Applications of Lean tools for Compressor Assembly Line

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Abstract. In last decades, competition between several industries to deliver high quality products is marginally increasing in terms of costs and performance. Lean manufacturing is one of those activities, which focus on the reduction of cost by eliminating non value adding activities. The general idea behind Lean manufacturing is to eliminate non value adding activities which again leads to eliminate waste. Higher flexibility, better quality and effective production system the manufacturer requires new ideas on production line. All the Lean tools are used to implement newer ideas into production line which improves the overall production process. This Paper addresses the application of lean manufacturing philosophy to the compressor assembly line of a well-known industry. In this paper, Failure Mode Effective Analysis, Value Stream Analysis and Takt time are the lean tools effectively integrated resulting in the improvement in terms of cycle time, space available, distance travelled by worker and productivity which leads to delivering the customer demand within time.

Keywords. Lean, Failure Mode and Effects Analysis (FMEA), Takt time, Cycle time, Kaizen

1. Introduction
The basic goal of any business is to satisfy the customer demand. Customer demand in the industry manufacturing the natural gas compressors is increasing day by day as the CNG market right now is on the peak. The present Gas Packaging and Process (GPP) line is unable to cope up with the increased demand due to its so many losses like more non-value-added time, old method related to material handling, improper material flow, less space and flexibility, more distance travelled by a worker in assembling station and bad ergonomics etc.

Lean manufacturing is a production practice which adds the value to a process and removes waste [1]. There are many non value adding processes on production line which can be overlooked, which increases the overall lead time of a production activities [2]. Due to competition between businesses, companies are facing more challenges and complexities. In order to respond to the changes by customer, to strengthen the product value in the organization which may be service oriented or manufacturing oriented, systematic production line with minimum non value adding processes is desired [3]. So, there is need of more value adding processes than that of non value adding processes to achieve this target. Therefore, Lean manufacturing implementation is becoming a need for any type of organizations to sustain [4].

Failure Modes and Effects Analysis (FMEA) is a technique used in product development and operations management for analysis of failure modes within an organization to classify and rate the processes in three factors as severity, detection and occurrence of the failures [5]. Risk Priority Number (RPN) is calculated where the failure occurs every time and based on these numbers, necessary action is taken.
Implementation of lean tools and its principles leads to change in organizational cultures, higher efficiency, better productivity, cost reduction and customer satisfaction. Also we use FMEA to avoid any failures in production processes. Also to detect the problem and its intensity and deciding the priorities of the failures which helps the organization to eliminate these failures in the most economical way[6]. Today the organizations are not depending upon their single way of solution the are interested in the integrations of theses tools so the efforts are being made by various researchers to integrate the Lean tools and FMEA [7]. The same efforts are made in this paper in order to make the assembly line leaner and deliver the customer demand.

DeSouza and Carpinetti [5] explained a proposal of adaptation of the FMEA method which analyses wastes and define priorities for the actions aiming at minimization or elimination of these wastes based on the criteria of occurrence, severity, and detection. Shekari and Fallahian [6] implemented Lean and FMEA together, in such a way that not only specific ability of each method, but also combination of these methods raised the overall performance of the organization. Amin and Karim [7] developed a method which evaluates the applications of lean tools selected to reduce production wastes within the assemblers time constraints. Nguyen and Do [8] transformed a traditional production line model to lean one of electronics assembly line with the help of mapping current state value stream and drawing future state value stream mapping in order to establish and implement plan, resulting in reduction of nearly 40% manpower with the same output daily, also saved 30% floor area on the line and reduced delivery time from 7.5 days to 3 days. Sapkal and Jadhav [9] have implemented Kanban and VSM in Residual Current Circuit Breaker manufacturing company and concluded that this approach helps to analyse loopholes in the current system. By implementation of this approach, they have achieved lead time reduction from 16.824 days to 8.59 days and about 18% reduction in processing time.

By studying various literature regarding the lean implementation techniques, it has been found that for manufacturing and processing industries, possible and easy way is to determining the non-value-added activities and implementation of effective lean tools like FMEA and VSM, which eliminate bottlenecks from the system. Researchers focused on removing non-value-added activities from every department of the organization like Engineering, Production, warehouse and the outsourcing. The current GPP line is facing similar kinds of problems that have addressed by researchers in their work. Therefore, integration of lean implementation tool with effective use of FMEA can be used for solving such problems.

2. Data Collection

In the factory of compressor assembly Atlas Copco, there are total 5 stations for assembly line out of which station 1 is only for block assembly where there are 2 fixtures. And other 4 stations are for full package assembly where at each station no. 2,3,4,5 separate compressor assembly carried out manually. Data has been collected at each station in terms of Cycle time, Flexible space available at each station and distance travelled by worker. The time studies of each assembly process were taken in terms of videography analysis with the help of hand and with support of company staff and operators. This video analysis is used to analyse the task times. So, the time analysis has been done for the block area using Avix software. Table 1 shows the detailed data collected from the industry in terms of cycle time, value added time, non value added time, space available and average distance travelled by worker, for block assembly and package assembly.

2.1 Value adding activities

Value adding activities are activities, which transform the product towards completion, particular step is done right for the first time, the customer generally pays for this step to be done [10].

In CNG compressor assemblage of special parts like Block, coolers, vessels, instruments, priority panel, driving unit etc. adds the value to the machine for which customer is paying for the So, the value adding time is more precise time in the assembly system. So, there must be no compromise for this time. The worker has to take this time to complete the assembly.

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2.2 Non Value-Adding Activities
Non value adding activities are activities that actually do not add value to the machine. These are further divided in 3 parts as Required, Wait, and Loss. Addition of all these times is considered as non-value adding time.

2.2.1 Required - These activities are the one which must be done, but they do not actually add value to the customer. These activities are cleaning of the parts, fitting the nut, bolt, washer, Studs. Also, the time required for handling the material.

2.2.2 Wait - Waiting caused by resetting, bad process flow or internal balancing losses. Waiting occurs when the operator waits for the product to be assembled to be arrived or the material handling equipment to be arrived. This is one of the most conspicuous wastes and it does not add value to the customer.

2.2.3 Loss - These are due to excess motion of the material handling equipment like forklift, overhead crane. Also, worker searching the part to be assembled and the tool finding to complete the assembly.

In order to implement the lean tools in an organization the main target should be to eliminate or to reduce the Non value adding time which helps the factory to deliver the goods to customer within time [10].

Table 1 shows the data collection at initial stages of the assembly line. Cycle time is the time required actually to complete the process or step. Which again is divided into value adding and non value adding time which helps us to understand how much actually non value adding time which we are going to reduce or eliminate. This step is done in AVIX software where the videography of all the steps is imported and divided accordingly.

| Table 1. Data Collection |
|-------------------------|
| Cycle time (min.) | VA time (min.) | NVA time (min.) | Space available (m²) | Average dist. Travelled by worker (m) |
|-------------------|---------------|----------------|---------------------|---------------------------------|
| Block Assembly    | 2086          | 565.63         | 1520.75            | 37.66                           | 982                             |
| Package Assembly  | 4320          | 1606           | 2374               | 12.51                           | 660                             |

3. Takt Time Calculation
Takt time is a function of available production time and product volume[10]. In this, it is used to calculate the rate at which we are supposed to produce the product in order to satisfy the customer demand. It is determined by using formula [11]:

\[
Takt\ time = \frac{Available\ time}{Customer\ demand\ per\ day}\quad (1)
\]

The takt time and cycle time are different concepts and should not be mixed with each other. Takt time remains same for all stations on an assembly line, which means time for which work piece should stay at a station. Cycle time is process or operation time of product that is completed while the workpiece is at the station.

Customer is demanding 12 machines per month so demand for Package station will be 12 for all 4 stations. From this the demand per station per month is calculated as 3. Similarly, for block station for preparing 12 machines 12 blocks are required so demand for the block i.e. station 1 is 12 machines per month. On this station there are two fixtures on which two workers works on two different blocks so, demand per fixture per is 6. Table 2 shows the detailed takt time calculation with regarding the customer demand per month which gives the rate at which we are supposed to produce the product.
Table 2. Takt time calculation

|                      | Station 1: Block | Station 2: Package |
|----------------------|------------------|--------------------|
| Customer demand per month | 12               | 12                 |
| Customer demand per station/fixture | 6                | 3                  |
| Demand per day       |                  |                    |
| Considering average 24 working days per month | \( \frac{6}{24} = 0.25 \) | \( \frac{3}{24} = 0.125 \) |
| Available Time       |                  |                    |
| Total working hours Per day. | 8.5               | 510                |
| Contractual time per day | 1.67             | 70                 |
| Available working time per day | 7.3               | 440                |
| Takt time            |                  |                    |
| \( \frac{440}{0.25} = 1760 \text{ min} \) | \( \frac{440}{0.125} = 3520 \text{ min} \) |

4. Comparison of Takt and cycle time
As shown in figure 1, the takt time compared with cycle time and is found that the takt time is more for both block and package station which is not desired. In order to fulfill customer demand, the cycle time must be equal to or less than that of takt time.

Figure 1. Comparison of Takt time and Cycle time

5. Implementation of Lean Tools
After Collection of data collection and finding the bottlenecks in the current system, the lean tool to be implemented in order to remove the bottlenecks from the system to satisfy customer demand. The FMEA is tool used to do so. Risk Priority Number (RPN) is calculated to prioritize the cause of failure and wastes. It develops the FMEA solution and the action which is necessary, based on the RPN data.

\[
\text{Severity} \times \text{Occurrence} \times \text{Detection} = \text{RPN}
\]  

(2)
5.1 Rating Scales
Severity: Rating 1 to rating 10 = Not Severe to Very Severe
Occurrence: Rating 1 to rating 10 = Not Likely to occur to Very Likely occur
Detection: Rating 1 to rating 10 = Likely to Detect to Not Likely to Detect

All three above factors are based on the importance of the product to the customer and how much a failure affects the quality of the product and is decided in co-ordination with managing team of the industry [2].

Table 3. FMEA Analysis for Package assembly

| Sr. No | Assembly Process                          | Severity | Occurrence | Detection | RPN Number |
|--------|-------------------------------------------|----------|------------|-----------|------------|
| 1      | Keeping the Frame, Driver unit and block  | 7        | 4          | 4         | 112        |
| 2      | Alignment of the Engine and block         | 10       | 9          | 6         | 540        |
| 3      | Driver accessories                        | 6        | 6          | 3         | 108        |
| 4      | Vessel Mountings with fittings            | 8        | 9          | 7         | 504        |
| 5      | Cooler mountings with fittings (4 coolers)| 4        | 6          | 5         | 120        |
| 6      | Plenum mounting with fan and motor        | 9        | 9          | 5         | 405        |
| 7      | Actuator with their Fittings              | 3        | 6          | 7         | 147        |
| 8      | Instruments with their Fitting            | 4        | 9          | 5         | 180        |
| 9      | Gauge Panel and gauges                    | 2        | 5          | 6         | 60         |
| 10     | Canopy with their Fitting                 | 6        | 5          | 7         | 210        |
| 11     | Priority Panel with their fittings        | 5        | 5          | 4         | 100        |
| 12     | Factory Assured Test                      | 8        | 8          | 6         | 384        |

Table 3 shows the detailed assembly process for block station and the factors allowed to each of the activities. The next step is prioritizing cause of failure and is done by calculating RPN number. The Process having higher Risk Priority Number are targeted first to deliver the product of good quality within the time. Activities at sr. no. 2, 4, and 6 in the table 3 show the higher priority number and are targeted first and Kaizen to be implemented for these processes.

5.2 Kaizen Implementation

Once the priorities decided with the help of FMEA different feasible solutions to the different targets in order to implement kaizen, which will reduce the non-value adding time are decided. Best solution amongst them considering cost, efficiency is implemented for all targeted activities with permission of the managing team which shown in table 4.

Table 4. Kaizen Implementations

| Process                                  | Kaizen                                                                 |
|------------------------------------------|------------------------------------------------------------------------|
| Alignment of Engine and Block            | A LASER alignment machine is implemented instead of previous dial gauge alignment method which reduced time for alignment from 470 min. to 180 min. |
| Vessel Mounting                          | A Fixture is developed which carries all 6 vessels in it instead of 6 different pallets for different vessel resulting in time reduction to travel the vessel and space reduced of pallets |
| Plenum Mounting with fan and motor       | An assembly of Plenum, Fan, Motor is outsourced, instead different parts assembling within factory. This reduced assembly time and space occupied within station. |
Also, movable Cluster trolley implemented in place of big lineside racks which resulting in reduction in distance travelled by worker and that of space lineside for block as well as packaging stations. Also, wooden pallets are been replaced with movable steel pallets with steps helps reduction in space.

6. Results and Discussion of Lean Implementation

Once the Kaizen is implemented for all the targeted activities there is again need to collect the data in order to determine the kaizen results, so again data is collected as previous. Table 5 shows the data collection after kaizen and lean implementation.

|                      | Cycle time (Min) | VA time (Min) | NVA time (Min) | Space available (m²) | Average dist. travelled by worker (m) |
|----------------------|------------------|---------------|----------------|----------------------|---------------------------------------|
| Block Assembly       | 1542.02          | 563.62        | 978.40         | 51.84                | 487                                   |
| Package Assembly     | 3291             | 1606          | 1705           | 30.08                | 320                                   |

6.1 Improvement in Cycle time

As shown in figure 2, the takt time compared with cycle time after the process improvement by lean and is found that the cycle time is less than that of takt time for both block and package station which fulfill the factory to customer demand. Also, there is some buffer time which the factory can sustain for further increase in customer demand.

![Figure 2. Improvement in Cycle Time.](image)

6.2 Improvement in other Factors

Other factors such as non-value adding time, flexible space available, Avg. distance travelled by worker before and after lean implementation is analyzed and resulting in marginal improvement in all these factors.
Table 6. Improvement in Factors

| Factor                   | Block Section                  | Package Section                  |
|--------------------------|--------------------------------|----------------------------------|
|                          | Before implementation | After implementation | Before implementation | After implementation |
| Takt time (min)          | 1760                         | 1760                            | 3520                  | 3520                  |
| Customer demand (per Month) | 12                          | 12                              | 12                    | 12                    |
| Cycle time (min)         | 2086.5                        | 1542.02                        | 4340                  | 3291                  |
| Non-Value adding time (min) | 1520.75                     | 978.40                         | 2374                  | 1705                  |
| Flexible space available (m2) | 37.66                       | 51.84                          | 12.51                 | 30.08                 |
| Dist. Travelled by worker (m) | 982                         | 487                            | 660                   | 320                   |

Table 6 shows the improvement factors under consideration in both block assembly and package assembly. This shows 26% reduction in cycle time this is due to reduction in non-value adding activities which is achieved with effective kaizen. This non-value adding time is marginally reduced by 35%. Also, by putting effective fixtures for material handling and putting cluster trolley for bins, flexible space is improved by 37% and distance travelled by worker is reduced by 50%. Improvement in all these factors helped the product to be delivered within time.

7. Conclusions

Lean manufacturing philosophy implemented in a GPP line of compressors to eliminate non-value adding activities.

- By using Lean tools like Value Stream Analysis, FMEA, Takt time and effective use of kaizen, the performance of the organization is found to be improved in terms of cycle time, flexible space available, and distance travelled by worker resulting in the improvement in productivity.
- FMEA tool is successfully used to analyse waste and define the priorities for the processes aimed at minimizing the wastes effectively.
- For Block section and Package section, Cycle time reduced by 25.8% and 24.1%, NVA activities reduced by 35.6% and 28.1%, Flexible space available is increased by 38% and 140%, Distance travelled by worker reduced by 50.4% and 51.5%.
- Monthly customer demand of 12 machines is achieved with reduction in cycle time by comparing it with takt time and extra buffer time is remained which can sustain for further increase in demand.

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References

[1] Bhamu J and Sangwan K 2014 Lean manufacturing: literature review and research Issues, *International Journal of Operations & Production Management* **34** (7) pp 876-940

[2] Kjersem K, Halse L, Kiekebos P and Emblemsvag J 2015 Implementing Lean in Engineer-to-Order Industry: A Case Study, *International Federation for Information Processing- Part II* **460** pp 248–255

[3] Vinodh S and Chethan Kumar A G 2015 A Case Study on Lean Product and Process Development’, J.P. Davim (ed.), *Management and Industrial Engineering*, pp 17-30

[4] Rahani A R and Al-Ashraf M 2012 Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study, *Procedia Engineering* **41** pp 1727 – 1734

[5] B. de Souza R and Carpinetti L R 2014 A FMEA-based approach to prioritize waste reduction in lean implementation, *International Journal of Quality & Reliability Management* **31** pp 346-366

[6] Shekari A and Fallahian S 2007 Improvement of Lean methodology with FMEA, *POMS 18th Annual conference Dallas, Texas, U.S.A.* 007-0520

[7] Al Amin M & Karim M A 2013 A time-based quantitative approach for selecting lean strategies for manufacturing organisations, *International Journal of Production Research* **51**(4) pp 1146-1167

[8] Nguyen M, Do N 2016 Re-engineering Assembly line with Lean Techniques *Procedia CIRP* **40** pp 590-595

[9] Sapkal S and Jadhav R 2015 Productivity Improvement by using Value Stream Mapping in Manufacturing Company, *3rd International Conference on Industrial Engineering* **1** pp 496-50

[10] Sundar R, Balaji A N and Satheesh Kumar R M 2014 A Review on Lean Manufacturing Implementation Techniques, *Procedia Engineering* **97** pp 1875 – 1885

[11] Rajenthirakumar D and Sridhar R 2014 Development of Lean Assembly Line – A Case Study, *International Journal of Lean Thinking* **5**(1)