Productivity improvement of an electrical appliance industry by implementing lean manufacturing tools and a low-cost intervention (a case study)

Anil Chaudhary

Department of Mechanical Engineering,
Global Institute of Technology,
Jaipur, India
Email: anil1fgiet@gmail.com

Ashish Kumar Singh*

Department of Design,
Indian Institute of Technology,
Guwahati, India
Email: singh.mechanical@yahoo.com
*Corresponding author

M.L. Meena

Department of Mechanical Engineering,
Malaviya National Institute of Technology,
Jaipur, India
Email: mlmeenamnit@gmail.com

Abstract: The focus of lean manufacturing tools is the cost reduction by eliminating non-value added activities (waste, i.e., *Muda*), thus, enables continuous improvement. The purpose of this paper is to address the importance of value stream mapping (VSM) in a lean manufacturing environment in an Indian electrical appliance industry. This research aims to highlight how lean tools can be utilised to reduce the bottleneck, meet customer demand and increase productivity. A current state mapping study was conducted to find the areas of improvement. Several lean tools were implemented to determine the production pace. The study reveals that the wiring and connection workstation had maximum bottleneck value; hence, the customer demand was not met. Furthermore, wireless connection as an intervention was introduced in the production process to reduce the bottleneck in the cycle time. The improvement can be visualised through future state VSM. Lean tools along with some small interventions could play a significant role in improving the productivity of the company.

Keywords: lean manufacturing; value stream mapping; VSM; takt time; bottleneck process; productivity.

Reference to this paper should be made as follows: Chaudhary, A., Singh, A.K. and Meena, M.L. (xxxx) 'Productivity improvement of an electrical appliance industry by implementing lean manufacturing tools and a low-cost intervention (a case study)', *Int. J. Productivity and Quality Management*, Vol. X, No. Y, pp.xxx–xxx.

Biographical notes: Anil Chaudhary is working as an Assistant Professor in Department of Mechanical Engineering at Global Institute of Technology (GIT) Jaipur. He graduated in Mechanical Engineering and obtained his Master's from from MNIT Jaipur. His research areas include productivity engineering, lean manufacturing and quality management.

Ashish Kumar Singh is a Postdoctoral Research Fellow in Department of Design at Indian Institute of Technology Guwahati (IITG). He graduated in Mechanical Engineering from University of Rajasthan, Jaipur. He obtained his Master's in Quality Management from Birla Institute of Technology and Science (BITS), Pilani. He earned his Doctorate in Ergonomics in Design from National Institute of Technology Jaipur (MNIT). He has published more than 20 research articles in various international journals and conferences. His research areas includes product design, ergonomics in design, biomechanics and bio-potential measurements, human response to vibration, noise exposure, quality, and productivity engineering. He has eight years of extensive experience in industry, research and academia.

M.L. Meena is an Assistant Professor from the Department of Mechanical Engineering in Malaviya National Institute of Technology (MNIT) Jaipur. He graduated in Mechanical Engineering from the University of Rajasthan, Jaipur in 2005. He obtained his Master's in Manufacturing System Engineering from the MNIT Jaipur. He earned his Doctorate in Industrial Engineering also at the MNIT Jaipur. His research areas are ergonomics and productivity engineering. He has published more than 50 research papers in various international journals. He has ten years of teaching and industrial experience.

1 Introduction

Higher productivity is the key to success of any organisation. Gross domestic product (GDP) growth of a country could be considered as a measure for living standard of the people. It is a quality approximation of the productivity growth of that country in a given period. Therefore, a higher standard of living requires higher productivity growth. Indeed the productivity enhancement should be the goal of every manufacturing firm (Choomlucksana et al., 2015).

Productivity and quality improvement are essential to full-fill the increasing customer demand and also to keep the operational costs at a minimal level. Production systems and total quality management practices are found to be crucial in maintaining competitive gains (Lee and Park, 2016). Innovations or improvements for rising productivity and quality, happens independently, with or without affecting each other. In some cases these both rises together and some time they rises independently (Selvam et al., 2018). Productivity tells how well the available resources are used for obtaining the output. If an increased output is produced from the same input resource, it means productivity improved (Singh et al., 2019). Also, if the same amount of output is generated by using minor inputs, then productivity again increases. Resource means all the human and physical resources that include people and assets that are providing the goods or service (Grünberg, 2007).

Lean manufacturing (LM) is a business concept that was developed in Japan. Most of the organisations implement LM approach to produce quality products at the least possible cost, without compromising the desired level of customer satisfaction and timely delivery. Therefore, it is important for organisations to implement lean strategies for competing in a global market (Rohani and Zahraee, 2015). The idea of LM provides an effective and productive strategy by reducing all types of waste from the production process (Bhamu and Singh Sangwan, 2014). The goal of LM primarily focuses on producing products with zero defects, reducing excessive motion, inventory and all form of waste. Lean practices reduce lead time, in turn, leads to on-time delivery of the product (Bhamu et al., 2012).

The outcomes from the LM and baseline production models were compared to evaluate the effect of the anticipated improvements. The results revealed that through the application of LM techniques, reductions in process time, and cycle time and increases in labour productivity process efficiency and can be achieved (Goh and Goh, 2019). To implement lean practices in any organisation, there are several lean tools, value stream mapping (VSM) is one such tool, which help identifying all the value added and non-value added activities within the production process (Abdulmalek and Rajgopal, 2007). To improve the operational parameters such as cost, productivity and quality LM implementation play a very important role (Kumar and Kumar, 2016).

Generally VSM is describing as a classical pen and paper method which map value adding activities and non-value adding activities. It also maps conserving activities that are needed to produce a product (Sunk et al., 2017). A value stream is the collection of all activities (both values added and non-value added) that are required to convert the raw material to end product. The goal of VSM is to identify all form of waste in the value stream and take the actions to eliminate those (Rother and Shook, 1999). So VSM is one of the most significant LM tools which can be used to advance the production line of the company.

The main purpose of this paper is to use a case centred methodology and to demonstrate how lean tools, when used properly in production system, can help in eliminating waste, improving product quality, reliability and productivity, maintaining better inventory control, and obtaining a better operational control. This research has been done in an Indian electrical appliance Industry which produces energy metres. In this study, VSM is first used to map the current operating conditions for the company. This map is used to identify the sources of waste and to find the lean tools for eliminating the waste. Then a future state map is developed and lean tools applied to it. The study focused on to identify the major sources of waste by using tools like VSM, takt time, production rate, bottleneck and reducing waste by using other tools. The major objectives are given below:

- to identify workstations having bottlenecks through VSM
- to eliminate the bottleneck using an intervention (wireless connectors) and reducing their production cycle time
- to assess the effect of an intervention on the change in the cycle time

- to quantify the change in labour productivity and energy productivity before and after using the intervention
- to improve the volume of production and meeting customer demand.

2 Literature review

Many pieces of evidence recommended that the lean concept is helpful for sustainable manufacturing, dominantly on perspective, economic and environmental aspect. LM make the best use of skills of the employees, by assigning them more than one task, combining direct and indirect task, and cheering consistent improvement activities (Dankbaar, 1997). LM is a standard of production that emphasises the reduction of the number of entire resources (including time) used in different activities in the industry. It includes searching and eliminating non-value added activities in production, design, supply chain management, and dealing with the consumers (Cox and Blackstone, 1998). Lean gives a fundamental change in how the people within the industries think and what they value, thus transforming their performance. It is an attitude proposed to extensively reduce cycle time and cost throughout the whole value chain while enduring product performance (Comm and Mathaisel, 2000).

Lean production is defined as a production philosophy to transport the maximum value to the consumer by removing waste all through the human drawing elements and process (Shah and Ward, 2003). LM is a production attitude that reduces the lead time between an order placed by the customer and the final delivery of the products through the removal of each type of waste. LM is cooperative to organisations in reducing cycle time, cost and unnecessary, non-value adding activities, ensuing in a more viable, flexible, and reactive market corporation (Alukal, 2003). The worker participation in LM has confirmed to have an encouraging outcome on the work situation. LM is theoretically versatile, and worker contribution is but one of ten extents of a lean method (Shah and Ward, 2007). Lean has been useful more commonly in discrete manufacturing than in the consistent area, mostly due to some apparent barriers in the latter surroundings that have caused managers to be unenthusiastic to make the required assurance (Abdulmalek and Rajgopal, 2007). On the other hand, VSM only provides inefficient tools for the mapping of information streams. Further it neither gives tools to target the improvements at shop floor nor does it give tools for the satisfactory analysis of information stream (Metternich et al., 2017).

An examination of the literature reveals logical relations between lean production and work organisation practices. On the other hand, general reports on lean production hardly deal with work organisation Major publications on LM mention but do not consist of, complete images of work organisation. The works mostly focus on the need for particular features of work organisation for implementing lean production (Olivella et al., 2008). The correlation among lean, green and globally used supply chain strategies with the stress on the simultaneous execution of all three planned initiative, to develop a program to guide theoretical-based future research that informs administrative judgment making (Mollenkopf et al., 2010). A multi-dimensional way that consists of production with the smallest amount of waste (JIT), uninterrupted and continuous flow (cellular layout), the well-established quality system (TQM), and well-maintained equipment, empowered and well-trained workforce which has positive effects on production process (Taj and

Morosan, 2011). In a study conducted in Jordon service, it was concluded that the managers should consider total quality management practices as a way to improve performance, develop an environment, distribute resources and that supports continuous improvement ideas (Sweis et al., 2016).

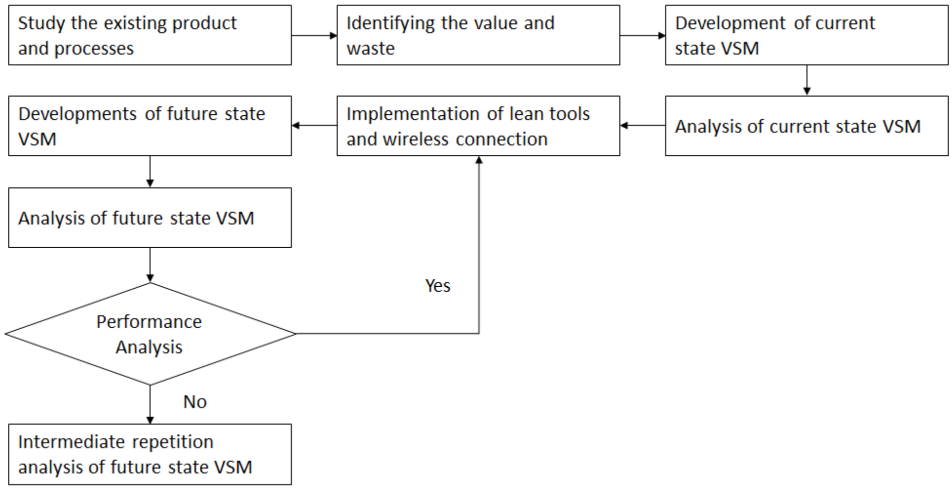
The impact of lean on the workforce was discussed from the beginning of the introduction of the lean concept. The effect of lean on the working situation and worker health is very good. For the study of LM and the working surroundings relevant databases were searched (Hasle et al., 2012). Industries are facing struggles to go on existing in the demanding competitive situation, unpredicted breakdown occurs at unpredicted times, so leading to the appearance of disruptions in production and complications in production plans. Maintenance plans are essential in avoidance of the losses due to breakdowns in organisations. This gains additional significance mainly when the number of production increases and production system grows (Arslankaya and Atay, 2015). A process improvement carried out in the nacelle unit of a wind turbine manufacturing. Implementation of LM improved productivity regarding manufacturing throughput time and also reduced rework/manufacturing costs (Sutari, 2015).

LM is one of the unbeaten enhancement concepts that are useful for removing the waste and activities which are non-value added occurring in the organisations (Choomlucksana et al., 2015). Hartini and Ciptomulyono (2015) explored and evaluated previous work based on the relationship and links between sustainable manufacturing and LM. Their relationships include overlapping area, correlation, integration, difference, and classification focused on sustainability dimensions. They explained the impact of sustainable production and LM to improve performance. The concept of LM is characterised as 'doing more with less', lean tools such as Kaizen is used to recognise value and to remove non-value adding activities. To succeed in the competitive market LM is considered as strategic tool for organisations (Khalili et al., 2018). The effect of LM tools such as Kaizen were investigated through a semi organised interview in Japanese companies in manufacturing sector (Zailani et al. 2015).

3 Research methodology

The study was performed in an Indian electrical appliance industry which was suitable to apply the concept obtain from research. It was found that the company was producing electrical appliances like energy metre, panel metre, LED lights and many other electrical items. The firm has been producing energy metre in the plant located within the urban region of Jaipur district. The company operates with a workforce of 70 workers working in several facilities for producing the energy metre. The daily production of the company was recorded as 60 pieces in 2017 while daily demand was around 100 pieces in the same year. The study was conducted during the month of May-June, 2018. The data was collected from the existing process by drawing the current state VSM. By analysing these data, the several problems within the process (bottlenecks, excessive cycle time) were observed. To improve the performance of the firm, lean tool like VSM, takt time, and cycle time was used to assess the problematic areas that need improvement. The wireless connections were used to curtail the overall cycle time and bottlenecks. The improvement was measured by drawing the future state VSM. The study design was charted in Figure 1 which shows various steps involved in this research.

Figure 1 The methodology of implementing VSM in a metre production assembly line (see online version for colours)



3.1 *Study of existing product and process followed by the company*

By a thorough study of the existing process, it was found that the metre producing process was outstretched, having 17 workstations. From the historical and forecast information on supply and demand provided by the company's management, it was also observed that the production rate was slower than the customer demand. Since the production rate was slower than the customer demand, it was resulting delays in meeting orders timely. Table 1 shows the data obtained from the company for further analyses.

Table 1 Descriptive data of production process

Parameters	*Values*
Shift length	9 hour 30 minutes = 570 minutes
Break time	60 minutes = (2 × 15 + 1 × 30) minutes
Number of workstations	17 stations
Customer daily demand	100 pieces
Daily production	60 pieces
Planned production time	510 minutes
Number of employee	70
Daily energy consumption	40 unit

It was found that the company was having a shift length of 9 hours 30 minutes (570 minutes) with two short breaks of 15 minutes and one meal break of 30 minutes. Currently, the company was producing 60 pieces per day, and its daily demand was 100 pieces. The company was using total 17 workstations to produce the electric metre. Due to such a large number of workstations, the process was very lengthy and time-consuming. Figure 2 shows all the 17 processes in metre production.

Figure 2 Metre producing process (see online version for colours)

(a) (b) (c) (d)

(e) (f) (g) (h)

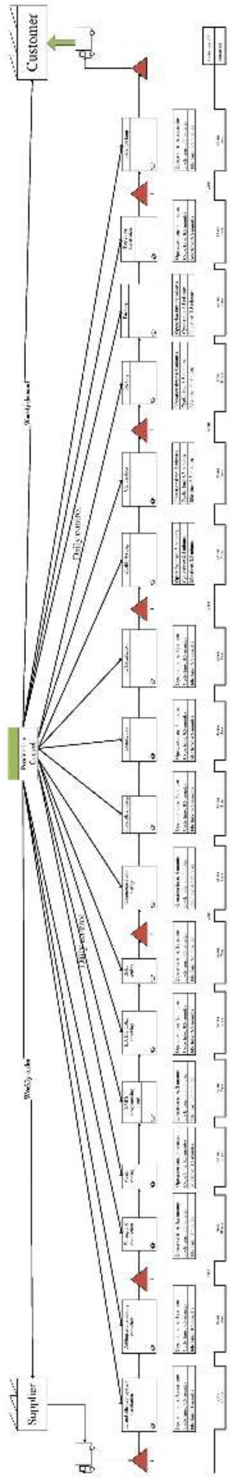
(i) (j) (k) (l)

(m) (n) (o)

(p) (q)

Notes: The names of different workstations: (a) IC and other component installation, (b) adding and removing the capacitor, (c) wiring and connections, (d) visual testing, (e) SMPS programming, (f) EB, DG, solar checking, (g) relay setting, (h) communication testing, (i) front plate fixing, (j) connection, (k) C installation, (l) quality testing, (m) calibration, (n) socking, (o) packing, (p) top cover installation, and (q) final packing.

Figure 3 Current state value stream map (see online version for colours)



3.2 Development of current VSM

To understand the causes behind slower production rate current state VSM was drawn. Current state VSM is a tool that is used for recognising all value added and non-value added activities involved in the production process. VSM systematically maps all the processes involved in the production process. It also determines all form of waste within the production processes and helps in identifying the problems in the value chain. It provides the sequential illustrations of the time required by each workstation involved in the production line. So, using current state VSM, the cycle time required by each workstation was estimated (Figure 3).

3.3 Analysis of current state VSM

On the basis of current state VSM, the analysis of each workstation was performed by calculating the takt time, cycle time, production rate, productivity, and bottleneck workstations. Table 2 shows the data obtained from current state VSM which is used for further analysis and calculations.

- Takt time: Takt time is defined as the ratio of planned production time to the customer demand. Takt time helps organisations to achieve a steady and continuous flow of production (Rahani and Al-Ashraf, 2012).

$$\text{Takt time} = \frac{\text{Available minutes for production}}{\text{Required units for production}} = \frac{510 \text{ minutes}}{100 \text{ pieces}} = 5.1 \text{ minutes/pieces} \tag{1}$$

  Takt time plays a very important role to decide that whether a process is running with a required speed or not. In equation (1), takt time is calculated and is found as 5.1 minutes/piece. This value of takt time is further used to found the rate of production. Takt time is also used as measures that whether the organisations will be able to meet the customer demand or not. Equation (1) is showing that takt time is 5.1 minute per piece, which means that the company should produce one piece in 5.1 minutes to meet the customer demand. If the company requires more time than 5.1 minutes to producing a single product, then it will not ensure on-time delivery.

- Production rate: Production rate is defined as the ratio of planned production time to the number of a part produced per day.

$$\text{Production rate} = \frac{\text{Planned production time}}{\text{Number of parts produced per day}} = \frac{510 \text{ minutes}}{60 \text{ pieces}} = 8.5 \text{ minutes/pieces} \tag{2}$$

  Production rate is the rate of production by which company is producing its product. Production rate is calculated in equation (2) is used for further discussion. Equation (2) shows the calculated value of production rate as 8.5 minutes/piece, which means the company requires 8.5 minutes gap between two consecutive products. From equations (1) and (2) it is found that production rate

(8.5 minutes/piece) is slower than the takt time (5.1 minutes/piece), so the company was not able to meet the customer demand.

- Labour productivity: Labour productivity is defined as the ratio of output to labour input (Sumanth, 1997).

$$\begin{aligned}&\text{Direct labour productivity per worker per hour}\\&=\frac{\text{Volume of output per day}}{\text{Direct labour input per day}\times\text{shift length}}=\frac{60}{40\times 9.5}\\&=0.157\text{ piece/worker-hour}\end{aligned} \tag{3}$$

In the calculation of direct labour productivity, only those labours were included who is directly involved in the production of the product. Direct labour productivity is calculated in equation (3) by using proper formula. Equation (3) is showing the value of direct labour productivity as 0.157piece/worker-hour. This value of direct labour productivity is used for further calculations and discussions.

$$\begin{aligned}\text{Indirect labour productivity/hour}&=\frac{\text{Volume of output/day}}{(\text{Indirect labour input/day}\times\text{shift length}}\\&=\frac{60}{30\times 9.5}=0.210\text{/worker-hour}\end{aligned} \tag{4}$$

In the calculation of indirect labour productivity, those labours were included who is indirectly involved in the production of the product. It is defined as the ratio of output to indirect labour input required to produce the product. Indirect labour productivity is calculated in equation (4) by using the formula given by Sumanth (1997). Equation (4) is showing the value of indirect labour productivity as 0.210/worker-hour. This value of indirect labour productivity will help to compare the result in further discussion in Table 3.

$$\begin{aligned}\text{Total productivity per worker per hour}&=\frac{\text{Volume of output per day}}{\text{Labour input per day}\times\text{shift length}}\\&=\frac{60}{70\times 9.5}=0.09\text{ piece/worker}\end{aligned} \tag{5}$$

Total labour productivity includes direct as well as indirect labour for its calculation. It tells about the requirement of the total number of labour hour (direct and indirect) to produce output. It is measured by the change in output per labour hour for a fixed period. Total labour productivity is calculated in equation (5) and found as 0.09piece/worker. This value is further used in Table 3 to compare the result of total labour productivity before and after improvement.

- Energy productivity: Energy productivity is defined as the ratio of output to energy input (Sumanth, 1997).

$$\begin{aligned}\text{Energy productivity}&=\frac{\text{Volume of output per day}}{\text{Electricity cost in monetary unit per day}}\\&=\frac{60}{264}=0.227\text{ piece/rupees}\end{aligned} \tag{6}$$

Electricity was the energy used by the company to produce the metre. Since the company was using a large number of workstations (17) to produce the metre, so the consumption of electricity was high. To understand the energy uses energy productivity is calculated in equation (6) and found as 0.227 pieces/rupees. This value is further used in Table 3 to compare the improvement in energy productivity.

- Total operation time: Total operation time is defined as the total time required by a product to process on each workstation.

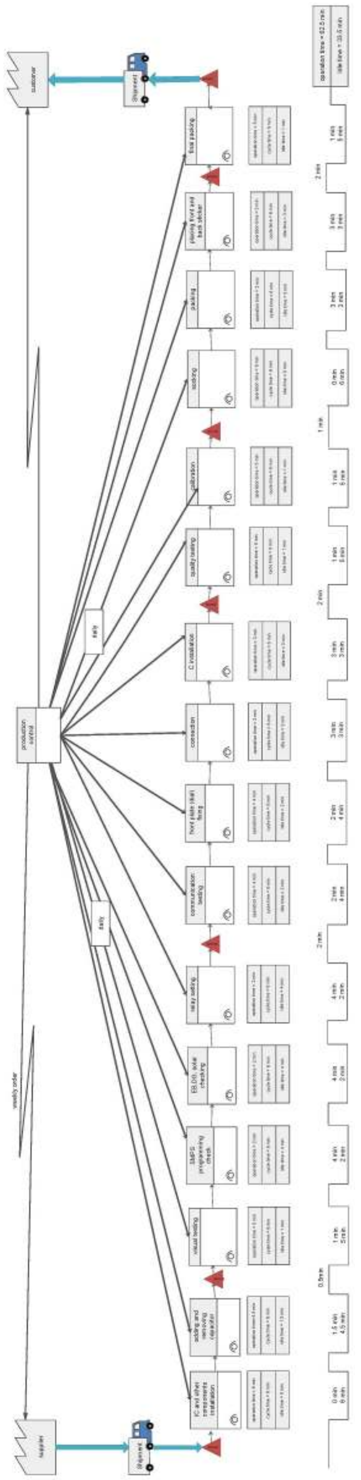
$$\text{Total operation time} = (4.5+4+8.5+5+2+2+2+4+4+4 +3+5+5+6+8.5+3+5) \text{ minutes} = 75.5 \text{ minutes} \quad (7)$$

Total operation time is calculated in equation (7) and is found that the total time required to produce a product is 75.5 minutes. In equation (2) production rate is found as 8.5 minutes/piece it means that the time gap between two consecutive products coming out from assembly line is 8.5 minute. Takt time calculated in equation (1) shows that the time gap between two successive products should be 5.1 minutes. Since the time gap between two consecutive products is more (8.5 minute) than the required time gap (5.1 minutes), which results in slower production rate and unfilled customer demand. This time gap (8.5 minutes) is equal to the time required by the wiring and connection workstation, which is the maximum time-consuming workstation. So to reduce the time gap (8.5 minutes), it is required to reduce the time needed for the wiring and connection workstation. To fulfil the customer demand production rate must be improved and for this, some changes are required.

Table 2 Processing time required at the metre assembly line

Process	*Processing time required in minutes*
IC and components installation	4.5 ± 0.5
Adding and removing of capacitor	4.0 ± 0.4
Wiring and connection	8.5 ± 0.6
Visual inspection	5.0 ± 0.5
SMPS programming check	2.0 ± 0.3
EB, DG, solar checking	2.0 ± 0.3
Relay testing	2.0 ± 0.2
Communication testing	4.0 ± 0.4
Front plate fixing	4.0 ± 0.4
Connection	4.0 ± 0.5
C installation	3.0 ± 0.4
Quality testing	5.0 ± 0.5
Calibration	5.0 ± 0.4
Socking	8.5 ± 0.5
Packing	6.0 ± 0.3
Top cover installation	3.0 ± 0.3
Final packing	5.0 ± 0.5

Figure 4 Future state value stream map (see online version for colours)



3.4 Replacement of wiring and connection by wireless connection

From the current state VSM analysis, it is found that wiring and connection are consuming maximum time and this workstation is a bottleneck workstation. So for reducing the bottleneck of this workstation wiring and connection are replaced by the wireless connection. The wireless connection has two parts (male and female) which need to insert one part into other parts. A wireless connection needs very less time as compared to wiring and connection. Since it does not require wiring and all the connection are provided at a single workstation, so one workstation is also reduced. It was found that wireless connection is very simple no special skilful worker is needed for this operation as the previous connection process was required, skilled worker. So by implementing the wireless connection total time required for producing a product is reduced. It is found that labour utilisation is also improved by applying this process. Other resources utilisation like energy is also improved using this process. Improvement in other parameters can be found by developing future state VSM.

3.5 Future state VSM

Future state VSM is showing that the number of workstations is reduced by one and now 16 workstations are required (as it was 17 previously). Wiring process is removed, and wireless connection is used which reduced the time required to produce the metre. Again calculating production rate, productivity and operation time for future state map is discussed below. Future state value stream map is shown in Figure 4.

3.6 Analysis of future state VSM

To understand the impact of changes made in assembly line future state VSM is analysed. Like current state VSM analysis, all the calculations in future state VSM analysis is done by using the same formulas. These calculations are given below:

$$\text{Production rate} = \frac{510}{85} = 6 \text{ minute/piece} \tag{8}$$

Production rate is calculated by using the formula from equation (2) and is found as 6 minutes per piece. Results obtained from equations (2) and (8) shows that the time gap between two consecutive products is reduced by 2.5 minutes (from 8.5 to 6 minutes). This reduction in the time gap between two consecutive products means faster production rate. This increases the number of product producing per day, which reduces the gap between the demand and supply.

$$\text{Direct labour productivity per worker per hour} = \frac{85}{40 \times 9.5} = 0.223 \text{ pieces/worker-hour} \tag{9}$$

Direct labour productivity is calculated by using the formula from equation (3) and is found as 0.223 piece/worker-hour. Results obtained from equations (3) and (9) shows that direct labour productivity is improved by 42.03% (from 0.157 to 0.223 piece/worker-hour). This increase in direct labour productivity reduces the labour cost of production and increases profit.

$$\text{Indirect labour productivity/hour} = \frac{85}{30 \times 9.5} = 0.298 \tag{10}$$

Equation (4) is used to calculate the value of indirect labour productivity and is found as 0.298. Indirect labour productivity obtains from equations (4) and (10) shows that it is increased by 41.90% (from 0.21 to 0.298). The comparisons of these results are shown in Table 3.

$$\begin{aligned}\text{Total labour productivity per worker per hour} &= \frac{85}{70 \times 9.5} \\ &= 0.127\text{pieces/worker-hour}\end{aligned} \tag{11}$$

By using equation (5) total labour productivity is calculated in equation (11) and found as 0.127 piece/worker-hour. The comparison of result from equations (5) and (11) shows that total labour productivity is improved by 41.11% (from 0.09 to 0.127).

$$\text{Energy productivity} = \frac{85}{294.54} = 0.288 \text{ pieces/rupees} \tag{12}$$

Energy productivity is calculated by using the formula used in equation (6). The value of energy productivity is calculated in equation (12), and it is 0.288 pieces/rupees while its value according to equation (6) is 0.227piece/rupees. So from equations (6) and (12), it is found that energy productivity is increased by 26.87%.

$$\begin{aligned}&\text{Total operation time} = (6 + 4.5 + 5 + 2 + 2 + 2 + 4 + 4 \\ &+3 + 3 + 5 + 5 + 6 + 3 + 3 + 5) \text{ minutes} = 62.5 \text{ minutes}\end{aligned} \tag{13}$$

According to the calculation of equation (13) total operation time is found as 62.5 minutes, while its value was 75.5 minutes as calculated in equation (7). So the result from equations (7) and (13) shows that there is a reduction in total operation time by 17.21%.

4 Results and discussion

The case study from the number of literature surveys demonstrates the lean element reflection and the execution process. In practice, the industry focuses on only a few facets of lean elements such as VSM, takt time, production rate, production levelling, cellular manufacturing, pull system, etc. for driving their industrial system towards the success. In actuality, the long-term success of the industrial system in the competitive business environment depends on the proper implementation of lean tools (Sundar et al., 2014). Lean elements must be implemented in order in-line with corresponding mutually dependent factors with a proper plan. The outcome of the survey suggests the lean road map which gives the complete guideline for implementation of lean tools. Some studies also summarised the use of other lean tools likes just in time, group technology, 5S, mistake proofing, total productive maintenance, etc.

In this research, VSM was implemented to identify the source of waste in the electrical industry. First, current state VSM was drawn to understand the current situation of the company. After analysing the current state VSM takt time and production rate is calculated. The takt time is the demand rate and is defined as the ratio of planned production time to production rate (Frandson et al., 2013). To calculate the takt time, the formula is used in Section 3.1 of this paper Rahani and Al-Ashraf (2012). Takt time help the industries to maintained continuous and steady production. It plays a vital role in manufacturing organisations. A lot of sectors run this without knowing its importance that how it is beneficial to maintained the production pace (Abdullah and Rajgopal, 2003). In a difficult flow, takt time helps to make calculations easy. Also, the essential speeds of machines and other capital tools are determined. The minimum batch sizes are estimated with the help of takt time when there are changeovers involved.

During bottleneck operations, the cycle time is always higher than the takt time Brioso et al. (2017). The calculation [equations (1) and (2)] shows that the takt time and production rates are 5.1 and 8.5 minutes/piece. As it was evident that the rate of production was slower than the takt time, it would result in bottleneck operations (Hopp and Spearman, 2008). Therefore, workstations should have a processing time less than 5.1 minutes/piece to avoid bottlenecks. From Figure 3, it could be seen that the wiring and connections, and packing workstations were bottlenecks. The apparent reason was that wiring and connection workstation was the most time-consuming station because it required a lot of manual wiring. Moreover, the manual wiring not only increases the time but also has the reliability issue as the wire may detach from the connection due to manual handling. However, the socking workstation was also having the processing time of one metre is more than 5.1 minutes/piece, but it was not considered as the bottleneck because several metres were processed simultaneously at a given time.

Overall, due to several bottlenecks, the industry was finding it difficult to fulfil customer demands. It was a big challenge of the company to minimise the time the time of this workstation. Lean tools were used to identify and eliminate workstations having bottlenecks by reducing their production cycle time. So to reduce its cycle time the wireless connection was used because it does not require any manual wiring. In wireless connection, two chunks are available which fits with each other and requires very less time. To assess the effect of an intervention (wireless connectors) on the change in the cycle time wireless connectors were used as an intervention instead of wire connections which in turn reduced the cycle time. Reliability and quality of the product are also improved by replacing the wiring and connection process with the wireless connection.

Future state VSM was drawn to recognise the reduction in cycle time by implementing wireless connection in the industry. To compare the performance of both VSM (current state and future state), Anand and Kodali (2008) found many performance measures in his study. Some of them are used to quantify the degree of improvements. Table 3 shows the comparison of the performance measure of the company for the current state and future state VSMs. From the outcome of the study, it is observed that after using lean tools and wireless connection the performance of the organisation is improved.

From the current state, VSM total operation time was found 75.5 minutes. But after applying wireless connection future state, VSM observed it reduce to 62.5 minutes. Reduction in total operation time reduces bottleneck by reducing the cycle time of workstations. Since wiring and connection was a very time-consuming station, so it consumed more energy, so earlier energy productivity was recorded low. Improvement in energy productivity is observed due to the reduction in cycle time of bottleneck workstation. The change in energy productivity before and after using the intervention was measured. The study shows that energy productivity has increased using interventional change. Table 3 shows a 26.87% improvement in energy productivity from 0.227 to 0.288.

Table 3 Before and after implementation of lean tools

Parameter	*Before*	*After*	*% change*
Total number of workstations	17	16	5.88 (decrease)
Total number of bottleneck work stations	2	1	50 (decrease)
Total operation time (minutes)	75.5	62.5	17.21 (decrease)
Production volume (number of piece)	60	85	41.66 (increase)
Production rate (minute/piece)	8.5	6.0	29.41% (increase)
Direct labour productivity/worker-hour	0.157	0.223	42.03 (increase)
Indirect labour productivity/worker-hour	0.21	0.298	41.90 (increase)
Total labour productivity/worker	0.09	0.127	41.11 (increase)
Energy productivity	0.227	0.288	26.87 (increase)

In this study, three type of labour productivity is described. First is direct labour productivity, second is indirect labour productivity, and the third is total labour productivity. The change in labour productivity before and after using the intervention was measured. This case study shows that there is a significant improvement in direct, indirect and total labour productivity. This research shows that earlier total number of employee 70, shift length was 570 minutes, daily demand 100 pieces and daily production was 60 pieces. So the company was not able to meet the customer demand due to more cycle time and bottleneck stations. The other contribution of the study was to improve the volume of production and meeting demand for energy metres. It has found Improvement in the volume of production and reducing the difference in demand and supply of energy metres. Implementation of wireless connection increase daily production from 60 to 85 pieces without increasing employees and shift length. Customer satisfaction was increased by increasing product quality, production rate, and reliability.

It is observed that labour productivity (direct, indirect and total productivity) is improved by using a wireless connection. Direct labour productivity is enhanced by 42.03%, and indirect labour productivity is increased by 41.90% while total labour productivity is improved by 41.11%. Figure 5 shows direct labour, indirect labour, and total labour productivity before and after improvement. Direct labour productivity, indirect labour productivity and total labour productivity change from 0.157, 0.21 and 0.09 to 0.223, 0.298 and 0.177 respectively.

Implementation of lean tools reduced the cycle time and total production which results in significant improvement in energy productivity. Figure 6 shows the change in energy productivity before and after improvement. Energy productivity changes from 0.227 to 0.288 so there is an increase in energy productivity of 26.87%.

Figure 7 is showing how some workstations and a number of bottleneck stations are changing before and after improvement. Before applying the improvement number of workstations and the number of bottleneck stations was 17 and 2 respectively. But after using the improvement number of workstations and no of bottleneck stations are 16 and 1 respectively. So the number of workstations and the number of bottleneck stations are reduced by 5.88% and 50% respectively.

Figure 5 Change in labour productivity (see online version for colours)

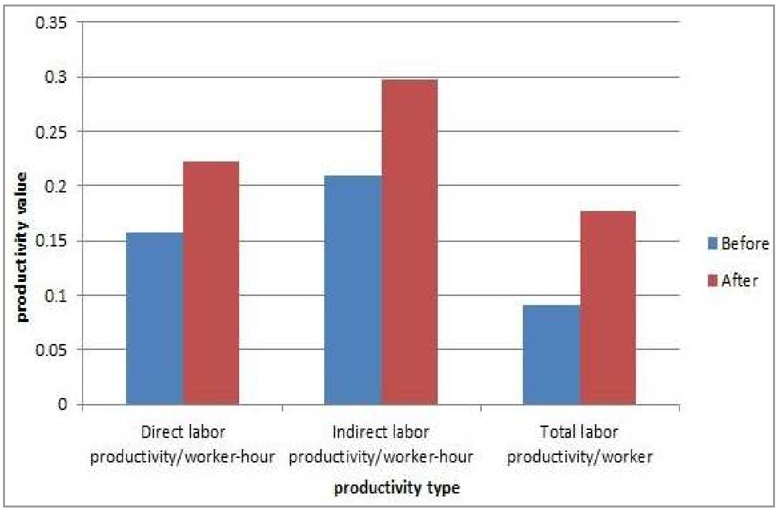


Figure 6 Change in energy productivity (see online version for colours)

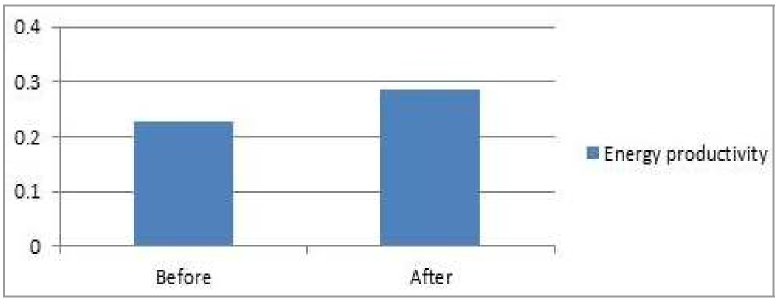
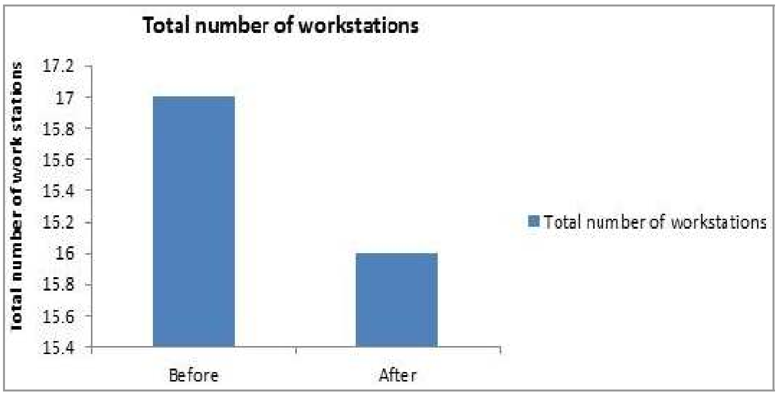
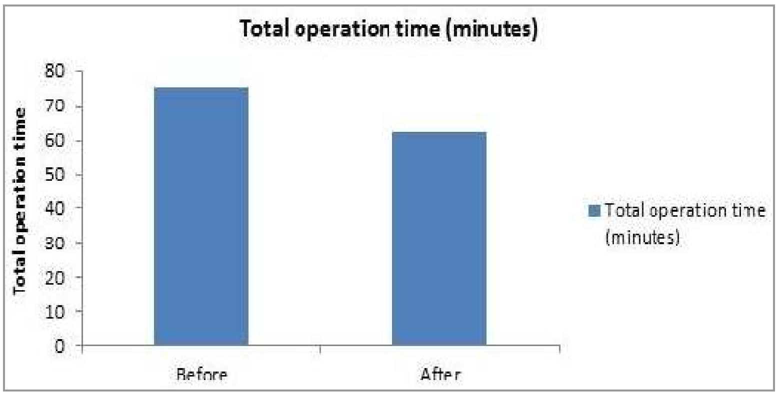


Figure 7 Change in number of workstations (see online version for colours)



It was observed the reduction in total operation time by applying lean tool and wireless connection. Figure 8 is showing the change in total operation time before and after improvement. Total operation time is changed from 75.5 minutes to 62.5 minutes, so there is a reduction in total operation time of 17.21%.

Figure 8 Change in operation time (see online version for colours)



5 Conclusions and future scope

Lean tools and wireless connection has been used by the company to enhance the performance. Current state and future state VSM have been used to understand the situation of the production line. Takt time is calculated to find the bottleneck workstations. If calculated takt time is less than production rate, then it results in bottleneck workstation. It was found that wiring and connection were consuming maximum time which results in higher productions lead time. So for reducing the time of this workstation wireless connection is used.

It was observed that current state VSM and takt time recognised bottleneck workstations. Wireless connection reduces the cycle time of bottleneck workstation which results in the reduction in bottleneck workstation. Production volume was increased by 25 (from 60 to 85) with a percentage increase of 41.66% after using a wireless connection and lean tools. Energy productivity is improved significantly after applying the lean tools and wireless connection. Production rate is improved by 2.5 minutes/piece with percentage improvement of 29.41%. It was found that total operation time is reduced by 13 minutes. (From 75.5 minutes to 62.5 minutes). In the present study finally, it is concluded that the use of VSM takt time and wireless connection is beneficial for the company. So it is found that the overall performance of the company is improved by using these tools.

It is best tried to improve the performance of the organisation, and very significant improvements are achieved. But still, there are chances for improvement. Some proposals for future study are discussed. In future study can be performed to reduce the number of workstations as it is still a large number of stations. The bottleneck of workstations cannot be removed completely, so scopes are present to reduce the bottleneck of workstations. It is observed that the current production rate is slower than demand, so customer demand is not met. In future study can be performed to improve the production rate. In this study, only some lean tool like VSM, takt time, bottleneck, and production lead time are used. For further study, other lean tools can also be used.

Disclaimer

There is no specific funding from any provider source for this study.

References

Abdullah, F. and Rajgopal, J. (2003) 'Lean manufacturing in the process industry', *Proceedings of the IIE Research Conference, CD-ROM*, Portland, OR, IIE, Norcross, GA.

Abdulmalek, F.A. and Rajgopal, J. (2007) 'Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study', *International Journal of Production Economics*, Vol. 107, No. 1, pp.223–236.

Alukal, G. (2003) 'Create a lean, mean machine', *Quality Progress*, Vol. 36, No. 4, pp.29–34.

Anand, G. and Kodali, R. (2008) 'Performance measurement system for lean manufacturing – a perspective from SMEs', *International Journal of Globalization and Small Businesses*, Vol. 4, No. 2, pp.371–410.

Arslankaya, S. and Atay, H. (2015) 'Maintenance management and lean manufacturing practices in a firm which produces dairy products', *Procedia-Social and Behavioral Sciences*, Vol. 207, pp.214–224, doi: 10.1016/j.sbspro.2015.10.090.

Bhamu, J. and Singh Sangwan, K. (2014) 'Lean manufacturing: literature review and research issues', *International Journal of Operations & Production Management*, Vol. 34, No. 7, pp.876–940.

Bhamu, J., Shailendra Kumar, J.V. and Sangwan, K.S. (2012) 'Productivity and quality improvement through value stream mapping: a case study of Indian automotive industry', *International Journal of Productivity and Quality Management*, Vol. 10, No. 3, pp.288–306.

Brioso, X., Murguia, D. and Urbin, A. (2017) 'Teaching takt-time, flowline, and point-to-point precedence relations: a Peruvian case study', *Procedia Engineering*, Vol. 196, pp.666–673, doi: 10.1016/j.proeng.2017.08.056.

Choomlucksana, J., Ongsaranakorn, M. and Suksabai, P. (2015) 'Improving the productivity of sheet metal stamping subassembly area using the application of lean manufacturing principles', *Procedia Manufacturing*, Vol. 2, pp.102–107, doi: 10.1016/j.promfg.2015.07.090.

Comm, C.L. and Mathaisel, D.F. (2000) 'A paradigm for benchmarking lean initiatives for quality improvement', *Benchmarking: An International Journal*, Vol. 7, No. 2, pp.118–128.

Cox III, J.F. and Blackstone Jr., J.H. (1998) *APICS Dictionary*, 9th ed., Falls Church, Falls Church, Virginia, USA.

Dankbaar, B. (1997) 'Lean production: denial, confirmation or extension of sociotechnical systems design?', *Human Relations*, Vol. 50, No. 5, pp.567–583.

Frandson, A., Berghede, K. and Tommelein, I.D. (2013) 'Takt-time planning for construction of exterior cladding', in Formoso, C.T. and Tzortzopoulos, P. (Eds.): *21st Annual Conference of the International Group for Lean Construction. Fortaleza*, Brazil, 21–22 August, pp.527–536.

Goh, M. and Goh, Y.M. (2019) 'Lean production theory-based simulation of modular construction processes', *Automation in Construction*, Vol. 101, pp.227–244.

Grünberg, T. (2007) *Performance Improvement: A Method to Support Performance Improvement in Industrial Operations*, PhD thesis, Royal Institute of Technology, Stockholm, Sweden.

Hartini, S. and Ciptomulyono, U. (2015) 'The relationship between lean and sustainable manufacturing on performance: literature review', *Procedia Manufacturing*, Vol. 4, pp.38–45.

Hasle, P., Bojesen, A., Langaa Jensen, P. and Bramming, P. (2012) 'Lean and the working environment: a review of the literature', *International Journal of Operations & Production Management*, Vol. 32, No. 7, pp.829–849.

Hopp, W.J. and Spearman, M.L. (2008) *Shop Floor Control. Factory Physics*, p.495, Waveland Press, Long Grove, IL.

Khalili, A., Ismail, M.Y., Karim, A.N.M. and Daud, M.R.C. (2018) 'Soft total quality management and lean manufacturing initiatives: model development through structural equation modelling', *Int. J. Productivity and Quality Management*, Vol. 23, No. 1, pp.1–30.

Kumar, R. and Kumar, V. (2016) 'Effect of lean manufacturing on organizational performance of Indian industry; a survey', *International Journal of Productivity and Quality Management*, Vol. 17, No. 3, pp.380–393, DOI: 10.1504/IJPQM.2016.074856.

Lee, S.H. and Park, B. (2016) 'Impact of manufacturing systems on quality management practices, competitive advantages, and operational performance', *International Journal of Productivity and Quality Management*, Vol. 19, No. 3, pp.301–318, DOI: 10.1504/IJPQM.2016.10000206.

Metternich, J., Müller, M., Meudt, T. and Schaede, C. (2017) 'Lean 4.0 – between contradiction and vision', *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 112, No. 5, pp.346–348.

Mollenkopf, D., Stolze, H., Tate, W.L. and Ueltschy, M. (2010) 'Green, lean, and global supply chains', *International Journal of Physical Distribution & Logistics Management*, Vol. 40, Nos. 1/2, pp.14–41.

Olivella, J., Cuatrecasas, L. and Gavilan, N. (2008) 'Work organization practices for lean production', *Journal of Manufacturing Technology Management*, Vol. 19, No. 7, pp.798–811.

Rahani, A.R. and Al-Ashraf, M. (2012) 'Production flow analysis through value stream mapping: a lean manufacturing process case study', *Procedia Engineering*, Vol. 41, pp.1727–1734.

Rohani, J.M. and Zahraee, S.M. (2015) 'Production line analysis via value stream mapping: a lean manufacturing process of color industry', *Procedia Manufacturing*, Vol. 2, pp.6–10.

Rother, M. and Shook, J. (1999) *Learning to See: Value Stream Mapping to Add Value and Eliminate Mudda*, The Lean Enterprise Institute, Inc, Brookline, MA.

Selvam, G., Prince, S.A.D., Surya Prakash, V. and Rohit, T. (2018) 'Quality and productivity improvement through spot welding process optimisation in automobile body shop', *Int. J. Productivity and Quality Management*, Vol. 23, No. 1, pp.110–127.

Shah, R. and Ward, P.T. (2003) 'Lean manufacturing: context, practice bundles, and performance', *Journal of Operations Management*, Vol. 21, No. 2, pp.129–149.

Singh, A.K., Meena, M.L. and Chaudhary, H. (2019) 'Application of multiple-response optimization methods for the ergonomic evaluation of carpet weaving knife', *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 29, No. 4, pp.293–311.

Sumanth, D.J. (1997) *Total Productivity Management (TPmgt): A Systemic and Quantitative Approach to Compete in Quality, Price and Time*, CRC Press, Boca Raton, Florida, USA.

Sundar, R., Balajib, A.N. and Satheesh Kumar, R.M. (2014) 'A review on lean manufacturing implementation techniques', *Procedia Engineering*, Vol. 97, pp.1875–1885.

Sunk, A., Kuhlang, P., Edtmayr, T. and Sihn, W. (2017) 'Developments of traditional value stream mapping to enhance personal and organizational system and methods competencies', *International Journal of Production Research*, Vol. 55, No. 13, pp.3732–3746.

Sutari, O. (2015) 'Process improvement using lean principles on the manufacturing of wind turbine components – a case study', *Materials Today: Proceedings*, Vol. 2, Nos. 4–5, pp.3429–3437.

Sweis, R.J., Saleh, R.A., Al-Etayyem, R.H., Qasrawi, B.T. and Mahmoud, A.M.A. (2016) 'Total quality management practices and organisational performance in Jordanian courier services', *International Journal of Productivity and Quality Management*, Vol. 19, No. 2, pp.258–276.

Taj, S. and Morosan, C. (2011) 'The impact of lean operations on the Chinese manufacturing performance', *Journal of Manufacturing Technology Management*, Vol. 22, No. 2, pp.223–240.

Zailani, S., Shaharudin, M.R. and Saw, B. (2015) 'Impact of Kaizen on firm's competitive advantage in a Japanese owned company in Malaysia', *International Journal of Productivity and Quality Management*, Vol. 16, No. 2, pp.183–210.

Annexure

The names of different workstations: (a) IC and other component installation, (b) adding and removing the capacitor, (c) wiring and connections, (d) visual testing, (e) SMPS programming, (f) EB, DG, solar checking, (g) relay setting, (h) communication testing, (i) front plate fixing, (j) connection, (k) C installation, (l) quality testing, (m) calibration, (n) socking, (o) packing, (p) top cover installation, and (q) final packing:

a This process is used to install different like integrated circuit (IC), capacitor and track card on bare printed circuit board.

b At this workstation, some capacitor added as well as some capacitor removed according to the requirement.

c Wiring is used to connect the printed circuit board (PCB) from another component for power supply. The different component is connected through electrical wire

d Visual testing is used to check that weather all the component on printed circuit board is installed properly or not. It also used for checking that wiring and connection are proper or not.

e SMPS (switched mode power supply) programming checking is used to check that output (power supply) are obtained or not as per requirement.

f At this workstation, the metre is checked for three power source like electricity board (EB), diesel generator (DG) and solar.

g This process is used to check the relay of the metre.

h This process is used to check that all component of the metre is communicating properly or not. Components should communicate properly to work metre properly.

i This process is used to fix the front plate on the PCB.

j This process is used to connect the printed circuit board with metre base, terminal wire, current transformer, and relay.

k In this process prepared printed circuit board are enclosed inside of a C shape part.

l This process is used to check the voltage, current, resistance and another parameter of the metre using a multi-metre. The quality of the metre is checked in this process.

m In this process, metre performance is tested at 240 volt and 5 amperes for different power factor. Leading and lagging are also checked at various power factors.

n In this process, the performance of the metre is checked. In this is the last testing process performance of the metre is checked.

o At this workstation, PCB is packed into a box so that PCB is enclosed from three sides.

p A cover plate is installed over the top of the box.

q This is the last process of the production line. In this process, metre is packed after which label and logo of the company are provided on the metre.