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Production Enhancement through Integration of Lean, Life Cycle Assessment & Industry 4.0

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ABSTRACT

Advancement in the manufacturing sector has attained a dominate interest from the researchers as well as the industrialists, for attaining the more products efficiencies. The concept of Lean Manufacturing set the cornerstone for excellence in manufacturing sector by improving the production times and reducing the non-value-added processes. In 2011, the concept of Industry 4.0 pivoted the concept of automation in factories to complement the production improvement processes. The under developing countries such as Pakistan, the manufacturing sector is run with the conventional manufacturing practices, which yields the products of lower quality and much time is being wasted resulting in overall poor efficiency. Moreover, those industries which want to improve their processes are not very much certain, about the methodologies they shall implement. In this research study, the authors have used the mathematical modelling approach of Analytical Hierarchy Processes (AHP) to recognise the pertinent Industry 4.0 technologies and lean perceptions – this technique empowers opportunity of organizing and analysing the intricate decisions for a strong understanding. By using Value Stream Mapping and Automation in a simulation-based case study, improvements of 44.70% in lead time, 17% in value added time and 45.25% in non-value-added time were witnessed. This research explores the avenue of Multi-Criteria Decision-Making (MCDM), based decision making in Industry 4.0 related environments. It will provide clarity to academicians regarding the integration of lean and Industry 4.0 through optimized and logical selection of relevant approaches, in addition to aiding practitioners in intelligent decision making.

Keywords: Lean Manufacturing, Industry 4.0, Production Improvement, AHP method, Case Study.

INTRODUCTION

As there are advancements in the industry with the industrial revolutions, the reduction of wastes and quality improvement are essential for a highly competitive business environment. Newer tools and techniques are being introduced to provide more reliable and sustainable solutions in manufacturing sector. The application of Lean Manufacturing (LM) concept has produced a considerable positive impact on the different industries since its beginning and it has been a very popular technique during the recent couple of decades. The higher application of this techniques in industries is due to its effectiveness in simplifying the complexities and in reducing the different types of wastes which leads to the poor efficiencies. The advent of fourth industrial revolution has revamped the manufacturing landscape, and researchers have indicated that there are high chances to integrate the technique of lean to the concept of Industry 4.0. The potential advantage of this integration is to attain the combined benefits of both, resulting in optimized performance (Rafique et al. 2022). However, many tools and techniques of lean manufacturing are not very much familiar by the manufacturing industries, which is a considerable hurdle for its successful implementation on industrial level. Many times, efforts become unsuccessful, when there is not much understanding about the technique. The aim of this present work was to attain a better understanding about the different tools and techniques of Lean Manufacturing (LM) and their integration feasibility to the industry 4.0. In this work authors utilized the approach of AHP via mathematical modelling for a simulation-based case study on a pipe manufacturing facility. This work proposes a conceptual framework for a sustainable integration of lean manufacturing with Industry 4.0.

As the concept of lean manufacturing was introduced by Taiichi Ohno of Toyota, in which the concept of manufacturing wastes was redefined; thereby establishing it as a philosophy (Bhasin and Burcher 2006) that enables industries to achieve manufacturing excellence. Popularized by Womack et al. (1990), the concept of lean urged the practitioners to explicitly define the customer need, eliminate wastes, subject the processes to a flow, introducing a pull system and producing as per customer demands. The universality of this concept was such that it was successfully adopted by services (Swank, 2003) and construction sector (Lauri, 1992). The tools of Sort, Set in Order, Shine, Standardize, Sustain (5S), Kanban, Value Stream Mapping (VSM), Andon etc. were proficient in improving the productivity and the business performance (Nawanir et al. 2013) as well as the operational performance (Rahman et al. 2010). The implementation of lean manufacturing reduces the production time and improves the processes. In the current paper VSM is selected as it identifies and evaluates the current state of any system. As first decade of the second millennium came to a close, a new concept of Industry 4.0 was introduced which called for digitalization of the systems through cyberphysical systems, interconnected sensors and artificial intelligence (Kolberg and Zühlke, 2015). By applying the concepts of BigData and cloud computing, high operational performance can be achieved (Schmidt et al. 2015) in addition to productivity improvement (Schuh et al. 2015). Ganzarain and Errasti (2016) gained 30% improvement in production time through application of Industry 4.0 principles in a small manufacturing firm. It can be seen that Industry 4.0 complements Lean principles and can be integrated in a harmonious manner. Clinton P. and H. K. Sachidananda concluded that Industry 4.0 technologies have a positive impact on lean manufacturing and organizational productivity. Also, that both lean and I4.0 technologies support each other. (Pereira and Sachidananda 2021)

The objective of this study was to explore the most pertinent lean and Industry 4.0 concepts through the multi-criteria-decision-making tool of AHP, which is an efficient tool to organize and analyse complex decisions with multiple variables by providing a rational and elaborated framework for structuring a problem by decomposing into various hierarchies. This approach has been profusely used in lean manufacturing implementation (Vinodh et al. 2011; Badurdeen et al. 2011; Bañuelas and Antony 2003) but the integration with Industry 4.0 remains an unexplored avenue. The paper is structure as follows: section 2 discusses the current state of the art and research gap, section 3 discusses the mathematical modelling whereas section 4 elaborates the implementation on a case study, the results of which are elaborated in section 5 along with research implications and limitations.

LITERATURE REVIEW

VALUE STREAM MAPPING (VSM)

The concept of VSM is a tool of lean Manufacturing (LM), this tool helps to analyse the information related to the material and flow of a specific product related to a family. Jasti and Sharma (2014) made an effort to visualize the importance of the VSM in the environment of the Lean Manufacturing by a Case Study in an Indian automotive parts industry. From the results it was found that this tool helps to bring a positive impact on the process ratio, TAKT time, controlling the inventory level, and speed of assembly line. It also helps to reduce the lead time and to reduce the labour requirement, thus satisfying the customers in terms of quality, cost and delivery.

Zahraee et al. (2014) also utilized the methodology of case study, and in his work the technique of VSM was applied to a production line of an automotive parts manufacturing industry. The purpose of this effort was to reduce the waste and the non-value-added activities. In that work a first version of VSM framework was developed on the basis of interviews and observations, afterwards another version was proposed for the future on the basis of the results from the first one. From the results it was very much clear that this tool is very much helpful and applicable for reducing many types of wastes. It was found that production lead time was reduced nearly to 80% and the value-added time up to 12% by applying VSM.

Jasti and Sharma (2014) utilized the case study method for VSM in the environment of Lean Manufacturing. From his work, it was found that Value Stream Mapping helps to bring a positive impact on the process ratio, TAKT time, controlling the inventory level, and speed of assembly line. It also helps to reduce the lead time and to reduce the labour requirement, thus satisfying the customers in terms of quality, cost, and delivery. However, in this research/case study the main focus was only a single company. So results are not very much generalized. Zahraee et al. (2014) also made effort for analysing the VSM framework through the methodology of the case study. The results revealed that clearly, this tool is very much helpful and applicable for reducing many types of wastes. It was found that production lead time was reduced nearly to 80% and the value-added time up to 12% by applying VSM. However, as this complete case study was carried out without any type of simulation, or computer software, the results can be further improved by adding simulation or computer integration. Rohani and Zahraee (2015), through a case study, analyzed the fundamental principles of Lean Manufacturing that were utilized to construct VSM. To identify and eliminate the different wastes, by doing the team formation, selection of product, and takt time calculation. The results revealed that this methodology reduced production lead time from 8.5 to 6 days and the value-added time was reduced from 68 minutes to 37 minutes. Their work was quite detailed however, a more deep analysis can be done by involving the computer simulations along with Value Stream Mapping, so that it shall evaluate more important factors on overall reduction of wastes. Zahraee et al. (2020), investigated through a case study and found that the implementation of the Value Stream Mapping was done along with the computer simulation. Consequently, it assisted in the identification and reduction of the wastes of a small-scale heater manufacturing plant. Principles of Lean and takt time were the main focus in this work. Additionally, their work can be further extended by the addition of computer simulation assistance, moreover, the green manufacturing concept should be also included to reduce the waste as much as possible.

MULTI-CRITERIA DECISION MAKING

MCDM is a mathematical tool which aids in choosing the best alternative from a set of choices, after subjecting them to rigorous assessment. It does not only pertain to selection of best alternative, but also the priority order in which the resources are allocated for best concept selection, in order to combine the strengths of preferences in a collective manner.

Through the introduction of mathematics, the decision-making process becomes more logical, in which various preferences are decomposed into many properties that are attributed to the alternatives, in which their importance is determined. By comparing the relative preference, with respect to each property, results are synthesized to obtain the overall performance. In simpler terms, the strategy entails breaking down a complex problem into smaller components and establishing a rank order of priorities to discuss the alternatives and selection of the most pertinent choice.

Tzeng and Huang (2012) applied mathematical modelling approach, to understand the concepts of Hybrid MCDM & Decision-Making Trial and Evaluation Laboratory (DEMATEL). Bai et al. (2018) applied mathematical modelling approach to analyze the, Grey Based Rough Set & TODIM (an acronym in Portuguese of interactive and multi-criteria decision making) framework. The authors took 30 lean manufacturing practices and sought the performance of the most pertinent practices in operational and environmental domain. Aliakbari Nouri et al. (2015) utilized the mathematical modelling approach through the method of case study.

LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a tool which identify and measure the impact of energy on the environment, which is being used in the manufacturing of a product or service throughout its life span. LCA starts from the very first raw material and its abstraction to the end disposal

Industry 4.0 digitalizes the manufacturing and process interconnections to improve the production and sustainability of the system. Fernando GM and Maria S. proposed a framework using social organizational LCA which concluded that digitalization enables environmental assessment. Their framework (García-Muiña et al. 2021)s Marco Cucchi and Lucrezia Volpi also used Organizational LCA in manufacturing sector to provide evidence that Industry 4.0 operating models acts as enablers to greener technologies and facilitates organizational environment (Cucchi et al. 2022)

METHODOLOGY

In order to achieve the goal of the research, the authors worked on a real time cross- sectional case-study analysis. After the literature review, the authors have gathered data by visiting the manufacturing plant and observing their methods and problems. Research methodology is shown in FIGURE 1.

The MCDM technique has been employed to arrive at the most relevant technique suited to the industry. The conventional decision-making techniques of DMGA, Ishikawa, Fishbone diagram etc., are empirical in nature and are not backed by substantiating theory or logic. Therefore, the authors have used the MCDM of AHP to select the appropriate technique

The technique of AHP is an oft-used methodology having a wide array of applications. In this concept, the processes of rating alternatives and aggregating are combined for finding out the most suitable alternatives. This methodology enables the ranking of the alternatives sets; it can also be utilized for the selection of the best from the alternatives. The processes of ranking are dependent upon the achievement of the goal, which is further divided into set of criteria. This AHP method depends upon the importance/ weight assigned to the criteria in achievement of the overall goal. It has been broadly applied to boost rice crop yield [23].

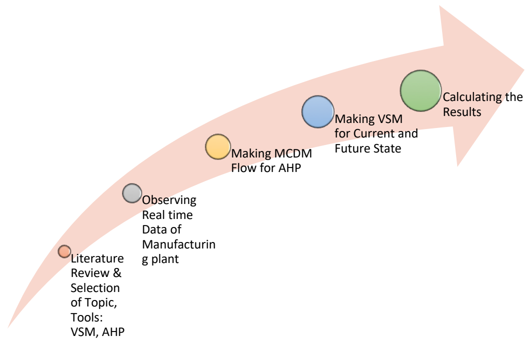


FIGURE 1. Research Methodology

HIERARCHICAL STRUCTURE OF THE SELECTED MANUFACTURING PLANT

The authors selected a Lahore based pipe manufacturing facility, which is one of the major suppliers of Electric Resistance Welded (ERW) pipes and galvanized hexagonal lighting poles to public and private sector. With an annual turnover of PKR 800million, it is one of the leading Lahore based steel industry in export business. The company's top management is committed to quality (ISO 9001 certified) and has been awarded a certificate by American Petroleum Institute (API).

Even though the facility is market leader in production of galvanized poles and ERW pipes, it was observed that there has been difficulty in meeting customer demands within the stipulated time. Thus, the author visited the facility to do a comprehensive analysis of the processes and identify the wastes. The major products of the company, in the descending order of revenue generation, are given as follows:

1. Carbon Steel Galvanized Poles (Ø2"-Ø8")
2. Carbon Steel ERW pipes (Ø1/2"-Ø18")
3. HDPE Pipes (Ø4"-Ø36")

4. Carbon Steel Pipe Fittings (Elbows, Tees, Reducers etc.)
5. PVC Pipe Fittings (Elbows, Tees, Reducers etc.)

The authors developed a production improvement level with four criteria and twelve attributes. The four criteria include cost, quality, productivity and manufacturing flexibility. There were three choices:

1. Standalone implementation of lean manufacturing principles
2. Standalone implementation of Industry 4.0 principles
3. Integrated implementation of lean and Industry 4.0 principles

Regarding Industry 4.0, the authors had consensus on automation and smart production control as the driving force since it fit seamlessly with the demands of the selected manufacturing industry. The criteria are described as under:

1. Cost: This includes the following sub-criteria:
   a. The total manufacturing cost borne by the organization for producing one pipe spool
   b. The operational cost borne by the organization, including human resource costs, benefits, endowment, consumable costs, cost of sales, etc.
   c. The liabilities incurred by the organization in terms of bank loans, dividends, repayments, etc.
2. Quality: The manufacturing facility prides itself in producing high quality products with minimal rejection rates, therefore the following sub-criteria were defined:
   a. The rejection rate for every order, regardless of the order size, from customer
   b. Process capability analysis i.e. number of faulty pieces in a batch
   c. The size of the batch which is being produced as per customer demand
3. Productivity: One of the major challenges faced by the organization is excessive overtimes, therefore the following sub-criteria were defined:
   a. The total lead time for the pipe spool given to customer
   b. The minimum time required to produce one pipe spool as per the given order
   c. Work in process inventory
4. Flexibility: Since the industry aims to be market leader in pipe and pole manufacturing, therefore it is imperative to have manufacturing flexibility which enables mass customization
   a. Automation of the processes, since the working weights may exceed ergonomic limit for the worker
   b. Mass customization in case of non-standard requirements from client

In case of various orders that associate with mass customization, the production levelling may become a daunting task, therefore it is one of the sub criteria since it directly effects flexibility.

The defined criteria and sub criteria were compared pairwise with the three choices in order to select the best approach. For better understanding and clarity authors have tried three different approaches in this part of Analytical Hierarchy Process, means standalone lean techniques, standalone industry 4.0 and the integrated approach of combining both of these two to achieve the best production result as much as possible from the pipe manufacturing facility and from the multi-criteria it was found that higher the flexibility, higher the customization higher the customer satisfactions due to the reduction in the lead times

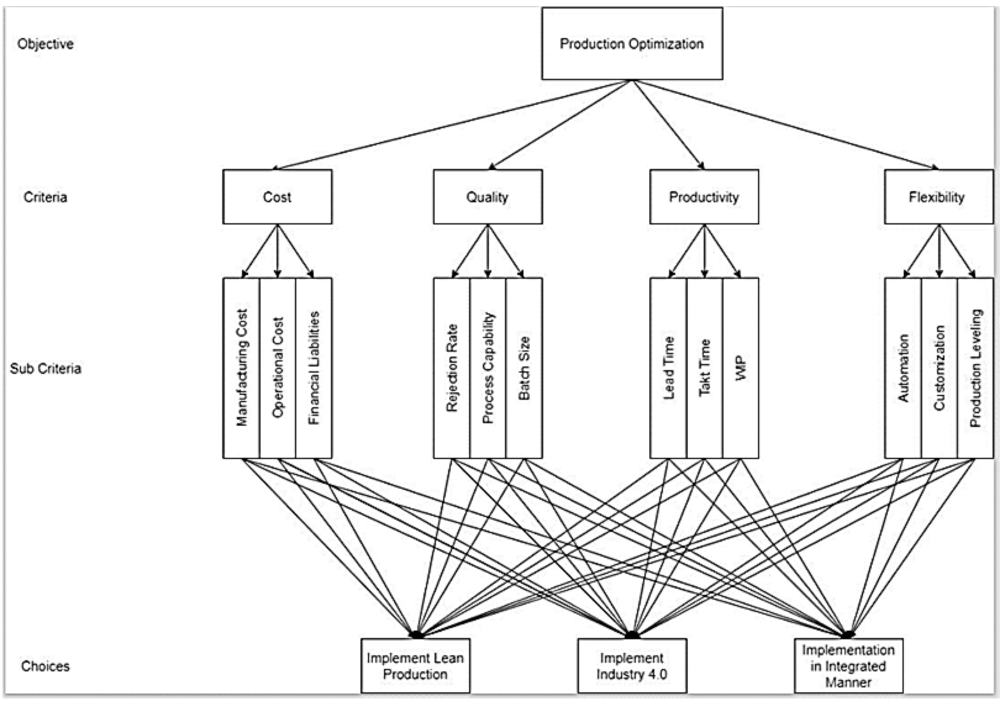


FIGURE 2. MCDM Flow for AHP

ANALYTICAL HIERARCHY PROCESS

This MCDM technique hinges on pair-wise comparisons and derivation of priority analysis as per judgment of the experts, where the scales are measuring the intangibles in relative terms. By forming a scale of absolute judgment, the dominance of one element over another is described (Saaty, 1990). This technique helps in improving the judgment by making it logical and efficient as described in this paper where various alternatives are studied and the best concept is selected. Through multiplication of derived scales with their parent nodes, further addition results in their synthesis (Saaty, 2008). The immense strength of this tool led to its involvement in lean environments where the decisions for optimal tool selection were made using this technique. Stages proposed by Saaty (1990) were followed during this AHP case study. Main stages or phases for any AHP modelling are problem structure, comparative judgements and priority analysis. The unit under analysis in this study is Lahore based pipe manufacturing facility which is one of major supplier of ERW pipes and galvanized hexagonal lighting poles to public and private sector. It was observed that there has been difficulty in meeting customer demands within stipulated time. Thus, the authors visited facility and observed all processes involved in the production.

The company under consideration does not have any method to solve this problem when there are multiple criteria factors effecting the production or improve the current process to meet customer demands. Thus, AHP method was presented to solve this multi-criteria decision problem. So, according to the company's requirement hierarchal structure of the criteria is given in the above FIGURE 2. At the top level of hierarchy level 1, is the objective of our AHP decision making process. In level 2 criteria is directly related to the objective at level 1 and relative priorities are calculated. Many important criteria at level 2 such as cost, quality, productivity, flexibility and competitive advantage. To clarify all these criteria options, the decision maker considers some more criteria options. At level 3, sub-criteria are directly connected to alternative decisions available for our problem. (Implement lean production, implement industry 4.0, implementation of integrated system).

In phase 2 of this case study pairwise comparisons were made between level 2 sub-criteria and pair judgement scale was used for this. After these values obtained, comparison matrix was generated for the sub-criteria cost, quality, productivity, flexibility and competitive advantage of size $A = 3 * 3$, $B = 4 * 4$, $C = 3 * 3$, $D = 3 * 3$, $E = 4 * 4$ respectively. Supposing all these matrices are consistent.

$$A = C = D = \begin{bmatrix} 1 & W_{12} & W_{13} \\ \frac{1}{W_{12}} & 1 & W_{23} \\ \frac{1}{W_{13}} & \frac{1}{W_{23}} & 1 \end{bmatrix} \quad (1)$$

Similarly,

$$B = E = \begin{bmatrix} 1 & W_{12} & W_{13} & W_{14} \\ \frac{1}{W_{12}} & 1 & W_{23} & W_{24} \\ \frac{1}{W_{13}} & \frac{1}{W_{23}} & 1 & W_{34} \\ \frac{1}{W_{14}} & \frac{1}{W_{24}} & \frac{1}{W_{34}} & 1 \end{bmatrix} \quad (2)$$

Above matrices are only equal in terms of representation. Pairwise comparison matrix (reciprocal diagonal matrix) has properties given below,

$$W_{ij} = \frac{1}{W_{ji}}, W_{ii} = 1 \quad (3)$$

Where,

$$W_{ij} > 0, \qquad i, j = 1,2,3 \ldots . n \quad (4)$$

For consistent decision maker, pairwise matrix must satisfy must this property,

$$W_{ij} W_{jk} = W_{ik} \; (Transitive\ Property) \quad (5)$$

After these matrices generated from our pairwise judgement data, next step is to calculate priority vector (weight vector) for decision maker of the form,

$$P = [p_1 \quad p_2 \quad \cdots \quad p_n]^T, \sum_{i=0}^{n} p_i = 1 \quad (6)$$

Above priority vector actually the eigenvector of pairwise comparison matrix

$$\begin{bmatrix} 1 & W_{12} & \ldots & W_n \\ . & . & . & . \\ W_{n1} & W_{n2} & \ldots & 1 \end{bmatrix} \begin{bmatrix} W_1 \\ . \\ W_n \end{bmatrix} = \begin{bmatrix} p_1 \\ . \\ . \\ p_n \end{bmatrix} \quad (7)$$

Where,

$$wv = p \quad (8)$$
$$wv = \lambda v \quad (9)$$
$$(w - I\lambda)v = 0 \quad (10)$$

And for every row of pairwise comparison matrix,

$$p_i = W_{i1} W_1 + W_{i2} W_2 + \cdots W_{in} W_n = \sum_{j}^{n} W_{ij} W_j \quad (11)$$

From this we can get principal eigenvalue. In order to check consistency, the authors used consistency ratio defined by Saaty (1990). If the value of consistency ratio is less than 10%, the AHP analysis is considered consistent.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (12)$$

$$CR = \frac{CI}{RI}, \quad (13)$$

Following which the authors calculated level 2 weight vectors and the reference with the given alternative to get the results given below. The results of criteria selection are given as follows in Table 1:

TABLE 1. Scoring Table for Criteria

Criteria	Score
Production Flexibility	0.57
Quality	0.20
Productivity	0.13
Cost	0.10

Delving further, the sub-criteria are detailed as follows in TABLE 2:

TABLE 2. Global Weights of Sub-Criteria

Sub-Criteria	Criteria	Global Weight	Choice A (Standalone Lean Implementation)	Choice B (Standalone Industry 4.0 Implementation)	Choice C (Integrated Implementation)
Automation of Processes	Flexibility	0.364		✓	✓
Customization	Flexibility	0.160		✓	✓
Lead Time Reduction	Productivity	0.099	✓		✓
Reduction in Customer Rejection Rate	Quality	0.096	✓		✓
Increase in Process Capability	Quality	0.082	✓	✓	✓
Decrease in Operational Cost	Cost	0.071		✓	✓
Production Levelling	Flexibility	0.042	✓	✓	✓
Meeting Takt Time	Productivity	0.024	✓		✓
Meting Batch Size	Quality	0.023	✓	✓	✓
Reducing Financial Liabilities	Cost	0.018		✓	✓
Reducing Manufacturing Cost	Cost	0.012		✓	✓
Reducing WIP	Productivity	0.009	✓	✓	✓

From the results in Table 1, it can be seen that the important concept that is tantamount to production improvement in the present case study is production flexibility, followed by quality, cost and productivity. The detailed results given in

TABLE 2 establish that the following measures should be taken for production improvement, and the top five most important measures are given as under:

1. Automation of the processes to implicate manufacturing flexibility
2. Enabling mass customization so that an assortment of orders can be achieved
3. Reducing lead time to meet customer demand
4. Reducing customer rejection rates
5. Increasing process flexibility

From the choices at disposal, one can clearly see that standalone implementation of lean manufacturing or Industry 4.0 is not enough, therefore an integrated approach is required to brave the challenges. Therefore, the authors decided to implement the concepts of Industry 4.0 and lean manufacturing in an integrated manner.

CASE STUDY

For practical implementation and validation of the considered methodologies, a case study methodology was planned. This effort was done, after the compilation of results. Authors personally visited the facility and selected the pipe manufacturing process line, at that place the sheet were rolled and then welded to the final product of a pipe, since it provided the maximum revenue and utilized the maximum number of resources. Gemba walk was performed and the following observations were made, which have been visually described in FIGURE 3.

- Total Lead Time : 67.31 days
- Cycle Time : 7.5 hours
- Available Working Time : 7 hours
- Shifts per day : 01
- Total Value-Added Time : 1.16 hours
- Total Non-Value-Added Time : 6.34 hours
- Monthly Production : 730 spools

During the Gemba walk and time study, it was observed that there is excess of waiting and motion by the workers, which are clearly known as wastes. The major issues are summarized below:

1. The process of offloading raw material from delivery trailer takes up a lot of time due to absence of dock levellers
2. Long waiting times for overhead traveling cranes
3. Preparation of slits in the coil rolls for attaching a harness result in material wastage
4. Poor preparation of workers regarding auxiliary tools
5. Lack of anticipation among the workers
6. Minor machinery breakdowns

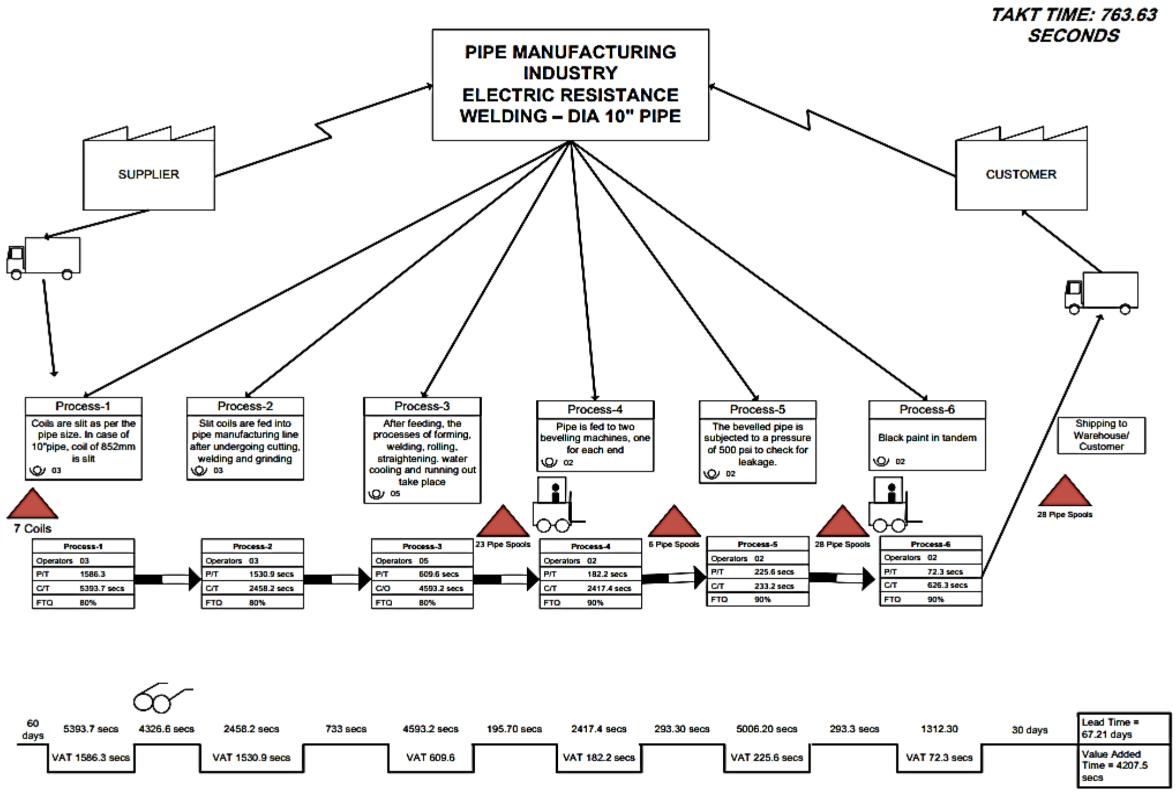


FIGURE 3. Current State Map

VSM IMPLEMENTATION

CURRENT STATE

The authors have based the concept of future state map generation upon the rules stipulated by Rother and Shook (2003) and followed by Abdulmalek and Rajgopal (2007). It was observed during Gemba walk that there is a vast room for improvement and accordingly, eight questions are answered. The takt time was calculated to be 763 seconds and supermarkets could not be used due to spatial constraints.

The pipe manufacturing process in which the plate is rolled and welded is the pacemaker process, and that was the scheduling point. The machine can prepare a 20ft spool in 12 minutes, however, it was observed that machine is taking 14 minutes and 45 seconds to produce one. By proper maintenance and major overhauling, the time was reduced by 28-32%. The eight questions of Rother and Shook (2003) were duly answered, given as follows:

Q-1. What is the takt time?

Mathematically, the takt time is defined as follows:

$$\text{Takt Time} = \frac{\text{Available Time Per Shift}}{\text{Customer Demand Per Shift}}$$

$$\text{Takt Time} = \frac{25200 \text{ seconds}}{33 \text{ spools}}$$

$$\text{Takt Time} = 763.63 \text{ seconds}$$

This suggests that customer is buying the pipe spools at the rate of 763.63 seconds per spool. This helped in synchronization of production line as per product sales, being the most important step in implementation of continuous flow and pull system.

Q-2. Will the supermarkets be used for production or finished goods will direct straight to shipping?

The manufactured pipe spools were 20 ft. in length and required a lot of storage space. The current storage space could not house more than 35 spools of sizes greater than Ø6”. Therefore, the finished goods were sent directly to shipping.

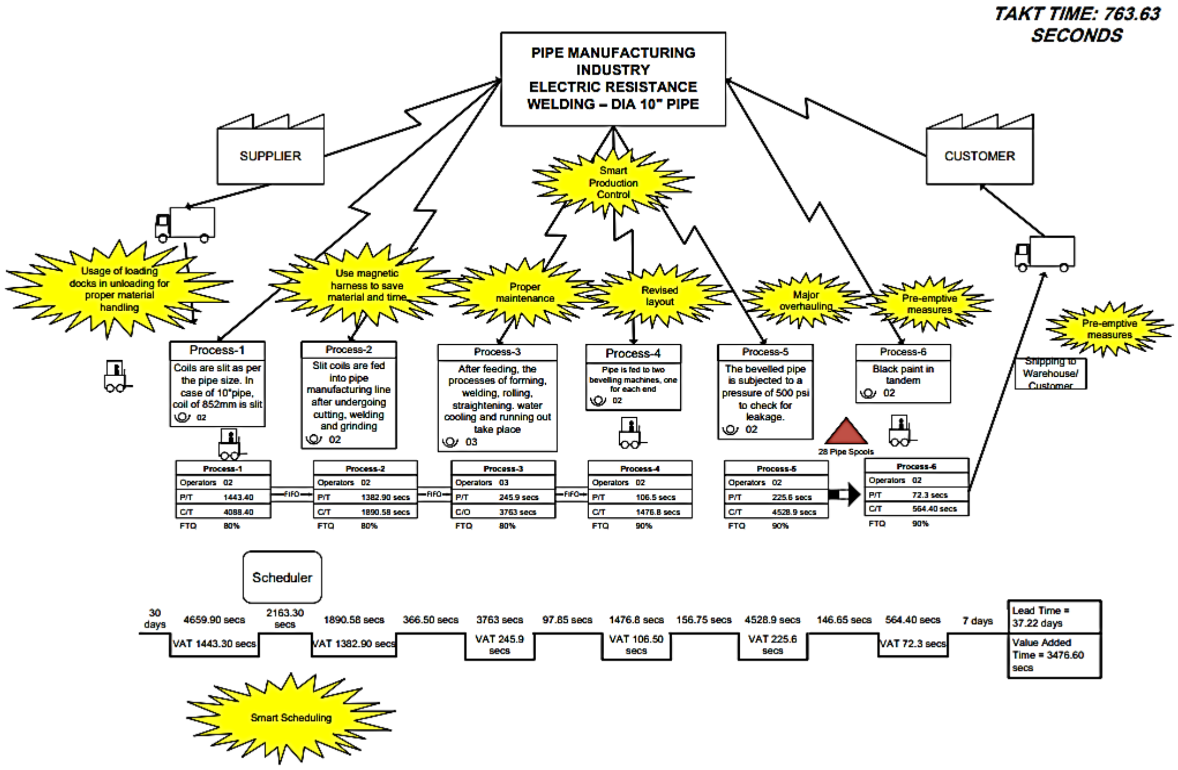


FIGURE 4. Future State Map

Q-3. Where can continuous flow be introduced?

The process was already working in a continuous flow; except the bevelling section where there is an inventory of 21-28 spools. Since the bevelling section was common, therefore an automated machine was introduced to cater to production demands of other production lines, and all the processes were subjected to First-In, First-Out (FIFO).

Q-4. Where can supermarket pull system be introduced?

The supermarket pull system was not applicable on the selected production unit.

Q-5. What is the pacemaker process that should be scheduled?

The pipe manufacturing process in which the plate is rolled and welded is the pacemaker process, and that must be the scheduling point of the process. The machine can prepare a 20ft spool in 12 minutes, however, it was observed that machine is taking 14 minutes and 45 seconds to produce one. By proper maintenance and major overhauling, the time was reduced by 28-32%.

Q-6. How can production mix be levelled at pacemaker process?

Since the production mix contains one single entity, the levelling cannot be achieved.

Q-7. What consistent increment of work should the facility increase and take away at the pacemaker process?

The pitch can be calculated on hourly basis and production can be synchronized as per.

$$\text{Pitch} = \text{Takt Time} \times \text{Total Number of Pieces Produced at Pacemaker Process}$$

$$\text{Pitch} = 763.63 \text{ seconds} \times 5 \text{ pieces/hour}$$

$$\text{Pitch} = 3{,}818.18 \text{ seconds}$$

This suggests that the facility should be competent enough to produce 5 pieces within 1 hour and 3.6 minutes approximately.

Q-8. What process improvements will be necessary for value stream to flow as future state describes?

FUTURE STATE MAP

The process improvements were as follows:

1. Introduction of automation
2. Usage of dock levellers in unloading
3. Pre-emptive preparation of slitting assembly
4. Usage of magnetic clamp harness instead of making a hole in the plate, helped in reducing 15-20 kgs of waste
5. Availability of auxiliary tools at each workstation
6. Periodic maintenance of overhead traveling cranes to increase transportation speed

7. 15% increase in pipe manufacturing machine speed (pacemaker point) after major overhauling
8. Modified layout of bevelling section and introducing an automated machine
9. Overhauling of hydro-testing machine
10. 50% reduction in waiting times
11. Production scheduling

RESULTS & DISCUSSION

RESULTS

As in the manufacturing sector, the major consideration for the efficiency and profitability, are the reduction of lead-time, Takt time, value added time and especially the non-value-added time. This shall allow the maximum utilization of time for the attainment of the profit margin. From the obtained results, it was found that these were reduced considerably.

REDUCTION IN LEAD TIME

Through the integrated application of lean manufacturing & Industry 4.0 principles, the lead time of the pipe manufacturing process was reduced to 44.70% by adopting monthly deliveries instead of bimonthly delivery schedule.

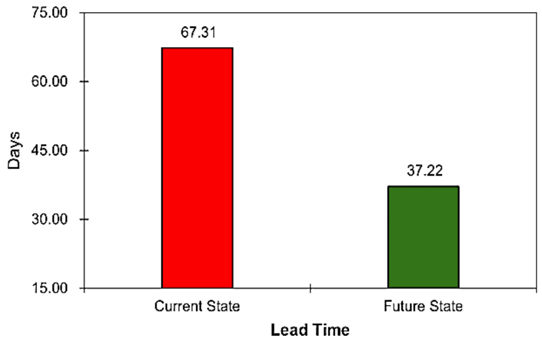
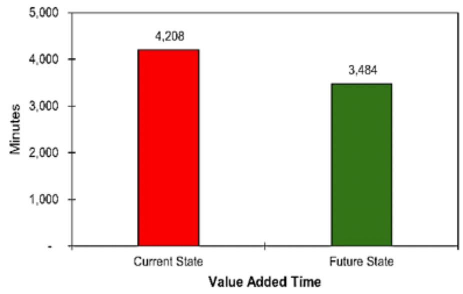
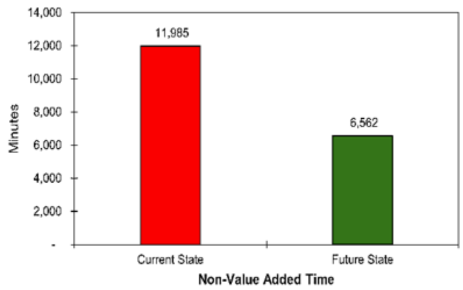


FIGURE 5. Reduction in Lead Time

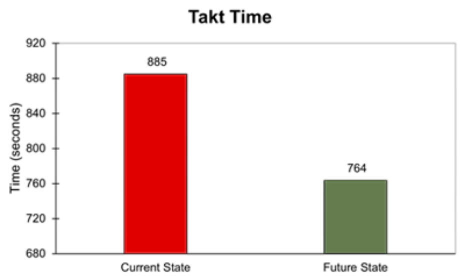
The cycle times were reduced by 29% in which major focus was the elimination and reduction of no-value added activities. Through the implementation of smart production control and automation of processes, the non-value-added time was reduced by 45%; supplemented by lean techniques of Sort, Set in Order, Shine, Standardize, Sustain (5S), First-In, First-Out (FIFO) and inventory reduction. The value-added time of the process was reduced by 17% through the implementation of Total Productive Maintenance (TPM), automation and introduction robotic equipment for material handling. Through the use of an automated machine, the process time at bevelling section was reduced by 40% approximately. Similarly, the non-value-added time was reduced by 45.25% through the successful implementation of Sort, Set in Order, Shine, Standardize, Sustain (5S), technique.



6a. Reduction in Value-Added Time



6b. Reduction in Non-Value-Added Time



6c. Reduction in Takt Time

FIGURE 6. Reduction in Value Added Time, Non-Value-Added Time and Takt Time

The results suggest that integrated application of lean manufacturing & Industry 4.0 helps in achieving production improvement, with the automation being the harbinger of change. Using the mathematical modelling approach of AHP, the choice of most pertinent option becomes fairly straightforward when faced with the challenge of multicriteria selection. Previously, fuzzy-MCDM approach was utilized by Erdogan et al. (2018) to identify the most suitable strategy for Industry 4.0 implementation, In addition to this, order allocation and supplier selection in lean manufacturing was performed using MCDM approach by Rezaei et al. (2020). Furthermore, the techniques suggested in this research work, such as 5S, TPM, VSM, etc. are grounded in the lean manufacturing literature – considering the works of Prasad et al. (2020).

Moreover, the reduction in TAKT time is concurrent with the work of Deshkar et al. (2018), and the reduction in lead time and value added time is in the same vein as that of McDonald et al. (2002).

This research work aims to fill two gaps in the literature (a) lack of an Industry 4.0 based case study and (b) integration of lean and Industry 4.0 concepts using a MCDM approach, and the aforementioned have been duly addressed. The research work will provide clarity to academicians regarding the integration of the two approaches, and the utility of MCDM technique.

One interesting result of this research work is tacit in nature, and that suggests that standalone Industry 4.0 may not be as successful as deemed to be. Instead, the implementation of lean manufacturing concepts serves as a prerequisite for the implementation of Industry 4.0 principles. The results in the present case study took 11-14 months to mature, as the organization was partially working on lean principles beforehand. In cases where the industry is migrating from mass production to lean environment, it is suggested that time should be given for the holistic implementation of lean, so that the Industry 4.0 application is straightforward. Through AHP technique, the managerial personnel can gauge the priority levels of the criteria.

There is a conception that cost is the most important criteria, but research suggested that production flexibility is of extreme importance in such environments. However, it is pertinent to mention that the AHP results are specific to this case study and the results may differ when applied to a different industry.

For organizations which are in maturity phases, cost may be a decisive factor. However, there is consensus that integrated application of Industry 4.0 and lean manufacturing principles helps in achieving competitive advantage and production improvement. In this manner, this research work shall provide clarity to the managerial personnel regarding the integration of Industry 4.0 and lean manufacturing principles.

CONCLUSION

The authors worked on AHP method in current research work to choose between standalone lean implementation, standalone Industry 4.0 implementation and integrated application of the two approaches to attain production enhancement in the pipe manufacturing plant.

The MCDM analysis revealed the vital measures were automation of the processes to implicate manufacturing flexibility, permitting mass customization so a range of orders can be accomplished by reducing lead time to meet customer demand. Thus, the choice of integrated implementation was selected and through VSM the changes in production process were suggested and implicated.

Furthermore, the research in future can be carried out with other MCDM approaches such as VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Analytic network process (ANP), Linear Programming etc. The future recommendation can be written as the remedial to the limitation of this work.

AHP does not allow individuals to grade one instrument in isolation, but in comparison with the rest, without identifying weaknesses and strengths (Konidari and Mavrakis, 2007). In addition to that, as the size (n) of the hierarchy increases, the number of pairwise comparisons increases rapidly. The completion of n(n- 1)/2 comparisons (quite high in realistic problems) can become a very difficult task for the decision maker when applied to all levels of the hierarchy (Carmone Jr et al. 1997).

Moreover, the approach has only been applied to a medium sized manufacturing industry and the results through a cross sectional case study. The criteria and sub-criteria were tailored according to the requirements of the industry, and they may not fit well on another industry, thus requiring modification.

This research study will be a torchbearer for academicians in the integration of Industry 4.0 with several manufacturing methods in MCDM and VSM context, and will help practitioners of manufacturing facilities in knowledgeable decision making.

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DECLARATION OF COMPETING INTEREST

None

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