Materials Today: Proceedings 46 (2021) 10334–10338

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Lean and agile manufacturing for work-in-process (WIP) control

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ARTICLE INFO

Article history:
Received 30 October 2020
Received in revised form 30 November 2020
Accepted 12 December 2020
Available online 8 February 2021

Keywords:
Work in process
Operation planning and control
Quality assurance
Lead time and cycle time
Lean and agile manufacturing
Inventory

ABSTRACT

To become a world class organisation, the basic requirements of any manufacturing company are Cycle time reduction, lower manufacturing cost and minimal inventory. To compete in the digital and dynamic world, the lean and agile manufacturing play a vital role to uplift the production process. Lean manufacturing prioritise the value addition by eliminating the repetitive, null valued processes in the manufacturing cycle. Agile manufacturing supports optimization, standardisation and automation of the development processes. The purpose of Lean and agile manufacturing is the customer satisfaction with a cost-effective price. The role of lean and agile manufacturing is vital to maintain the optimum work in process inventory in the production flow. In the present work, the concept of lean and agile manufacturing is applied in the boiler component fabrication work, where the aim is to determine the factors affecting the Work-In-Process (WIP) inventory levels to meet the required demand for each product. The decision variables are identified and their effects are analysed. The analysis is focused on root cause of the problem, fundamental problems associated with the systems, implementation of Kanban, inventory cost, reorder point etc. The work provides methodologies to minimize the total WIP inventory across all elements of the boiler component.

1. Introduction

Today, the market has become increasingly demanding and cost conscious. Robustness of its quality processes is a prerequisite for any company to succeed in today's dynamic market scenario. To improve operational efficiency, it is a must to revisit the manufacturing processes and systems to deliver best-in-class products and services in this situation. Traditionally, mass production and complete utilization of plant capacity were the factors to garner money. The excess consumption of raw materials, more work-in-process and finished goods inventories are the negative outcomes of the traditional manufacturing method. This style of manufacturing resulted in inflexible plants and is very difficult to reconfigure. Organizations have introduced the strategies of lean and agile manufacturing to reduce the inventory, maintain minimal product lead-time and the reliability in the system flow. Lean utilizes 100% of the available resources viz, man, machine, and money and eliminates low value activities from the process. The lean manufacturing improves competitiveness by inventory reduction and lead-time reduction also improves overall quality of the process [1–7]. Using the lean and agile management techniques, a research work has been carried out in a heavy manufacturing industry wherein the production sequence of a boiler component is studied and analysed with an objective of maintaining the minimum work-in-process inventory, optimising the product lead time so as to have flexible system flow as per standards and procedures. Materials being a key and inevitable input, directly affects the fundamental economic objective, namely, profitability of any manufacturing organization.

Work in Process (WIP), in some cases also referred to as work in progress, refers to inventory which has entered the manufacturing process, is no longer part of the inventory of raw materials, but is not yet a complete product. In manufacturing, reduction of WIP results in a higher level of liquidity, improved cash flow, better customer service and lower risks to the business [8–10]. Having accurate forecasts will promote awareness and as a result, provide a sound basis for planning. The desired outcome should be a lessening of the buffer sizes in order to maintain continuous flow and avoid overstocking. Addition of machinery and improving the

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https://doi.org/10.1016/j.matpr.2020.12.473
2214-7853/

workforce may be a viable solution of last resort, resulting in significant reduction of WIP. Before implementation of this technique, it is vital to establish that the operational capacity of each machine and operator is calculated relative to demand. WIP has taken as a top-issue by the management. It is necessary to monetize it for better cash flows and to improve the revenues.

Phenomenon of long waiting time has always comes out in the production process before the next operation. Besides of large inventory, delay in delivery is also part of the problems. Therefore, the objective of the current study is to find out the specific problem among the production line which causes WIP inventory. In this present work, manufacturing of super heater / reheater coils of thermal power plant boiler is considered and the time required to complete each operation on the product were computed and analysed.

Section 2 details the importance and limit of work in process followed by suggestive methods to reduce the WIP. Section 3 briefs the lean and agile methods in context to the super-heater / reheater coil manufacturing process and the case study was explained in Section 4. This work will definitely aid in development of optimization techniques for work in process moving towards lean and agile manufacturing in boiler component production.

2. Work in process (WIP)

2.1. Importance of WIP

Efficient management in any of the input directly affects the output and results in the profitability of the organization. As materials consume maximum share of the investment and that too with a possibility of turnover, its efficient management directly contributes to the profitability of the organization.

Importance of WIP control can be seen from the following:

- Work is not valuable until it reaches the hands of the customer.
- Work in Process (WIP), in some cases also referred to as Work in Progress, refers to inventory which has entered the manufacturing process, is no longer part of the inventory of raw materials, but is not yet a complete product.
- In manufacturing, reduction of WIP results in a higher level of liquidity, improved cash flow, better customer service and lower risks to the business.
- Having accurate forecasts will promote awareness and as a result, provide a sound basis for planning. The desired outcome should be a lessening of the buffer sizes in order to maintain continuous flow and avoid overstocking.
- Addition of machinery and improving the workforce may be a viable solution of last resort, resulting in significant reduction of WIP. Before implementation of this technique, it is vital to establish that the operational capacity of each machine and operator is calculated relative to demand.
- WIP has taken as a top-issue by the management. It is necessary to monetize it for better cash flows and to improve the revenues.

2.2. WIP Limits

To deliver the efficient work across the production line it is required to have the WIP limits. Without limiting WIP, it is incredibly difficult to find the wasteful and inefficient processes across the line. The impact on the system can be disastrous, in terms of speed of delivery, work quality, cost and morale. Even though it may be challenging to implement the WIP limits, there are benefits of approaching the work with focus, clarity and discipline.

Need of WIP Limits: [11]

- WIP Limits Enable Us to Manage Capacity
- WIP Limits Encourage Us to Practice Systems Thinking
- WIP Limits Introduce Slack into the System
- Stop Starting, Start Finishing

2.3. Methodologies of reducing WIP

The huge power of reducing WIP is not in stopping multitasking or avoiding machine jams or reducing cycle times. It is reducing Overproduction, the worst waste and leads to unnecessary Inventory, Waiting, Transport as well as Unevenness and Overburden. [12]

Lead Time and Cycle Time are two important metrics in Lean and process improvement in general.

To get started with WIP limits, it is recommended to generate Roadmap of the team.

To understand the critical factors while generating roadmap the lean and agile manufacturing strategy finds an important role.

3. Operational elements in lean and agile manufacturing

In order to survive with increasing competitive intensity, manufacturing companies attempt to improve their manufacturing operations by addressing specific needs. Depending on the study and analysis of the market requirements, variety of improvement options like lean and agile manufacturing may be incorporated in the process cycle. Null value resources are required to be identified and eliminated for a company to be profitable. Determining the source of waste whether it is using inferior materials or inefficient manufacturing processes and then activating a lean or agile manufacturing process can save any company money, resources, and increase profitability. Also, it increases the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to dynamic and competitive markets, driven by customised products and services.

Agile Manufacturing supports the optimisation and automation in the development process, it is possible to develop the innovative methodologies to deliver the products according to the changes in customer demand. The lean operations are incorporated to have the mass and repetitive production adhering to the daily scheduling with the operation sequence in the process oriented layout. Both lean and agile initiatives significantly affect quality conformance, delivery speed and delivery reliability.

3.1. Lean manufacturing

Lean principles within a supply chain are the process of reviewing all aspects of manufacturing and removing anything not needed. In most situations, items removed are those that are deemed to have no positive impact in manufacturing.

The supply chain must also operate ‘lean and mean’ for the process to work correctly.

- Production should be based on demand and not on supply.
- The production is more efficient in order to exploit economies of scale;
- Taking the time to focus on quality also increases production and efficiency;
- Employers are responsible for defining their method of working;
- Rather than executing predefined tasks over and over again, workers must continually improve their way of Working.

The Lean methodology eliminates all that does not add value. Eliminating waste means eliminating unnecessary meetings, tasks and documentation, inefficient methods of working.

Generally, there are seven types of wastes within manufacturing organisations - overproduction, excess inventory, waiting (lost time), unnecessary motion, unnecessary transportation (double handling, or moving excess stock), re-work (poor quality) and over-processing/over-engineering (Six Sigma, 2017). It is recognised that even incremental improvements can help an organisation to increase efficiency and reduce costs [13].

3.2. Agile manufacturing

In order to have an efficient and intelligent use of valuable resources like man, machine, material, money, it is vital to study and analyse with accurate data for performing changes in manufacturing. By being agile or flexible, a company has the potential of fine-tuning their manufacturing.

Agile examines the speed and effectiveness of organisational responses to management information and/or business intelligence and the quality/relevance of the subsequent decisions made. [14]. Agile manufacturing supports for:

- Reducing expenses during downturns in business.
- Forecasting and proactive planning.
- Creating multiple manufacturing programs that can be activated without removing too much equipment or removing resources from the business
- Establishing preliminary manufacturing schedules based on forecasting

Manufacturing excellence can be achieved to deliver world-class performance while cultivating the right culture through leadership and mentoring with quality assurance and perfect operation planning and control.

3.3. Quality assurance

To assure the best quality of operational sequence, the no value items and activities shall be eliminated. To eliminate the no value items, continuous monitoring and improvement in the chain of operational sequence are required. For continuous improvement, the shared/collective involvement of all employees are required with the practice of following the below stimulants:

- Standard guidelines and procedures
- Motivation
- Team effect
- Brain storming
- Involvement
- Employee welfare and development.
- Job security.
- Innovativeness
- Total involvement.

It is the responsibility of a higher level to ensure that the processes involved directly and indirectly in the production are really optimized.

3.4. Operation planning and control

It is essential to plot a road map to the processes and to speed up the procedure to quickly respond to the customer needs.

Production planning, scheduling and control is concerned with manufacturing the right product types, in the right quantities, at the right time, at minimum cost and meeting quality standards. Production planning, scheduling and control are the heart of manufacturing firms [15].

The strategies being followed to achieve the perfect coordination in operation planning are:

- Line Balancing and distribution of loads suitably for better Resources Utilization.
- Keep abreast with latest manufacturing technology.
- Identify addition of Manufacturing Facilities for futuristic needs.
- Advance planning for Toolings and Welding Consumables procurement.
- Develop and establish appropriate new processes.
- Advance action for Fittings and components / Attachments manufacture.
- Continuous interaction / reviews with allied departments like Product Engineering. / Materials Management for timely inputs.
- Identify usage for non-moving materials for better utilization / conservation of Resources.
- Provide work instructions to Task Performers.
- Expedite and Monitor the progress of critical contracts and generate MIR.
- Computerization activities for Planning and Scheduling.
- Team approach to sort out interface issues.
- Modify manufacturing processes / practices for improving Quality and reducing rework.

3.5. Improvement of the workforce

Due to investment constraints, it is not possible to introduce additional machinery to scale down WIP, but this can be done by optimizing the deployment of the workforce. However, for this to be effective, it is necessary to establish the operational capacity of the operator concerning the demand.

4. Case study

Among various components, the manufacturing of one of the Heat transfer coils is considered for the present research work because of the utilization of more number of variants of tubes like dimension, material etc., and forms the major percentage in turnover of the company; also the operation sequence involves various processes which involves different machines.

Heat transfer coil analysis

- No. of Tubes: 2049
- No. of Bends: 4182
- No. of Edge Preparations: 8466 Ends
- Straight Tube Butt Welds (STB):3978&Orbital TIG:255
- Hydro Test Plugging: 28 × 51 = 1428 Ends

Time required to complete each operation on the Product (Table 1)

A. Edge preparation & tube cutting (ATCEP machine)
   Requirement:
      No of ENDS = 2049 × 2 = 4098 Nos
      Time Required = 4098 × 8/270 = 121.42 Hr
B. Straight tube Butt Welding (STB machine):
   Requirement:
      No of STB Joints = 3978
      Time Req. = 3978 × 8/45 = 707.2 Hr
C. Coil bending (System Bender machine):
   Requirement:
      No of BENDS = 4182 Nos

Table 1
Machine constraints.

Sequence ID	Operation	Machine involved	Thickness (mm)/Dia	Nos.	Hour/Shift
A	Edge preparation & tube cutting	ATCEP	THK $\leq$ 7.1	270 ends	8
B	Straight tube Butt Welding	STB	DiaTD 54 – 63.5 THK < 6	45	8
C	Coil bending	System bender machine		80 bends	8
D	Coils Orbital TIG Welding	O-TIG		16O-TIG JOINTS	8
E	Fit-Up Welding	WELDING		0.5 no of assembly	8
F	Stress relieving			One assembly	½ an hour
G	Hydro testing			36 ends	8

Time Required = 4182 × 8/80 = 418.2 Hr

D. O-tig:
Requirement:
No of OTIG Joints = 255
Time Req. = 255 × 8/16 = 127.5 Hr

E. Fit-up full welding:
Requirement:
No. of Assy. = 51 Assy.
Time Req. = 51 × 8/0.5 = 816 Hr

F. Stress Relieving :
Requirement:
Time Req. = 51 Assy. × ½ Hr = 25.5 Hr

G. Hydro testing:
Requirement:
No. of ENDS (51 Assy.) = 28 × 51 = 1428
Time Req. = 1428 × 8/36 = 317.33 Hr

Total Time for completion of product
Total Time(TT) = A + B + C + D + E + F + G
= 121.42 + 707.2 + 418.2 + 127.5 + 816 + 25.5 + 317.33 = 2533.15 Hr
UT = Total time × 10% = 2533.15 × 10/100 = 253.31 Hr
Actual total time = TT + UT = 2533.15 + 253.31 = 2786.46 Hr
DAY = 3 SHIFTS
Total days = 2786.46/(8 × 3) = 116.10 DAYS
Completion of one Assembly = 116.10/51 = 2.2 Days/Assy
Completion Time of one assembly for every product is given:
Heat transfer coil considered =>2.2 Days/Assy.

Pie-chart representation of**% amount of time** spend in each operation performed in heat transfer coil is here:

From Fig. 1, it can be observed which Operation takes more time and less time. Based on its share in hour, if any operation needs to be done in lesser amount of time can be chosen and can be done by increasing e.g. Manpower, No. of machine, No. of shift etc. This analysis indicates the manufacturing capacity and capability of operational flow layout, amount of time required to manufacture whole Assembly. This will help for monitoring as well as for future planning.

5. Discussion

This analysis focus on root cause of the problem, fundamental problems associated with the enterprise resource planning (ERP) system, implementation of Kanban, inventory cost and reorder point with reference to super heater / re-heater coil manufacturing in boiler production industry. The validation is being done in closed environment and the data are obtained from the ERP system. The optimization of a process for maximum efficiency, while maintaining quality standards, is a consequence of validation. The optimization of the facility, equipment, systems, and processes results in a product that meets quality requirements at the lowest cost. Creating a 360-degree view of the customer and being able to bring the product to the centre of the operations and understanding intimately how a product is used brings huge benefits from product development through improved models.

6. Conclusion

Nowadays, the companies are stepping into lean and agile behaviour. Though some traditional companies finding the change as a challenge, the companies need to understand the basic ideas and become intelligent respondents to the concepts to survive in the dynamic and digital business world. The implementation of the lean and agile strategy involves radically new concepts concerning strategies, organisation, people and technologies. Implementation of Lean and Six Sigma principles is one of the best ways to reduce WIP. Use of a predictive performance format in reporting aids to make these decisions. Transformation from traditional to efficient

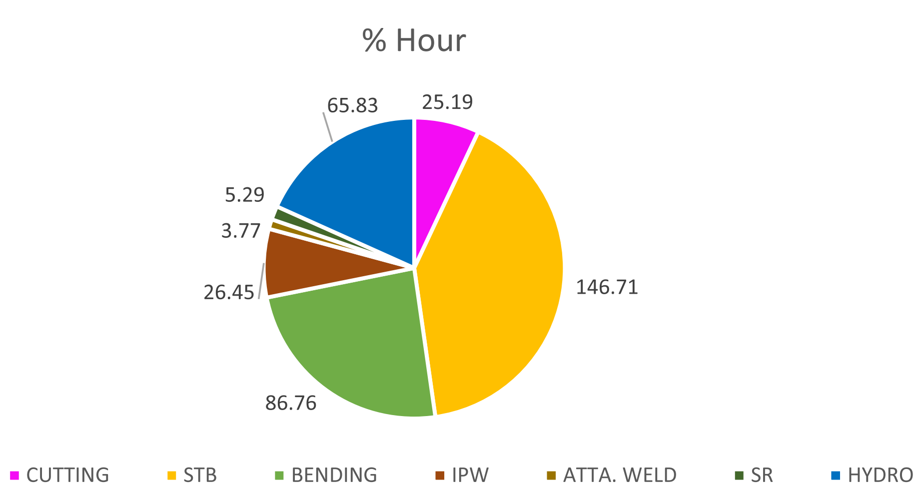

Fig. 1. % Distribution of Time for Operations Performed on Heat transfer coil.

operational environment has the various strategic plans for the creation of a steady and flexible production process and easier growth of company's success.

CRediT authorship contribution statement

C. Hemalatha: Conceptualization, Validation, Investigation, Writing - original draft. **K. Sankaranarayanasamy:** Supervision, Resources. **N. Durairaaj:** Methodology, Formal analysis, Data curation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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