# DESIGN AND IMPLEMENTATION OF LEAN LINE CONCEPT IN PE-PUMP ASSEMBLY LINE

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## *Abstract*

*A study was carried out in an automobile fuel injection pump manufacturing assembly line. An aluminium housing which passes through 22 different work stations arranged in a sequence gets assembled with different components and comes out as an assembled fuel injection pump ready for performance test. Such assembly lines were not very productive as they were established 15 years back when lean line concepts were not yet matured and lot of non value additions were part of the line. This work was selected to make the assembly line highly productive as cost reduction was one of the major focuses of the company.*

*This study focuses on improving the productivity, reduce the space and lead time and finally reduce the overall cost of production. The methodology used in this study is lean line design. Value stream was mapped (VSM), identified all the NVA's (Non value additions) and eliminate/ reduce using lean tools and techniques like VSM, Line balancing, Stab Chart, Customer takt, Kanban, Ergonomics, Time study etc. Results were validated through various trial runs.*

*Study during experiment revealed that the non productiveness is mainly due to excess number of operators and improper balancing of line. More lead time and space was due to unnecessary lengthy stations and conveyors, inventories in the line and no control on production process. All such wastes were reduced using scientific methodology and results were validated. Productivity improved by 66%, reduction in space was around 50%, throughput time reduced by by 31% and lead time reduced by 75%.*

**Keywords: Lean line design, Takt time, Bosch production system, MTM (Method-Time Measurement) analysis**

## 1. INTRODUCTION

PE pump is an inline pump, which is also known as fuel injection pump. It is used in automobiles to supply and control the exact quantity of fuel (diesel) with correct timing. These are multi-cylinder pumps, which range from 3 cylinders to 12 cylinders depending on the application. The complete diesel fuel-injection system comprises

- A fuel pump for pumping the fuel from the fuel tank through the fuel filter and the fuel line to the injection pump
- A mechanical governor or electronic control system for controlling the engine speed and the injected-fuel quantity
- A timing device (if required) for varying the start of delivery according to engine speed
- A set of high-pressure fuel lines corresponding to the number of cylinders in the engine
- A corresponding number of nozzle-and holder assemblies

For the diesel engine to function properly, all of those components must be matched to each other. The operating parameters are controlled by the injection pump and the governor that operates the fuel-injection pump's control rod. The engine's torque output is approximately proportional to the quantity of fuel injected per piston stroke. Such pumps are being used in diesel engine vehicles, which are an old technology, but still it has huge market share in Asian countries and also exports to other countries to a small extent.

In the present day of manufacturing, assembly line can be formed easily for any industry whether it is a small-scale or a large-scale industry. When the Takt times are calculated for every part manufactured in the industry through different part movements, then the problem of locating machines on the shop floor occurs when it is a job type production unit. This problem is the main reason for reconfiguration of machines and layout design for every demand. To eliminate these problems, a proper method is required to achieve a rhythm in manufacturing lean assembly line by identifying value adding, non-value adding and necessary non-value adding activities through an optimum feasible takt time [1-4].

The study was carried out in Bosch Ltd, who is pioneer in manufacturing of fuel injection pumps. They manufacture different types of fuel injection pumps in their plants located in Bangalore, Jaipur, Nashik and Naganathapura.

In today's competitive business scenario, Bosch is under pressure to reduce cost and lead-time and to improve delivery performance. To achieve their goals, Bosch adopted an approach called Bosch Production System (BPS), which is derived from Toyota Production System with suitable modification to fit into Bosch culture. It is a lean manufacturing concept with a systematic approach to identify and eliminate waste through continuous and sustained improvements by manufacturing the product at the pull of the customer in pursuit of perfection.

The study carried out in this paper is to design and implement lean line layout for assembly of multi-cylinder pumps (PE pumps) with the features of lean manufacturing. There are 8 pump manufacturing line with different process, which were commissioned 15 to

20 years back. There were a lot of NVA built in the system. The main focus of the work is to identify all the NVA's and eliminate/reduce using lean tools and techniques like VSM, Line balancing, Stab Chart, Customer Takt, Kanban, Ergonomics, Time study etc.

In this paper, more effort has been put to use some of the new techniques for improving the lean line design that have not been used so far. The layout suggested is based on the study using MTM technique for cycle time calculation. IGEL software was used to check the ergonomic compliance of the line and ARENA software for simulating the model with different condition.

## 2. PROBLEM STATEMENT

Figure 1 shows the actual shop floor condition of material flow. According to the shop floor condition, there is no defined material flow and also information flow. Material moves at different directions and there is no FIFO or identification. This was creating lot of inventory, confusion, rejections and delayed decisions in the shop. This led to lower productivity and increase in cost. At company level, work was taken up to make an integrated line from assembly to packing (flow oriented layout) as shown in Figure 1. This work was divided into two small projects. First, optimization of assembly line and second, optimization of other remaining process. Finally, both were integrated them to make one integrated line. In this paper, assembly line optimization is described. The aim was to improve the productivity by 30%, reduce space by 20% and decrease lead-time by 10% using lean line design concept in PE pump assembly line. The other objectives of the study were to

- Map the current state of the line and to identify the improvement potentials
- Propose suitable line designs/ modifications based on required benefits
- Simulate and select appropriate solutions
- Implement and validate

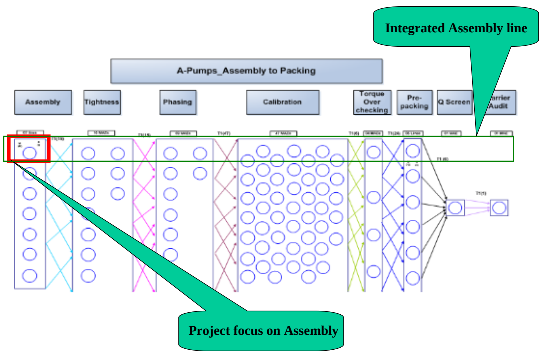


**Fig. 1 Bubble diagram and project focus**

## 3. DATA COLLECTION AND ANALYSIS

### 3.1 Methodology

Following data were collected and analyzed the present condition of the work

- Product requirement
- Process Flow Diagram,
- VSM
- Customer Takt
- Time Study
- Takt Time Chart
- Operator balance chart and
- Man, Material & Ergonomics

### 3.2 Product requirement

Pump customer requirement data was collected for 1 year and found an average requirement of 450/day.

### 3.3 Value stream mapping

Current condition of the assembly line were captured through value stream mapping (VSM)

Following problems were identified through VSM

- Lead time of the product was 2.8 hrs
- Value addition time was only 14.5% of total lead time
- Huge inventories in between stations and
- No pull system

### 3.4 Customer Takt and Target Cycle time

- Planned Requirement: 450 pcs. /day
- Working Time: 450 min. (480 min - 30 min lunch)
- 450 min x 60 sec x 3 shifts = 81,000 secs/day

Customer Takt --- 81000/450 = 180 sec

Target cycle time of 85 % of Customer Takt and 15% safety factor were considered in view of unforeseen problems [5].

**Target cycle time** = 85%*180 s = 153 secs

### 3.5 Time study and number of operators

Time study of each station done using stop watch and arranged in stack diagram as shown in Table 1. Each loop is identified in different colour and loop time is also captured. Total cycle time is calculated, number of operators and loops are present condition available in the shop.

**Table 1. Time stack diagram**

| Station | Individual time | Loop time |
|---|---|---|
| Station No1 | 88 | 88 |
| Station No2 | 80 | 80 |
| Station No 3 | 70 | |
| Station No4 | 53 | 123 |
| Station No5 | 60 | |
| Station No6 | 64 | 124 |
| Station No7 | 132 | 132 |
| Station No8 | 70 | |
| Station No9 | 75 | 145 |
| Station No10 | 134 | 134 |
| Station No11 | 30 | |
| Station No12 | 56 | 86 |
| Station No13 | 70 | |
| Station No14 | 70 | 140 |
| Station No15 | 30 | |
| Station No16 | 28 | |
| Station No17 | 34 | |
| Station No18 | 46 | 138 |
| Station No19 | 46 | |
| Station No20 | 25 | |
| Station No21 | 55 | 126 |
| Station No22 | 136 | 136 |

Total cycle time = 1452 secs. = 24.2 min

Total number of operators = 12
Number of loops = 12

### 3.6 Takt time chart

A Takt time chart was drawn as shown in Figure 2 based on customer Takt and target cycle time considering 12 loops.

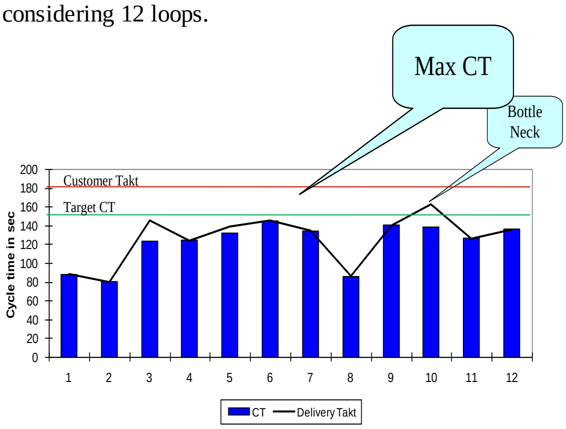


**Fig. 2 Takt time chart**

As per figure 2 maximum cycle time is less than target cycle time but the delivery Takt of loop 10 is greater than target cycle time. So there is a chance of customer fulfillment failure. Delivery Takt is the inability of the station to produce at the rate of cycle time due to losses. Cycle time of each station is divided by the OEE of the station to arrive at delivery Takt. Refer Appendix B for details of delivery Takt calculation.

| | |
|---|---|
| Customer Takt | = 180 secs |
| Target cycle time | = 153 secs |
| Delivery Takt | = 162 secs |

### 3.7 Line balance chart

A line balancing chart is shown in the Figure 3 for the current condition considering 12 loops, customer Takt 180 sec, target cycle time 153 sec and delivery Takt 162 sec. It can be observed from the chart that all the operators are not loaded equally i.e. there was a huge imbalance in the line. This imbalance was due to huge difference between customer Takt and maximum cycle time Takt loss. Line balance efficiency was found to be very low.

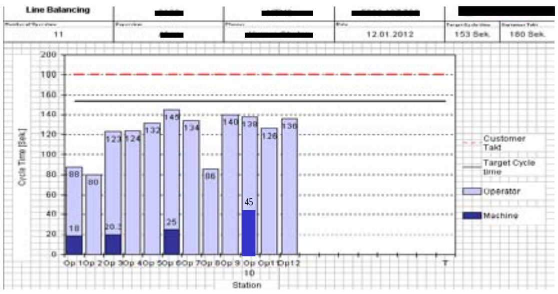


**Fig. 3 Line balance chart**

### 3.8 Assembly layout

Assembly layout was mapped and represented in figure 4. It was found that the layout is of External 'U' type causing inflexibility to the operators and difficulty in material movement. Total material movement distance was found to be around 34 m and total area of the line was 112 sq. m.

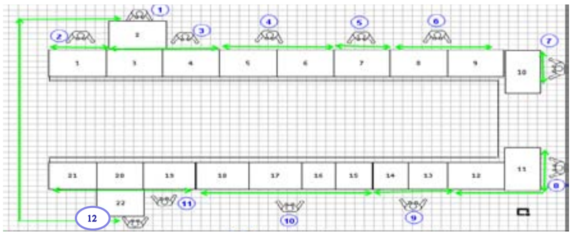

**Fig. 4 Assembly layout**

### 3.9 Key inference from problem analysis

All the problems were summarized based on their impact and shown in the Figure 5. 14 problems were identified in which 6 problems were having impact on cost, 3 problems were having impact on cost and quality, 3 problems on cost and delivery and 2 problems were impacting on only delivery.

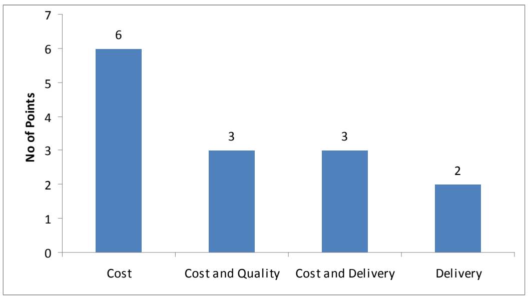


**Fig. 5 Key inferences**

## 4. PROBLEM SOLVING

### 4.1 Solution methodology

Following steps were followed to solve the problem

- Formation of cross functional team
- Gemba analysis of each station
- Identifying improvement points in each station
- Time study using MTM method for improved condition
- Calculation of number of operators, loops, etc.
- Simulation of new layout and final proposal
- Implementation of proposal
- Validation and
- Standardization

### 4.2 Gemba analysis:

Cross-functional team went for Gemba analysis and visited each and every station. The existing conditions were mapped and had a brainstorming session among team members and also with operators. 31 improvement points (open points) as shown in table 2 were listed out as a result of brain storming session. Along with that, team also made an analysis of parameters for improving the addressed open points.

### 4.3 Time estimation and number of operators

Considering all improvement points time estimation was carried out for improved condition using a technique called MTM (Method-Time Measurement) analysis [6] (using predetermined time for basic body motions). Stack diagram of time estimation of each arranged is shown in Table 3. Total cycle time was calculated. Number of operators and loops were calculated and each loop was identified in different colour and loop time was also captured. Loop time was calculated to match the plan cycle time. Activity of station number 2 was added with activity of loop number 6 to balance the line.

**Table 2. Open points**

| No. | Open Point | Improvement |
|---|---|---|
| 1 | Remove the chute from element assembly to DVH tightening | Ergonomic,space |
| 2 | Element freeness checking fixture - provide support at the back | Ergonomic, Cycle time |
| 3 | Make element freeness checking fixture inclined by 45º (The pump is placed vertical, process calls for the element to slide down freely) | Ergonomic, Cycle time |
| 4 | 1 MTM table can be removed from first 3 stations | Space,lead time |
| 5 | Workplace Arrangement of DVH subassembly for two handed operations | Cycle time |
| 6 | In DVH subassembly , housing name plate can be done & two MTMs can be removed so that one MTM associate assembles other assembly part & loads on DVH tightening | Space,lead time |
| 7 | Supermarket of DVH & subassembly to be given infront of DVH subassembly station | Cycle time |
| 8 | If single piece flow is made stn 2B can be made only 60 cms wide instead of 120cm today | Space |
| 9 | Different method for storing governor housing | Space,Cycle time |
| 10 | Governor housing to be delivered in plastic tray & tray modification to be done accorindgly | Cycle time |
| 11 | In governor housing Screw fixing & G H tightening operation bending to be avoided by removing screw bin, eliminating one press button and changing press button position | Ergonomic, Cycle time |
| 12 | Camshaft holding tray length and position to be reviewed | Space |
| 13 | In station 5B , 60cms table not required . Bearing inner assembly can be done with 30cm width table | Space |
| 14 | Pump stud tightening screwer is heavy needs to be changed (FP stud) | Ergonomics |
| 15 | Pressing of the inner race into the camshaft and placing into the pump to be done continously to reduce double handling | Cycle time |
| 16 | Place for the Pressed Bearing outer race not required, can be removed. | Space |
| 17 | Placement of shims used for cam play checking is far, should be brought closer and placed on right hand side also. | Cycle time |
| 18 | Bearing Outer race pressing and the cam play station can be placed next to each other,to avoid turning | Cycle time |
| 19 | Bearing Inner race removal fixture to be placed vertically & leg space to be provided at the fixture | Ergonomic |
| 20 | Provide location for the screwer in Stn 6A. | Cycle time |
| 21 | With providing leg space, the operator needs to move closer to the workplace in Stn 6B(overchecking) | Ergonomic |
| 22 | In Stn no. 7A, the Bigger parts in the bins should be placed in the upper position & smaller parts in bins to the lower positions. The bins can be arranged closer and the table distance reduced to 80cm | Space,Cycle time |
| 23 | Base cup pressing , the supply to be on the right hand side and the tray attached can be removed | Space |
| 24 | station No. 7B , Base cup pressing can be brought close by 20cm to 7A by removing the location for the bin with base of cups | Space,Cycle time |
| 25 | Stn 8A - Coupling Assembly & Tightening - Tilting the bins at an angle & also the bins with flyweights to be moved closer by 20cm by removing the intermediate table. | Space,Cycle time |
| 26 | Flyweights to be delivered next to the flyweight tightening-Stn 8B on the left hand side & move the lock timing table next to 8A | Space, Cycle time |
| 27 | Clamping jaw assembly stn can be moved closer to 8B by 20cm | Space |
| 28 | The table used for the governor cover sub assembly can be shortened to 1.2m + .8m for the gasket fixing. The smaller table can be avoided. | Space,lead time |
| 29 | A rack can be placed on the side with the necessary sub assembly components and the gaskets to avoid bending and picking up from below the table | Ergonomics,cycle time |
| 30 | Stantion No. 7A: clip dropping funnel position to be changed | Ergonomics,cycle time |
| 31 | Light curtain can be provided at screwing, pressing stations and operate single hand push button | Safety,cycle time |

**Table 3. Time stack diagram**

| Station | Individual time | Loop time-Sec |
|---|---|---|
| Station No1 | 65.44 | |
| Station No2 | 42.4 | |
| Station No 3 | 24.06 | |
| Station No4 | 45.01 | 134.51 |
| Station No5 | 67.08 | |
| Station No6 | 70.98 | 138.06 |
| Station No7 | 82 | |
| Station No8 | 72.23 | 154.00 |
| Station No9 | 31.12 | |
| Station No10 | 42.93 | |
| Station No11 | 76.01 | 150.05 |
| Station No12 | 30.93 | |
| Station No13 | 41.59 | |
| Station No14 | 53.55 | 126.07 |
| Station No15 | 30.77 | |
| Station No16 | 24.4 | |
| Station No 17 | 52.59 | 150.17 |
| Station No 18 | 93.99 | |
| Station No 19 | 48.55 | 142.54 |

### 4.4 Takt time chart - after improvement

A Takt time chart was drawn (Figure 6) based on customer Takt and target cycle time considering 7 loops. Delivery Takt of this line was 154 secs, which was almost equal to planned cycle time. So, the risk of customer fulfillment failure was eliminated.

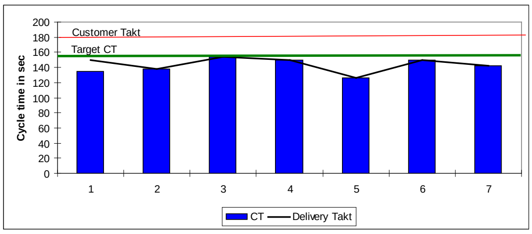


**Fig. 6 Takt time chart**

### 4.5 Line balance chart – after improvement

A line-balancing chart was drawn as shown in the Figure 7 for the improved condition considering 7 loops, customer Takt as 180 secs, target cycle time of 153 secs and delivery Takt of 154 secs. It was observed from the chart that all the operators were better loaded when compared to before condition i.e. there was a reduction in Takt loss. Line balancing efficiency increased to 92% from 83%.

**Fig. 7 Takt time chart**

### 4.6Assembly layout proposals

Considering all inputs for improved condition different assembly proposal were drawn and discussed the advantages and disadvantages of each proposal. Mock layout was prepared to validate the proposal using Paper Kaizen concept [5]. Different layout proposals and mock line for validations carried out are shown in Figure 8.

**Fig. 8 Mock layout proposals**

### 4.7 Final Assembly layout

Based on the validation result, final assembly layout was finalized as shown in the Figure 9. Layout was designed with seven loops, seven operators and nineteen workstations. New layout was made internal 'U' improving the operator flexibility. Material feeding was from outside so there was no problem for movement of material trolley. The area of the new line was 55 sq.m and material movement distance was 20 m.

**Fig. 9 Final Layout**

### 4.8 Standardized work

StAB chart (standardized work sequence) was prepared for each station as shown in the Figure 10. It consists of sequence of operation to be followed by an operator in a loop, manual time, auto time, walk time of each element is captured and depicted on the sheet.

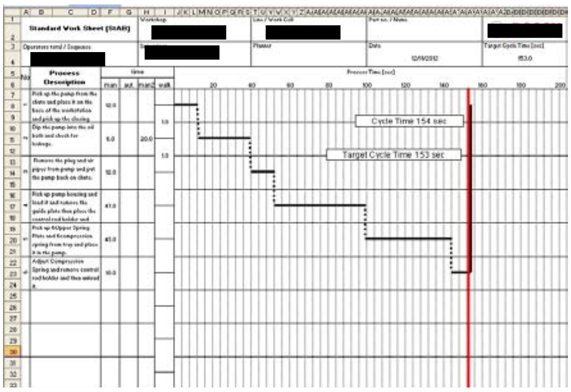

**Fig. 10 Standardized work sheet**

### 4.9 Implementation and Validation

Out of 31 improvement points shown in Table 2, 29 points were implemented successfully and 2 points were dropped due to technical feasibility. Point number 3 was dropped as pump had to be in vertical position to check free fall of plunger and point number 14 was dropped, as lightweight screwer was not able to provide required torque.

A trial run was conducted for one complete shift to validate the results. 7 operators were deployed in 7 loops as per the improved layout and produced 144 pumps in 7.5 hrs. 20.5 pumps/head/shift was achieved during trial run. Details of the production were captured in hourly monitoring chart as shown in Figure 11.

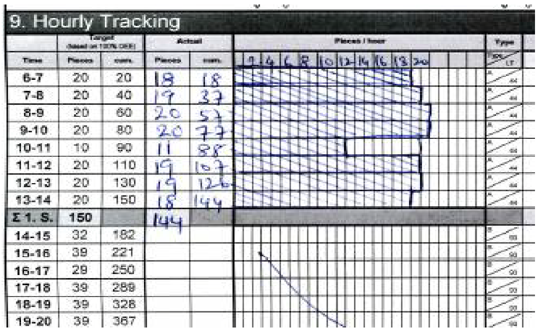


**Fig. 11** Hourly monitoring

Following observations were made during trial run, which can improve the performance:

- Standardized work needs improvement
- Fixture to be given in station 1
- Material feeding to be improved and
- Operator skill needs improvement

## 5. RESULTS AND DISCUSSION

Redesigning of assembly layout using different lean techniques by optimizing parameters like cycle time, number of operators, number of stations, work place improvements, material flow, standardized work, etc. resulted in following improvements as project outcome shown in Table 4.

**Table 4. Results of Project**

| Sl.No | Metrics | Existing line | Achieved during trial run | Improvement wrt existing line |
|---|---|---|---|---|
| 1 | Number operator (loops) | 12 | 7 | 41% |
| 2 | Productivity – (Pumps/associate/Shift) | 12 | 20 | 66% |
| 3 | workstations (Nos) | 22 | 19 | 13% |
| 4 | Throughput time | 24.2min | 16.6min | 31% |
| 5 | Space (m²) | 112 | 55 | 50% |
| 6 | Material movement | 34 m | 20 m | 41% |
| 7 | Lead time | 168 min | 41 min | 75% |

### 5.1 Recommendation based on solution

A detail analysis was carried out using ARENA software to make this line flexible based on number of pumps required as per varying customer Takt. Results of the analysis are shown in the Figure 12.

Number of operators can be varied from 6 operator model to 9 operator model based on customer requirement from 150 pumps to 200 pumps. Productivity (number of pumps/head) was shown for each model. As per this, 6 operator model found to give better productivity but number of pumps was less. So, it was recommended to run this line with 8 operator model to get maximum output as well as productivity.

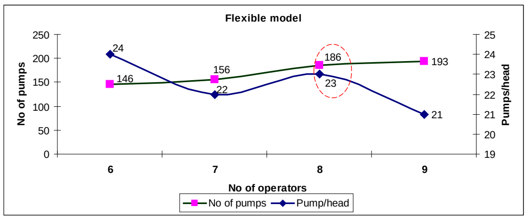


**Fig. 12 Variable model**

### 5.2 Validation of improvements

Improved conditions of the line were validated in GEMBA and captured as photographs and showed in Figure 13 and Figure 14.

## 6. SUMMARY

The work was started with an aim to achieve improvement of productivity by 30%, reduction in space by 20% and reduction in lead-time by 10%, which will help in overall cost reduction of the product. Different tools like VSM, Takt time, Customer Takt, Line balancing, Time study etc. were used under Lean line design technique. The optimization carried out on parameters like number of operators, cycle time, space and lead-time. Optimized layout was simulated and validated through trial runs.

Long distance line

Huge Inventory

Unwanted lengthy work stations

Improper work place arrangement

**Fig. 13 Before Improvement**

Small line

Optimized length work station

Improved work place arrangement

Combining two operation in one station

**Fig. 14 After Improvement**

The work yielded tangible benefit results in:

- Productivity improvement by 66%,
- Reduction in space by 50% and
- Reduction in lead-time by 75%

The work yielded intangible benefit results in:

- Optimized layout has better operator balance
- Reduction in number of work stations
- Facilitate operator flexibility
- Ergonomic compliant and
- Flexible line according to the variation in customer takt by adding or removing manpower

### 6.1 Conclusions

The following conclusions can be listed from this study and work:

- VSM approach helped to understand the current situation of the problem
- GEMBA and brainstorming session with cross functional team led to good understanding of each station and come out with improvement points
- Tools and technique like Time study, Takt time, customer Takt, delivery Takt, StAB chart, etc. was very useful in designing lean line
- New concept of MTM analysis helped in determining estimated time even before formation of physical layout
- IGEL software was useful in measuring and improving ergonomic compliance of new line and
- New line is capable of operating flexibly based on the variation of customer Takt

### 6.2 Recommendation for future work:

- All improvement points can be horizontally deployed to other lines
- Heijunka (leveling) and Kanban system can be implemented to make it a pull system
- Flexible model from 6 operators to 9 operators can be made to work with different Takt time requirements
- Rabbit chasing/ChakuChaku concept can be adapted to eliminate line-balancing problem (Takt loss), which will yield higher productivity
- The work can be extended to do further optimization on the running line after some period of stabilization

## 7. REFERENCES


[1] Rajenthirakumar D., *Process Cycle Efficiency Improvement through Lean: a Case Study*, Journal of Lean thinking, Vol. 2, Issue 1, 2011.

[2] Bosch production System, *Short description Lean line Design*, Version 2, May 2010.

[3] Meng Bo and DONG Mingyao, *Research on the lean process Engineering based on Value stream mapping for Chinese Enterprises*, Management Science and Engineering, Vol. 6, Issue 2, pp. 103-106, 2012.

[4] Guillermo Andrés Sánchez C., Juan Manuel Sanchez C, *KANBAN allocation in a serial supply chain*, Oscar Huberto Patiño H. Journal: Tecnura, Vol. 16, Issue 32, pp. 59-67, 2012.

[5] Bosch production System, *Implementation Guide lines Lean line Design*, Version 2, Dec 2009.

[6] Bosch Ltd, *Industrial Engineering Hand Book*, Issue No.2, Bosch India, 2000.