pump components

Lean Six Sigma philosophies are used to reduce the cycle time in a manufacturing plant utilizing two Units for the production of submersible pump components. The current manufacturing status of the plant and the factors responsible for the increase in cycle time of the product were first identified by process mapping.

MEASURE

Collection of cycle time for each component using time study.

S.No	Pump Components	Cycle time in seconds
1	Pump shaft	247.70
2	Impeller	48.53
3	Stage bowl	36.97
4	Top bowl	39.42
5	Top bush adaptor	28.35
6	SS tube	370.60
7	Rotor with shaft	718.67
8	Stator and SS tube	238.05

Table 3.1 Measured cycle time

The measure phase consists of collection of baseline data on cycle time for the various pump components, using stop watch time study. The most time consuming operation, was identified and was analyzed by using flow process chart.

ANALYZE

The measured baseline data is used in the analyzing phase for identification of the value added and non value added time using flow process chart as a tool for the most time consuming operation.

IMPROVE

In the improve phase an improvement plan was chalked out based on the results of the analysis phase using lean tools like Takt time and Value Stream Mapping, along with craft algorithm for design improvement in the facility layout.

CONTROL

Based on the analyzed and improved data, the suitable parameters for reducing the cycle time were identified and these parameters were controlled to obtain improved results.

IV. SOLUTION METHODOLOGY

The Lean Six Sigma DMAIC methodology along with lean toolkit and flow process chart is used to identify the possible causes to reduce the cycle time and craft algorithm is used to improve the facility layout.

4.1 TAKT TIME

Effective working hours / Customer demand

(22 hours x 26 days) / (1000 per month) = 3.432 minutes (205.92 seconds)

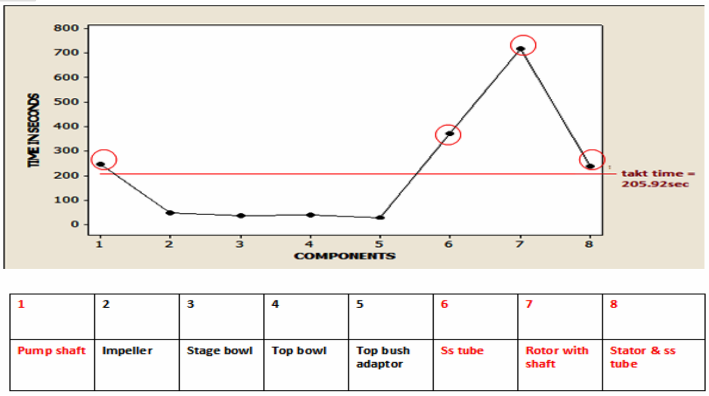

Fig 4.1 Chart on Takt time

The chart shows the Takt time which is plotted against the measured data. The key concentration is to be given to encircled points in the chart, which has a high cycle time when compared with the Takt time. Using this analysis the major components contributing for increase in cycle time of the pump components is identified and further analyzed by using flow process chart.

4.2 ACTIVITY CHART

The flow process charts were measured, recorded and converted into an Activity Chart for the pump components, which were identified by using the Takt time chart. The key concentration is given to the non value added activities which are to be reduced.

4.2.1 PUMP SHAFT

ACTIVITY			Distance (m)	Time(sec)
OPERATION	○	10		158.34
TRANSPORT	⇨	4	11.77	33.18
DELAY	D	1		34.16
INSPECTION	□	1		22.02
STORAGE	▽	3		

Fig 4.2.1 Activity chart on pump shaft

The above Activity chart indicates the value added time as 180.36 sec, non value added time as 67.34 sec and total distance travelled by the operator is 11.77 metres.

4.2.2 SS TUBE

ACTIVITY			Distance (m)	Time(sec)
OPERATION	○	22		233.77
TRANSPORT	⇨	11	45.7	136.83
DELAY	D	0		
INSPECTION	□	0		-
STORAGE	▽	10		

Fig 4.2.2 Activity chart on SS tube

The above Activity chart indicates the value added time as 233.77 sec, non value added time as 136.83 sec and total distance travelled by the operator is 45.7 metres.

4.2.3 STATOR AND SS TUBE

ACTIVITY			Distance (m)	Time(sec)
OPERATION	○	15		110.55
TRANSPORT	⇨	6	36.02	107.09
DELAY	D	1		20.41
INSPECTION	□	0		-
STORAGE	▽	6		

Fig 4.2.3 Activity chart on Stator and SS tube

The above Activity chart indicates the value added time as 110.55 sec, non value added time as 127.5 sec and total distance travelled by the operator is 36.02 metres.

4.2.4 ROTOR WITH SHAFT

ACTIVITY			Distance (m)	Time(sec)
OPERATION	○	25		485.52
TRANSPORT	⇨	12	103.7	233.15
DELAY	D	0		-
INSPECTION	□	0		-
STORAGE	▽	12		

Fig 4.2.4 Activity chart on rotor with shaft

The above Activity chart indicates the value added time as 485.12 sec, non value added time as 233.15 sec and total distance travelled by the operator is 103.7 metres. The key concentration is given to the non value added activities which are to be reduced.

The flow process charts obtained are used to identify the non value adding activities and value added activities of the process.

4.3 APPLICATION OF CURRENT STATE VALUE STREAM MAPPING

4.3.1 UNIT 1

The data obtained from the various flow process charts is used to construct the current state value stream map for Unit 1 using the various value stream mapping symbols.

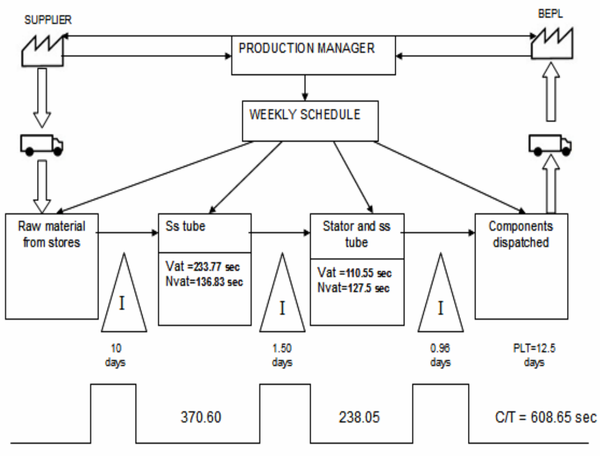

Fig 4.3.1 Current State Value Stream Map of Unit 1

The Current State Value Stream map of Unit 1 represents a weekly schedule for 350 components, along with the Value added time (VAT), Non Value added time (NVAT), Cycle Time(C/T) of 608.65 sec and a Production Lead Time (PLT) of 12.5 days.

4.3.2 UNIT 2

The data obtained from the various flow process charts is used to construct the current state value stream map.

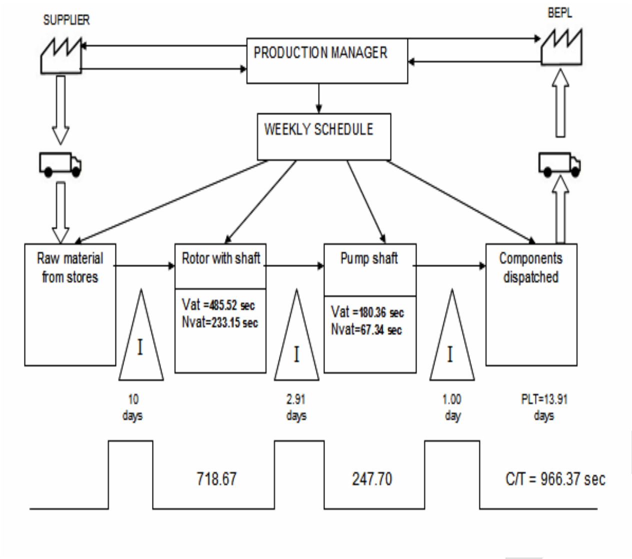

Fig 4.3.2 Current State Value Stream Map of Unit 2

The Current State Value Stream map of Unit 2 represents a weekly schedule for 350 components, along with the Value added time (VAT), Non Value added time (NVAT), Cycle Time(C/T) of 966.37 sec and a production lead time (PLT) of 13.91 days.

4.3.3 PARAMETERS CONSIDERED IN CRAFT ALGORITHM [6]

Objective is the minimizing the total layout cost. The following parameters are involved in finding the Total Layout Cost.

Total layout cost (TLC) = MFFC X (SRF_{whole} / AUF_{whole})

1. Material flow factor cost (MFFC)

$$= \sum_{i=1}^{n} \sum_{j=1}^{n} F_{ij} \times D_{ij} \times C_{ij}$$

Where,

F_{ij} – Material flow between the facility i and j

D_{ij} – Distance between centroids of the facility i and j

C_{ij} – transportation costs per Unit time from Dept i to j

n - Number of Departments

2. Shape ratio Factor $_{whole}$ = $\{\pi\, P_i/4\sqrt{A_i}\}^{1/n}$

Where,

Pi – Perimeter of the Department i

Ai – Area of the Department i

3. Area Utilization Factor $_{whole}$ = $\sum A_i / (\sum A_i + TBA)$

Where,

TBA – Total Blank Area of whole layout

Ai – Area of the Department i

4.3.4 DEPARTMENT PAIRS

The number of interchangeable departments based on common border and common area in Unit 1 and Unit 2 are recorded based on heuristic rules from Craft algorithm. Various departmental interchanges are done for facility improvement based on departments having common border and departments having common area. When there are N departments, theoretically, there are N_{C2} combinations. The problem in Unit 1 and Unit 2 is with five departments and so there are ten pair wise interchanges each respectively. The interchange between two departments means that their present centroids are interchanged. The existing layout is improved by pair wise interchanges between departments and this result in minimized transportation cost. The Material Flow between Departments, Transportation costs per second between Departments and Distance between centroids of the Department 1 to 5, are recorded and jotted in a [5x5] Matrix. This Matrix data is provided as an input to calculate the MFFC for existing and other proposed layouts.

V. RESULTS ANALYSIS AND DISCUSSIONS

5.1 APPLICATION OF CRAFT ALGORITHM

The various proposed layouts has been solved by using craft algorithm and the material flow factor cost for existing and various proposed layouts are obtained and presented. The Layout with minimum MFFC cost is selected to reduce the cycle time, by minimizing the non value adding activities like reduced space utilization, delay time and non value adding movements by operator, from the various proposed layouts, the reduced cycle time is also used as an input parameter for simulation analysis to forecast productivity.

UNIT 1

Interchange Pair	Interchange Rule	Material flow factor cost (MFFC)
Existing layout	-	Rs.5.25
1 & 2	Proposed Layout -1 common Area	Rs.4.71
1 & 4	**Proposed Layout -2 common area**	**Rs.4.47**
4 & 5	Proposed Layout -3 common border	Rs.5.80
3 & 5	Proposed Layout -4 common border	Rs.4.86
2 & 3	Proposed Layout -5 common border	Rs.5.32
2 & 4	Proposed Layout -6 common area	Rs.5.38

Table 5.1.1 layout and Material flow factor cost for Unit 1

The proposed layout -2 having material flow factor cost of Rs.4.47 is selected.

UNIT 2

Interchange Pair	Interchange Rule	Material flow factor cost (MFFC)
Existing layout	-	Rs.64.94
1 & 2	**Proposed Layout -1 common border**	**Rs.57.43**
3 & 4	Proposed Layout -2 common border	Rs.86.18
3 & 5	Proposed Layout -3 common area	Rs.64.95
4 & 5	Proposed Layout -4 common border	Rs.87.70

Table 5.1.2 layout and Material flow factor cost for Unit 2

The proposed layout -1 having material flow factor cost of Rs.57.43 is selected.

5.1.1 SHAPE RATIO FACTOR

The department shape is controlled by using shape measures to detect and penalize irregularly shaped departments. The perimeter for department is assumed to be a rectangle and the perimeter for various departments in Unit 1 and Unit 2 is calculated using the formula,

UNIT 1:

$SRF_{\text{whole layout}} = (5.106)^{1/5} = 1.386$

UNIT 2:

$SRF_{\text{whole layout}} = (6.03)^{1/5} = 1.43$

5.1.2 AREA UTILIZATION FACTOR (AUF)

The area utilization factor provides the effective usage of area in the facility, and provides data on area of the departments and non utilized area by using the formula,

UNIT 1:

TBA - Total Blank Area of whole layout = 7 Sq.m

$\sum Ai$ - Area of the Departments = 35 Sq.m

$AUF_{\text{whole}} = 35 / (35+7) = 83.33\%$

UNIT 2 :

TBA - Total Blank Area of whole layout = 12 Sq.m

$\sum Ai$ - Area of the Departments = 76.5 Sq.m

$AUF_{\text{whole}} = 76.5 / (76.5+12) = 86.44\%$

5.1.5 TOTAL LAYOUT COST (TLC)

The objective in craft algorithm is to obtain Minimum Total Layout Cost (TLC) of the proposed layout which is calculated from using the minimum flow factor cost, shape ratio function and area utilization factor. The values obtained by calculations are used to obtain the total layout cost for the various facility layout designs in Unit 1 and Unit 2 .The minimum total layout cost calculation for proposed layout is presented below.

UNIT 1:

Minimum Total Layout Cost

$= \text{Minimum MFFC X } (SRF_{\text{whole}} / AUF_{\text{whole}})$

= Rs.4.47 X (1.386 / 0.8333)

= Rs.7.44/-

S.no	Facility layout Designs	Total layout cost (TLC)
1	Existing layout	Rs.8.73
2	Proposed layout 1	Rs.7.83
3	**Proposed layout 2**	**Rs.7.44**
4	Proposed layout 3	Rs.9.65
5.	Proposed layout 4	Rs.8.08
6.	Proposed layout 5	Rs.8.84
7.	Proposed layout 6	Rs.8.95

Table 5.1.3 various total layout cost for Unit 1

The proposed layout -2 is selected from the various layouts having a total layout cost of. Rs.7.44.

UNIT 2:

Minimum Total Layout Cost

= Minimum MFFC X (SRF_{whole} / AUF_{whole})

= Rs.57.43 X (1.43 / 0.8644)

= Rs.95.01/-

S.no	Facility layout Designs	Total layout cost (TLC)
1	Existing layout	Rs.107.43
2	**Proposed layout 1**	**Rs.95.01**
3	Proposed layout 2	Rs.142.56
4	Proposed layout 3	Rs.107.45
5.	Proposed layout 4	Rs.145.08

Table 5.1.4 various total layout cost for Unit 2

The Total layout cost for various layout designs obtained by using the respective formula is used to select the minimum total layout cost. The proposed layout - 1 is selected from the various layouts having a total layout cost of Rs.95.01/-.

5.2 APPLICATION OF FUTURE STATE VALUE STREAM MAPPING

The minimum proposed layout obtained using craft algorithm in Unit 1 and Unit 2, reduces the non value adding activity in terms of distance travelled by operator. The cycle time and production lead time are represented in the lower dip of the time line graph and the inventory is represented by means along the higher dip of the time line graph in the future state value stream mapping presented below.

5.2.1 UNIT 1

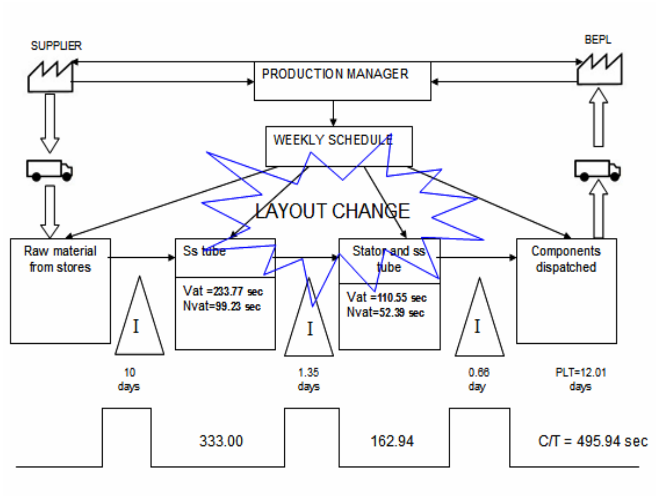

Fig 5.2.1 Future state value stream mapping of Unit 1

The future state value stream map of Unit 1 represents a weekly schedule for 350 components, along with the value added time (VAT), reduced non value added time (NVAT), reduced cycle time(C/T) of 495.94 sec and a reduced production lead time (PLT) of 12.01 days was obtained due change in layout, which is presented by the kaizen burst icon.

5.2.2 UNIT 2

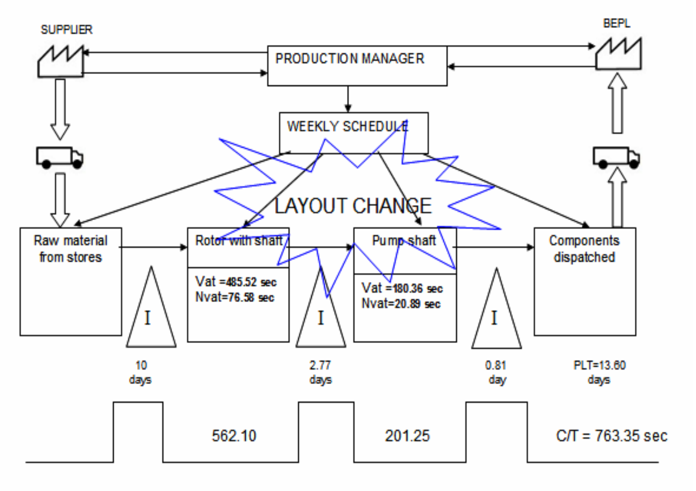

Fig 5.2.2 Future state value stream mapping of Unit 2

The future state value stream map of Unit 2 represents a weekly schedule for 350 components, along with the value added time (VAT), reduced non value added time (NVAT), reduced cycle time(C/T) of 763.35 sec and a reduced production lead time (PLT) of 13.60 days was obtained due change in layout, which is presented by the kaizen burst icon.

5.3 SIMULATION ANALYSIS

The reduced cycle time obtained using craft algorithm for Unit 1 and Unit 2, has been provided as input and analyzed by ARENA software with time period of one week and one month for each individual component. The existing output is compared with Arena output to verify, whether the customer demands are met. The output results include Cycle time, Number in and Number out which are presented.

5.3.1 SIMULATION MODEL OF A PUMP SHAFT [1]

The arrangement of machines and facilities as per the proposed layout -1 for pump shaft is shown in figure below.

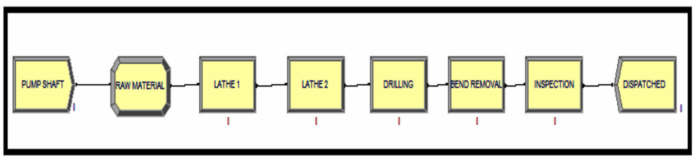

Fig 5.3.1 Pump shaft window flow chart model

5.3.2 PUMP SHAFT WEEKLY OUTPUT REPORT

PUMP SHAFT — Replications: 1

Replication 1 — Start Time: 0.00 Stop Time: 519128.50 Time Units: Seconds

Entity

Time

	Average	Half Width	Minimum	Maximum
VA Time				
Entity 1	0	0.000000000	0	0
NVA Time				
Entity 1	0	0.000000000	0	0
Wait Time				
Entity 1	0	0.000000000	0	0
Transfer Time				
Entity 1	0	0.000000000	0	0
Other Time				
Entity 1	201.25	(Correlated)	201.25	201.25
Total Time				
Entity 1	201.25	(Correlated)	201.25	201.25

Other

	Value
Number In	
Entity 1	1,923
Number Out	
Entity 1	1,922

	Average	Half Width	Minimum	Maximum
WIP				
Entity 1	0.7455	(Correlated)	0	1.0000

System

Other

	Value
Number Out	
System	1,922

Fig 5.3.2 Pump shaft weekly output report

5.3.3 PUMP SHAFT MONTHLY OUTPUT REPORT

PUMP SHAFT — Replications: 1

Replication 1 — Start Time: 0.00 Stop Time: 2103128.50 Time Units: Seconds

Entity

Time

	Average	Half Width	Minimum	Maximum
VA Time				
Entity 1	0	0.000000000	0	0
NVA Time				
Entity 1	0	0.000000000	0	0
Wait Time				
Entity 1	0	0.000000000	0	0
Transfer Time				
Entity 1	0	0.000000000	0	0
Other Time				
Entity 1	201.25	(Correlated)	201.25	201.25
Total Time				
Entity 1	201.25	(Correlated)	201.25	201.25

Other

	Value
Number In	
Entity 1	7,790
Number Out	
Entity 1	7,789

	Average	Half Width	Minimum	Maximum
WIP				
Entity 1	0.7454	0.000132426	0	1.0000

System

Other

	Value
Number Out	
System	7,789

Fig 5.3.3 Pump shaft monthly output report

5.3.4 SIMULATION MODEL OF A ROTOR WITH SHAFT [1]

The arrangement of machines and facilities as per the minimum proposed layout -1 for rotor with shaft is shown in figure below

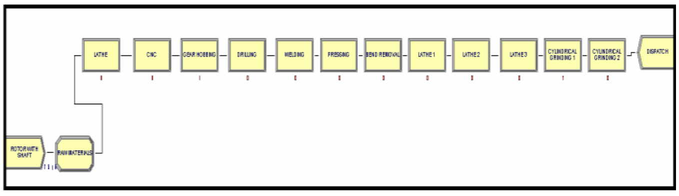

Fig 5.3.4 Rotor with shaft window flow chart model

5.3.5 ROTOR WITH SHAFT WEEKLY OUTPUT REPORT

ROTOR WITH SHAFT — Replications: 1

Replication 1 — Start Time: 0.00 Stop Time: 453386.08 Time Units: Seconds

Entity

Time

	Average	Half Width	Minimum	Maximum
VA Time				
Entity 1	0	0.000000000	0	0
NVA Time				
Entity 1	0	0.000000000	0	0
Wait Time				
Entity 1	0	0.000000000	0	0
Transfer Time				
Entity 1	0	0.000000000	0	0
Other Time				
Entity 1	562.10	(Correlated)	562.10	562.10
Total Time				
Entity 1	562.10	(Correlated)	562.10	562.10

Other

	Value
Number In	
Entity 1	1,680
Number Out	
Entity 1	1,678

	Average	Half Width	Minimum	Maximum
WIP				
Entity 1	2.0812	(Correlated)	0	3.0000

System

Other

	Value
Number Out	
System	1,678

Fig 5.3.5 Rotor with shaft weekly output report

5.3.6 ROTOR WITH SHAFT WEEKLY OUTPUT REPORT

ROTOR WITH SHAFT — Replications: 1

Replication 1 — Start Time: 0.00 Stop Time: 2037386.08 Time Units: Seconds

Entity

Time

	Average	Half Width	Minimum	Maximum
VA Time				
Entity 1	0	0.000000000	0	0
NVA Time				
Entity 1	0	0.000000000	0	0
Wait Time				
Entity 1	0	0.000000000	0	0
Transfer Time				
Entity 1	0	0.000000000	0	0
Other Time				
Entity 1	562.10	(Correlated)	562.10	562.10
Total Time				
Entity 1	562.10	(Correlated)	562.10	562.10

Other

	Value
Number In	
Entity 1	7,546
Number Out	
Entity 1	7,544

	Average	Half Width	Minimum	Maximum
WIP				
Entity 1	2.0817	(Correlated)	0	3.0000

System

Other

	Value
Number Out	
System	7,544

Fig 5.3.6 Rotor with shaft monthly output report

5.3.7 SIMULATION MODEL OF A STATOR AND SS TUBE [1]

The arrangement of machines and facilities as per the minimum proposed layout -2 for Stator and SS tube is shown in figure below

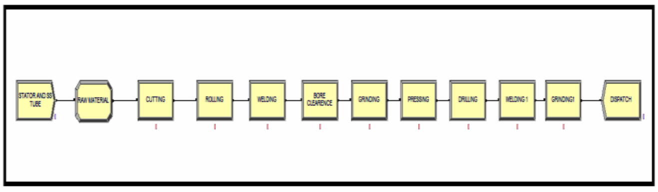

Fig 5.3.7 Stator and SS tube window flow chart model

5.3.8 STATOR AND SS TUBE WEEKLY OUTPUT REPORT

STATOR AND SS TUBE — Replications: 1

Replication 1 — Start Time: 0.00 — Stop Time: 518199.92 — Time Units: Seconds

Entity				
Time				
VA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
NVA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Wait Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Transfer Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Other Time	Average	Half Width	Minimum	Maximum
Entity 1	162.94	(Correlated)	162.94	162.94
Total Time	Average	Half Width	Minimum	Maximum
Entity 1	162.94	(Correlated)	162.94	162.94
Other				
Number In	Value			
Entity 1	1,920			
Number Out	Value			
Entity 1	1,919			
WIP	Average	Half Width	Minimum	Maximum
Entity 1	0.6035	0.000714462	0	1.0000
System				
Other				
Number Out	Value			
System	1,919			

Fig 5.3.8 Stator and SS tube monthly output report

5.3.9 STATOR AND SS TUBE MONTHLY OUTPUT REPORT

STATOR AND SS TUBE — Replications: 1

Replication 1 — Start Time: 0.00 — Stop Time: 2102199.92 — Time Units: Seconds

Entity				
Time				
VA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
NVA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Wait Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Transfer Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Other Time	Average	Half Width	Minimum	Maximum
Entity 1	162.94	(Correlated)	162.94	162.94
Total Time	Average	Half Width	Minimum	Maximum
Entity 1	162.94	(Correlated)	162.94	162.94
Other				
Number In	Value			
Entity 1	7,786			
Number Out	Value			
Entity 1	7,786			
WIP	Average	Half Width	Minimum	Maximum
Entity 1	0.6035	0.000160688	0	1.0000
System				
Other				
Number Out	Value			
System	7,786			

Fig 5.3.9 Stator and SS tube monthly output report

5.3.10 SIMULATION MODEL OF SS TUBE [1]

The arrangement of machines and facilities as per the minimum proposed layout -2 for SS tube is shown in figure below

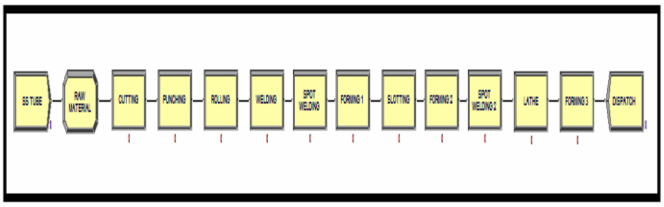

Fig 5.3.10 SS tube window flow chart model

5.3.11 SS TUBE WEEKLY OUTPUT REPORT

SS TUBE — Replications: 1

Replication 1 — Start Time: 0.00 — Stop Time: 520208.33 — Time Units: Seconds

Entity				
Time				
VA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
NVA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Wait Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Transfer Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Other Time	Average	Half Width	Minimum	Maximum
Entity 1	333.00	(Correlated)	333.00	333.00
Total Time	Average	Half Width	Minimum	Maximum
Entity 1	333.00	(Correlated)	333.00	333.00
Other				
Number In	Value			
Entity 1	1,927			
Number Out	Value			
Entity 1	1,926			
WIP	Average	Half Width	Minimum	Maximum
Entity 1	1.2332	(Correlated)	0	2.0000
System				
Other				
Number Out	Value			
System	1,926			

Fig 5.3.11 SS tube weekly report

5.3.12 SS TUBE MONTHLY OUTPUT REPORT

SS TUBE — Replications: 1

Replication 1 — Start Time: 0.00 — Stop Time: 2104208.33 — Time Units: Seconds

Entity				
Time				
VA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
NVA Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Wait Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Transfer Time	Average	Half Width	Minimum	Maximum
Entity 1	0	0.000000000	0	0
Other Time	Average	Half Width	Minimum	Maximum
Entity 1	333.00	(Correlated)	333.00	333.00
Total Time	Average	Half Width	Minimum	Maximum
Entity 1	333.00	(Correlated)	333.00	333.00
Other				
Number In	Value			
Entity 1	7,794			
Number Out	Value			
Entity 1	7,793			
WIP	Average	Half Width	Minimum	Maximum
Entity 1	1.2333	0.000124590	0	2.0000
System				
Other				
Number Out	Value			
System	7,793			

Fig 5.3.12 SS tube monthly output report

VI. CONCLUSION

Lean Six Sigma procedure was used to reduce cycle time in a pump industry, to identify, analyze, and minimize wastes, based upon customer and management request. Thorough investigations revealed various causes like non value adding movements by workers, waiting time and reduced space utilization that contributed largely to minimize production rate and increase wastes. Following a DMAIC procedure, various improvement opportunities are suggested and implemented. As a result, in Unit 1 the cycle time has been reduced from 608.65 seconds to 495.94 seconds and in Unit 2 the cycle time has been reduced from 966.37 seconds to 763.35 seconds respectively. The facility layout problem is an optimization problem that involves determining the location and shape of various departments within a facility, based on the inter-department volume and distance measures. The existing facility layout of various departments has been analysed and evaluated based on the inter-department volume and distance measures. The existing and interchangeable departments and various measures like material flow, distance and cost matrix have been studied. With the existing layout various facility layout designs have been found with a traditional algorithm, Computerized Relative Allocation of Facilities Technique (CRAFT). The proposed layouts in Unit 1 and Unit 2 have been analysed and reduction in non-value added activities like distance measures was done. Layouts with minimum total cost in Unit 1 and Unit 2 have been analysed using Arena, simulation software in which various performance metrics of the layout have been forecasted.

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