ANNALS OF FACULTY ENGINEERING HUNEDOARA – International Journal of Engineering
ISSN: 1584 - 2673

IMPLEMENTATION OF LEAN ASSEMBLY LINE: A CASE STUDY

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ABSTRACT:
This work addresses the implementation of lean assembly line in a gearbox manufacturing company with a focus on wind turbine gearbox assembly lines. Here, the prime objective is to evolve and test several strategies to eliminate waste on the shop floor. In this work, a systematic approach is suggested for the implementation of lean principles to showcase that lean could be applied to the wind turbine gearbox assembly line to reduce the assembly time and inventory, thereby making the line more efficient. The methodology followed was that of continuous improvement which used status studies and metrics as benchmarks to study the change. This paper describes an application of value stream mapping (VSM). Consequently, the present and future states of value stream maps are constructed to improve the production process by identifying waste and its sources. Finally, the results obtained show the path of improvement, measured through lean rate (LR) and dock-to-dock time (DtD).
KEYWORDS:
Lean Manufacturing, Lean assembly line, Value stream mapping, Lean rate

1. INTRODUCTION

Due to depleting resources in terms of conventional energy, the world is looking to clean and green sources of energy. Wind is a naturally occurring resource which has been under utilized. Modern engineering has transformed the conventional wind mill to the wind turbine generating and supplying megawatts of energy to support the local electricity grid. The gearbox used in the modern wind turbine increases the speed of the rotating shaft to meet the requirements of the electricity generator. Worldwide capacity reached 159213 MW, out of which 38312 MW were added in 2009. Wind power showed a growth rate of 31.7 %, the highest rate since 2001. The trend continued that wind capacity doubles every three years [1, 2]. In order to achieve this and compete with their global counterparts, the industries necessarily need to improve productivity while ensuring lower cost and world class quality. The global financial and economic crisis, all in all, had no negative impact on the general development of the wind sector worldwide. Many governments sent clear signals that they want to accelerate wind deployment in their countries and indicated that investment in wind and other renewable technologies is seen as the answer to the financial as well as to the still ongoing energy crisis. However, the authors strongly believe that unnecessary capital investment is not going to solve the problem entirely; rather, this will turn out to be a waste in the long run. Hence, the authors would like to suggest intense brain storming and planning before any capital investment. In this direction, the implementation of lean manufacturing is highly recommended, in order to identify the areas generating waste; thus, it further facilitates the optimization of the operating conditions in a minimal investment.

Although the lean manufacturing theory works on a broader domain; this paper will be circumscribed to the shop floor by only taking into account the limitations of time. This work addresses the implementation of lean manufacturing on the wind turbine gearbox, with a focus on the assembly line. The prime objective is to develop different strategies to eliminate waste by means of continuous improvement. The lean tool value stream mapping (VSM) applied as a method to lead the activities towards continuous improvement [3-7]. The strategic influence of VSM is studied using two lean metrics: lean rate (LR) and dock-to-dock time (Dtd) [4] as well as performance measures such as production rate and line efficiency. These metrics serve as indicators for further improvement. LR is a key, fundamental, and paradigmatic metric and it should be reduced. It is useful to find and tally inventory accumulations where the flow of value has to be interrupted due to process problems. DtD depicts the material flow through the value stream. Therefore, it is a measure of the ability to deliver on time and it is generally a good indicator of the effectiveness of lean initiatives to improve the flow. It is a reliable indicator of the extent to which inventories are being reduced [3]. The following sections illustrate a simple and systematic implementation of lean manufacturing in an assembly environment.

The rest of the paper is organized in the following manner. In Section 2, the relevant literature reviewed during this research was discussed. Section 3 gives a brief idea about the product. The various stages of operations practiced on a wind turbine gearbox assembly line are described in this section. An overview of lean manufacturing is described in Section 4. In Section 5, case study of a gearbox manufacturing company was discussed. Subsequently, implementation procedures, along with results obtained, are explained in Section 6 Section 7 concludes the paper with implications and final remarks.

2. LITERATURE REVIEW

Numerous literatures have extensively documented the implementation of lean manufacturing into various manufacturing sectors, but very few have addressed the assembly environment. Soderquist and Motwani [8] successfully mapped the quality management concepts of lean production in a French automotive parts supplier company. They outlined an integrated approach for quality, including customer relationships and operations, and thereby achieving a competitive advantage for automotive manufacturers. Bamber and Dale [9] explained the application of lean to a traditional aerospace manufacturing industry. They revealed that a number of methods of lean production were found to be not as effective as in the motor manufacturing sector. Shah and Ward [10] studied the effects of three factors, plant size, plant age and unionization status on the feasibility of implementing the key facets of lean production systems. The results indicate that lean implementation contributes significantly to the operating performance of plants. Pavnaskary et al. [11] have proposed a classification scheme to serve as a link between manufacturing waste and lean manufacturing tools. The proposed scheme classifies all well-known lean manufacturing tools and metrics. Also, it suggests the tools and metrics that will help to meet manufacturing problems. McDonald et al. [12] applied value stream mapping (VSM), enhanced by simulation, in a manufacturing plant. They have strongly suggested that simulation can be used to enhance the utility of VSM. VSM is prescribed as part of the lean toolkit and has been applied in a variety of industries. In this paper, application of VSM was described in order to identify the various forms of waste to a dedicated gearbox assembly line.

3. DESCRIPTION OF THE PRODUCT

Gearboxes are widely used in the modern wind turbine assembly. Their primary purpose is to increase the rotational shaft speed whose torque is generated with the help of wind power. The gearbox studied in this paper is referred by the name GB 4375 or simply 4375. This is a helical gearbox and has a shaft mounted gear unit with planetary gears. This paper deals with the assembly process of this gearbox. The major assembly tasks in the assembly process are sketched in Figure 1. All the parts of 4375 are received in the stores where the parts are categorically stored for retrieval at a later stage. It is necessary of most of the parts to be washed before assembly. The gearbox assembly consists of two subassemblies which are finally assembled with the housing to form the final gearbox (Figure 2).

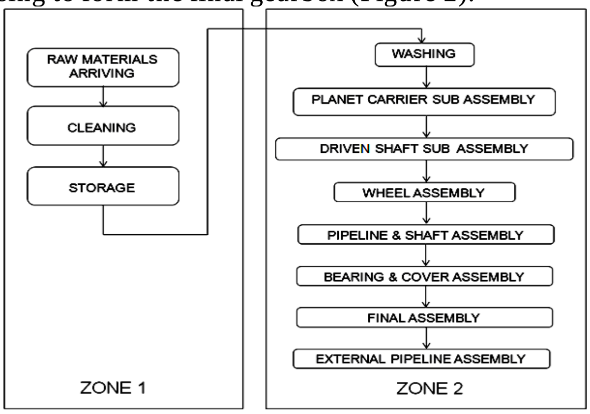


Figure 1. Flowchart of assembly line

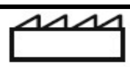
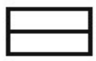
Figure 2. Different views of gearbox assembly

4. AN OVERVIEW OF LEAN MANUFACTURING

Lean manufacturing is a philosophy for structuring, operating, controlling, managing, and continuously improving industrial production systems [13]. It is based on Toyota Production System (TPS) which is the well-established philosophy in the manufacturing world that really endeavors for integrating and shortening the timeline between the supplier and the customer by eliminating hidden waste. Some of the standard tools, like VSM, production smoothing, continuous improvement, 5S, single-minute die exchange, total quality management, just-in-time, etc., have been conceived by TPS. The goal of lean manufacturing is to minimize waste in terms of non-value-added activities, such as waiting time, motion time, set-up time and WIP inventory etc. [14]. Further, waste in a manufacturing environment can be defined as any redundant application of resources that does not add value to the product, i.e., activities for which the customer is not willing to pay.

To implement lean principles in any organization, the first step is to identify the value stream, i.e., all those activities, both value-adding and non-value-adding, required to manufacture a product or to provide a specific service to a customer. In recent years, numerous literatures have been documented showing the implementations of VSM [15]. VSM can be defined as a pictorial representation of all of the value-added and non-value added activities required to produce 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 and thereby made it easy to recognize the implementation plan. A predefined set of icons are generally used to construct the value stream map as shown in Table 1.

Table 1. Standard icons used in VSM

Icon	Description	Icon	Description
	Customer		Material flow
	Work station with time		Information flow
	Inventory		Production lead time

VSM technique visually maps the flow of material and information from the time that the raw material enters into the production line, up to the dock yard as the finished product. In this case, mapping out the activities in the wind turbine gearbox assembly line with cycle time, down time, WIP inventory, material movements and information flow paths helps to conceptualize the current state of the assembly activities and guides towards the desired future state. Rother and Shook [15] explained a structured approach for improving a value stream. First, the relevant product families are identified for improvement. Second, the current state value map is constructed using information gathered from the actual process. Finally, the future state value stream is mapped.

5. GEARBOX ASSEMBLY LINE: CASE STUDY

The case study considered in this research is one of the leading wind turbine gearbox manufacturing companies in Southern India. The company ensures the smooth interaction of gearbox, coupling, generator and inverter. The central component of the drive system is the gearbox of the wind turbine. The task of the gearbox is to convert the low speed of the rotor shaft through several gear stages into high revolution of the high speed shaft, which drives the rotor of the generator via the coupling. The company was facing severe pressures to improve the performance of the gear box assembly line. In recent years, the company has made huge capital investments to take initiatives in capacity expansion, modernization etc. Previously, the company management has endeavored to implement concepts such as total productive maintenance and pull production; however, the results achieved were not significant. In the pursuit of consistency, the management decided to implement lean manufacturing.

After intense brain storming and a detailed work study, it was observed that the assembly line contains various forms of non-value-adding activities as follows: (i) excessive time gap between order release and delivery (ii) accumulation of work-in-progress inventory (iii) frequent inspection increases cycle time (iv) assembly area needs a rearrangement of the assembly stations. Certainly, all of these factors lead to high lead time. In the existing conditions, there is a need to decrease the assembly time of the gearboxes by creating a smooth flow of tasks.

6. LEAN ASSEMBLY LINE: IMPLEMENTATION

The mission of the lean implementation was to reduce the level of non value activities present in any form by implementing the various tools available. Thus, it was decided to first construct the value map in order to visualize the non-value-added activities.

6.1 Initial value stream mapping

The value stream map for the present state is constructed as shown in Figure 3. A first design of VSM is realized according to the original data and the layout, identifying the key times of each assembly station. This design represents the starting point of improvement. Next, the map of the parts flow is shown to verify the materials movement between the stations, calculating the productive and unproductive times, stocks and metrics that will help to characterize the process and marking some targets of progress. Metrics used are DtD and LR (Equation 1 and 2).

$$DtD = \text{Time for material flow through value stream} \quad (1)$$

$$LR = \text{Added value work time} / DtD \quad (2)$$

To establish a control of the accumulated stock, takt time (Equation 3 and 4) was used. Once the takt time is defined, it is possible to establish the cycle time.

$$\text{Takt time} = \frac{\text{Total time available for production per shift}}{\text{Required numbers of parts per shift}} \quad (3)$$

$$\text{Stocks} = (\text{Time of entire step} - \text{Time added value}) / \text{Takt time} \quad (4)$$

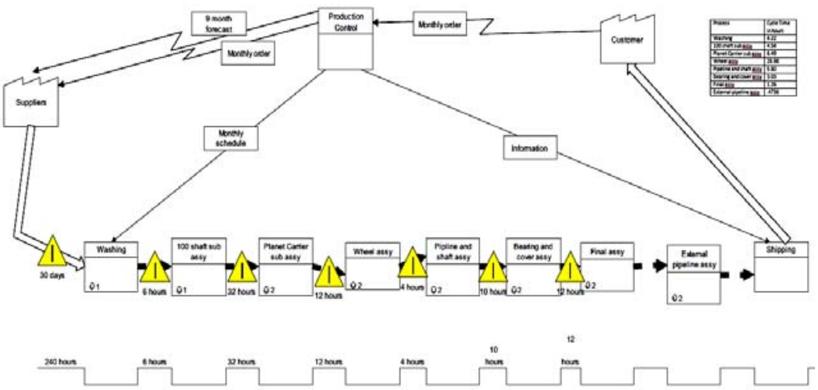


Figure 3. The present value stream map

The present state is based on the housing as the core component and the assembly of the gearbox is a push system. The majority of the raw materials are sourced from foreign country and the final product is supplied primarily to the Indian market. Every nine months, a forecast is generated based on customer requirements and every month the factory introduces the material requirements for the manufacture. In parallel, an electronic order is sent to the suppliers located outside India. The required materials are transported by sea in the usual case and by air when urgency arises. Once the raw materials arrive, cleaned and quality checked before they are stored systematically in shelves. When the actual customer order is generated, raw materials to assemble six gearboxes are released from the storage location to the assembly area. The raw materials are then washed in a pre-assembly washer, the order of the components are predetermined. There was an overstock of washed parts. This was a cause of concern as the parts occupied space thereby causing hindrance to the other processes. Thus there is an overstock of materials caused by the push production system.

The cycle time of the various tasks involved can be obtained from the present state VSM (Figure 4). From Figure 4, it can be concluded that the wheel assembly is the bottleneck. The transport of parts within the assembly area is done with the help of overhead cranes. The parts are pushed to subsequent assembly processes. The major point where inventory is accumulated can be pinpointed to the store where raw materials are kept before the assembly. The processing lead time for this process is found to be 33.16 days and the processing time is calculated as 51.83 hours. The final calculations of the Dtd and LR provide the following results: Dtd=35.31 days and LR= 6.12%. The average production rate for the assembly line was found to be 0.192 units per hour. The cycle time for the assembly line with an assumed line efficiency of 90% was calculated as 281.25 min/cycle and cycle rate was found to be 0.213 cycles/hr. These metrics depend on the present state.

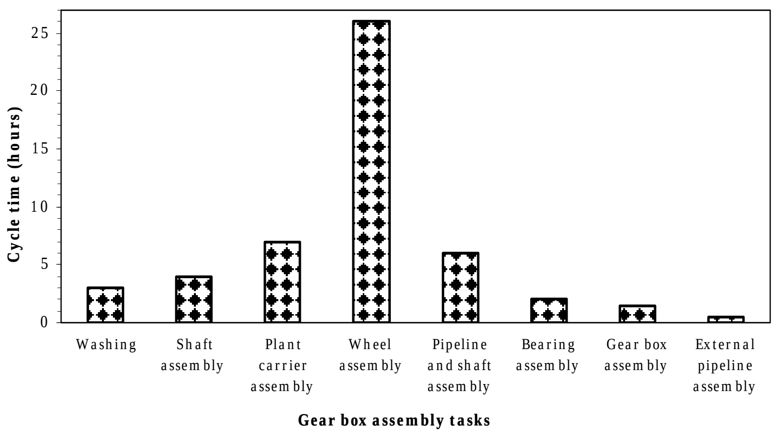


Figure 4. Cycle time for the various assembly tasks

6.2 Improvements

The following sub sections describe an integrated approach followed in this work to eliminate the non-value adding activities identified by the initial value stream mapping.

6.2.1 One piece flow

During the initial state, the system was leaning towards batch production where raw materials were supplied altogether to assemble a batch of six gearboxes. Combination of one piece flow and batch production has been found to produce optimum results. Following this philosophy, a maximum batch quantity of two was fixed for any process in the assembly while certain processes would follow pure one piece flow.

6.2.2 Just in time

Parts required for assembly at each station is supplied as and when required and transporting raw materials to the factory also done just in time with safety stock in case of delays. This results in reduction of lead time. Further, the strategies that are adopted to reduce assembly lead time are given in Figure 5.

6.2.3 Line balancing

It was found that the excess time due to the bottleneck operation could be equalized as a result of line balancing. A balanced takt time based production for a two shift operation was developed and implemented as shown in Figure 6.

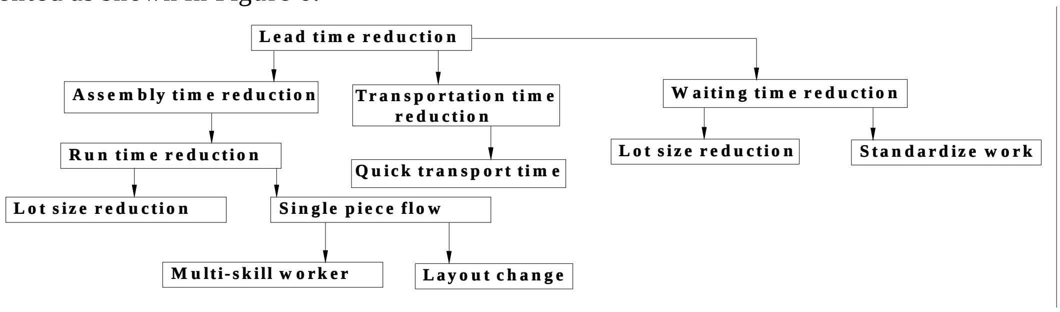


Figure 5. Lead time reduction strategies

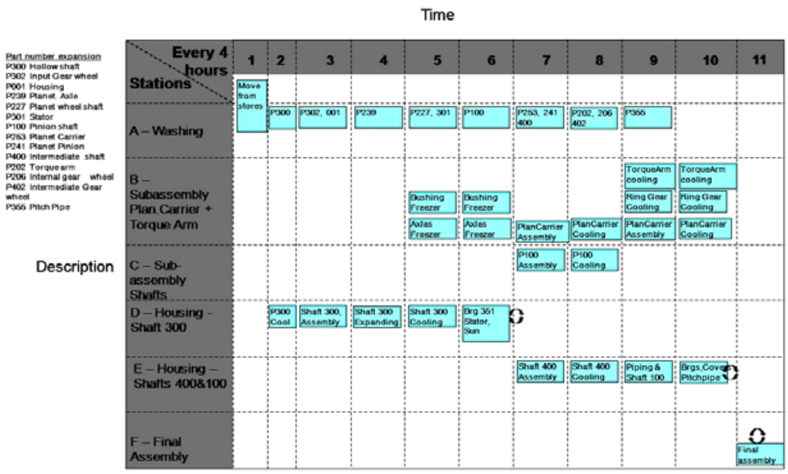


Figure 6. Work balance chart

6.2.4. Labour productivity

Another important activity was the labour productivity improvement. As a result of studying the layout and by assigning multi skilled workers to different stations, the workforce of the assembly team was reduced from 28 workers to 22 for two shifts.

6.3 Constructing the future value stream map

Table 2. Lean assembly line improvements

	Current state	Lean line - improvements
Lead time	33.16 days	14.68 days
Dock-to-dock time	35.31 days	15.68 days
Lean rate	6.12%	7.1%
Cycle time	281.25 min/ cycle	225 min/ cycle
Average production rate	0.192 units/ hour	0.24 units/ hour

The calculation of lean metrics DtD and LR indicated that the assembly line performance was improved. The DtD was reduced to 15.78 days from 35.31 days as a result of reducing the store inventory to 14 days from 30 days by improving the supply chain and material requirements planning. The LR was found to have increased. This can be attributed to the dramatic reduction of the DtD time over a comparatively marginal decrease in the value added time. The production rate was found to increase, meeting the challenge of the increased demand with a value of 0.24 units per hour. The results have been summarized in the Table 2 and the new value stream map is shown in Figure 7.

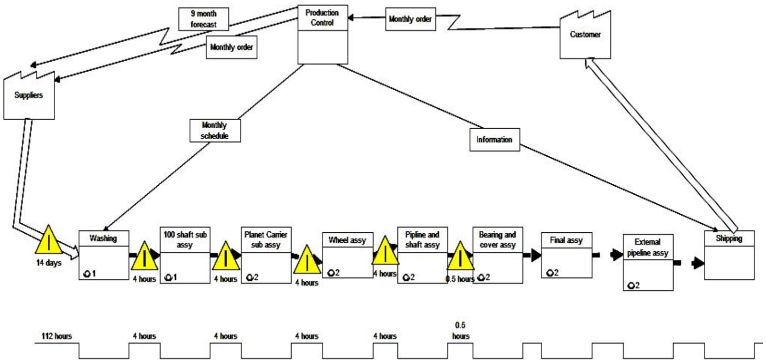


Figure 7. Improved value stream map

7. CONCLUSIONS

This work demonstrates the advantages when applying lean principles to the assembly line and the following conclusions are made:

- The LR was found to have increased after applying lean tools to the gear box assembly line. This indicates that the revised system is moving towards a leaner system of assembly.
- The DtD was dramatically reduced by optimizing store inventory. This means that the customer can expect his gearbox to be delivered in a shorter duration than before.
- The average production rate improved by 25%. The gearbox requires only a takt time of 4 hours compared to the previous average of 5 hours.
- The waiting time was reduced by almost 60 hours. This leads to faster assembly of the gearbox.
- By utilizing the lean layout, the inventory between various stations was reduced leading to cleaner and leaner assembly lines.
- A takt time based system was found to improve the assembly rhythm leading to a new gearbox being assembled every 4 hours.
- By providing multi-skilled training and making instructions clear to the assembly line workers, the employee morale has improved.
- Manpower was reduced from 13 persons per shift to 10 persons per shift by standardizing the layout and optimizing the work load to the employees.

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