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Energy conservation through lean initiative in a manufacturing company: a case study

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Abstract: Energy conservation is a significant concept due to global concern on climate change. Manufacturing sector is the major consumer of energy from overall electricity generation. The concept of lean manufacturing having its prime motive to eliminate non-value added wastes has a wide window of opportunity to save the energy. This paper is an outcome of a case study conducted in a solar water heater manufacturing industry in South India. This study combines the lean manufacturing and energy auditing techniques to assess the efficiency of the manufacturer. We implemented the concept of 5S and value stream mapping which reveal several non-value added activities present in the production system. Then the concept of Takt time is introduced to keep the company efficient to meet their demand. The backorders present in the system is addressed by introducing forecasting models. We have generated an optimum production mix through 'Heijunka' concept to obtain a levelled production schedule. The concept of leanness was also introduced in auditing the energy consumption of machineries present in the system, which was a novel attempt of applying lean concepts in electrical energy conservation.

Keywords: energy value stream mapping; EVSM; lean energy; lean energy management.

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1 Introduction

The consumption of electricity becomes modestly increased due to global competition, lifestyle, and development. Rising concerns on global warming and climate change alarmed the governments and regulatory bodies for a smooth transition of alternative technologies to maintain sustainability. Industries and manufacturing sector is the major consumer of electricity across the world. This escalating pressure on manufactures pushes them for energy-efficient practices. (Jamil et al., 2020) writes the need for sustainable manufacturing practices and its operational evolution for the industrial environment. Establishing sustainable manufacturing methods in the organisation required strategic thinking, efficient planning, and processing and should reduce environmental impacts on natural resources (like water, energy, time, and material). To manage this challenge an industry should adopt the change and competitiveness in terms of production, strategy, and management. Madhusoodanan (2018) presenting the art of manufacturing changes towards the modern world, he describes how the manufacturing system adopts the shifts according to environmental change. The author highlights how traditional manufacturing slowly marching towards sustainable manufacturing. (Yang et al., 2011) made an empirical study on the impact of lean manufacturing techniques in environmental performance. Data collected from 309 manufacturing firms across the world shown significant improvement in environmental performance after implementing lean.

Lean thinking is not only applicable for the manufacturing sector it can even be adaptable to industries like processing, management and service sectors, etc. because it is versatile. The need for alternate resources and energy efficient approaches in a manufacturing system is essential over time. The approach of lean in energy conservation motto is slowly rising because the consumption of electrical energy will keep on growing and it is inevitable. Sajan and Shalij (2020) surveyed on Lean implementation practices (LMP) of around 252 SMEs all across the country India. The collected data were analysed using modelling techniques and justified the induction of LMP also enhances the sustainability performances categorised as economic, environmental, and social performances.

Integrating lean techniques in resource conservation methods were most successful because the involvement of lean assessment enhance the complete manufacturing cycle. However, the optimum level of energy conservation and evaluation is not achieved substantially. This provides potential insight for the present work to identify the scopes of the evaluation process for energy conservation while implementing the lean tools. Specific objectives to achieve the overall aims are:

- Identify the value and non-value added activities of the manufacturing system through VSM.
- Audit the energy utilisation of the machines in the production facility according to energy audit standards.
- And to discuss, how the VSM can be integrated with a continuous improvement cycle of an energy audit for best operational and environmental performance.

The following literature survey provides the latest advancement in lean energy studies and their adoption in the manufacturing sector. The scope of subsequent research and methodology used in this case study are discussed in the following sections.

2 Literature survey

US Environmental Protection Agency (2007) first links the lean manufacturing and energy auditing and explores the potential benefits of this implementation. It explains various tools and practices of lean which has an opportunity to save electrical energy consumption. The hidden advantage of eliminating lean wastes can contribute more savings in terms of money, energy and environment is the major portion identified, this study also includes top manufacturing industries contribution in the framework and their study outcomes for a diversified manufacturing environment. Lean implementation holds different concept and tools to improve leanness in the application. Integrating lean concepts with energy conservation in practice evolves with the efficient use of VSM method. Keskin et al. (2012) discussed the value stream map for industrial energy efficiency. VSM helps to identify the non-value – adding activities in a manufacturing facility they use the VSM to understand the level of energy utilised in each manufacturing process this logic is entirely simple and lucid to understand the entire stream of production and associate information to find out the kaizen bursts. (Verma and Sharma, 2016) found out a gap between lean manufacturing and green manufacturing and they provide a solution using energy value stream mapping (EVSM). The lean tool of VSM assists us to find the value-added work from the manufacturing process. Energy consumed by machinery during the manufacturing is calculated using the power rating of the machine and this combined benefit of EVSM makes the manufacturer achieve green manufacturing. Apart from this study, these authors reveal lean manufacturing as the base of other improvised manufacturing practices. The contemporary transition of the sustainable-oriented approach in the manufacturing sector creates more mobility towards the lean oriented approach. Choudhary et al. (2019) address green initiated VSM with a futuristic approach. The hurdles in lean implementation of small and medium manufacturing enterprises (SME) are discussed and provided with an optimistic roadmap to deploy lean strategically to reduce the consumption of energy, water, garbage, and rare earth metals without affecting their operational efficiency and effectiveness. The detailed discussion of VSM along with the green allied technique is more adaptable for a versatile manufacturing environment. Viera et al. (2019) describe productive use of lean tools in energy management plans. The standardised energy audit principles are combined with 5S and Pareto diagrams for the best use of energy assessment. The measured time and clarity of understanding are significantly improved in this auditing method.

- Baki et al. (2019) comprise the sustainable supply chain network through lean which contains economic, social, and environmental aspect for manufacturing industries
- Shaardan et al. (2017) encourage the concept of using lean management tools for energy efficiency improvement in non-domestic buildings. The approach is quite useful for regular life cycle operations.
- Muñoz-Villamizar et al. (2019) introduce a new methodology named overall greenness performance for VSM. It potentially integrates, measures, and controls the performance parameters of the manufacturing industries.
- Sivakumar et al. (2020) evaluate the organisation's competitiveness after implementing sustainable manufacturing practices. It further discusses the global competitive scores in this field and encourages research and development.
- Domizio et al. (2019) use precise computational data of industrial assets, visualise the energy hotpots from the data to combine it with lean tools for efficient utilisation of energy.
- Gogula et al. (2011) detail the energy-saving opportunity using lean implementation and the impact of lean tools on the energy-saving motto. They conducted a study in gas cylinder valve manufacturing company the current and future state VSM is generated and compared to show the energy-saving benefits.
- Phuong et al. (2018) sustainable production process through sustainable VSM. Potential issues and challenges of Industry 4.0 consider big data, artificial intelligence, ergonomics, and radio frequency-based production and identification process were analysed for future research insights.
- Oey et al. (2020) explore the best cost-saving demand forecasting method for high-efficiency supply planning. This research was a case study in small and medium manufacturing enterprises in Indonesia. Outcomes of this research evaluated seven common forecasting tools and provide better ones.
- Ciccullo et al. (2018) developed a conceptual study for the integration between leanness, agility, and sustainability. These separate topics addressed in many evolutionary model manufacturing scenarios but not related mostly. This conceptual framework integrates these topics for social responsibility and sustainable supply chain management.

3 Methodology

The use of lean tools in energy-saving option is implemented in multiple ways. Most of the cases from the literature survey clarify the motto is to reduce energy consumption. In general, the energy conservation scenario regulatory bodies and even manufacturing industries conduct energy audit approaches. Because in Lean tool application on energy conservation machine in manufacturing facilities and its power consumption performance are not considered properly. The machine utilisation, it is loading, unloading effects, and running time is practically ignored in lean implied audits. Lean and energy audits are conducted separately in many manufacturing facilities. The scope of this study is to merge lean and energy audits in possible ways for simple systematic utilisation.

4 Industry and its background process

The manufacturing plant is situated in a well-established industrial city in South India. The plant is semi-automated with dynamic work force, it has a diversified production environment and they have different product variation according to the market demand and utilisation purpose. It has been observed that their major production is to assemble and shaping the physical structure of the solar water tank, 50% of the raw materials are imported from different countries and those are assembled and shaped in this manufacturing facility.

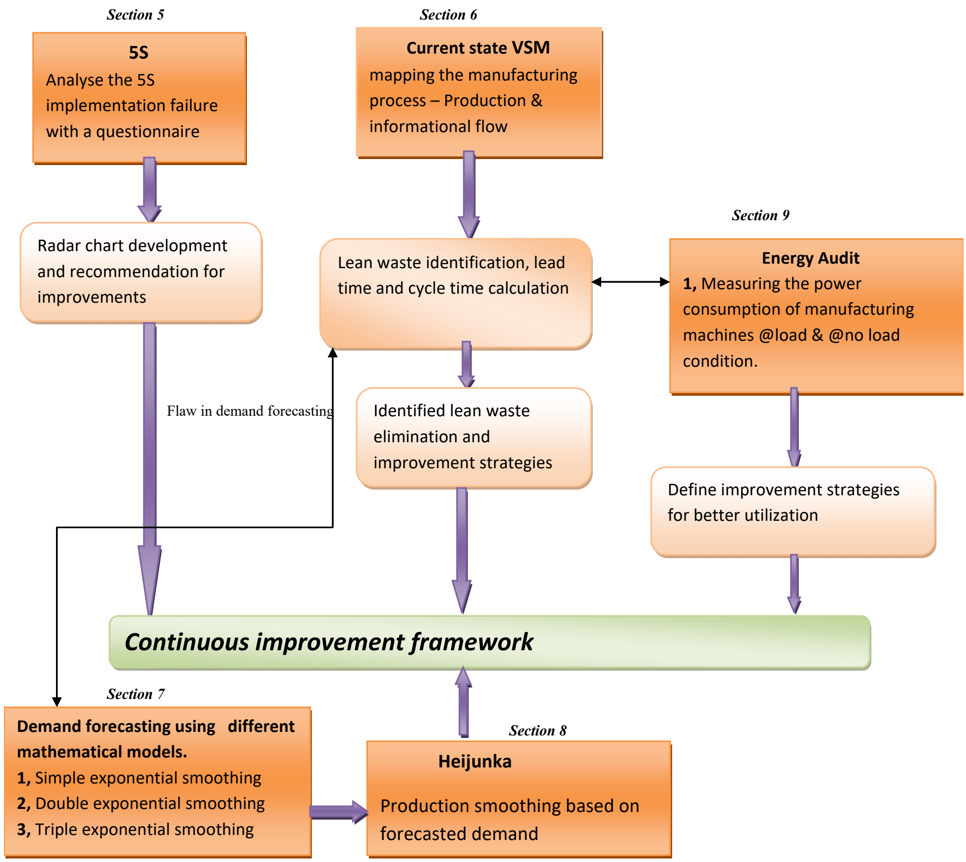
The company has only one manufacturing facility in South India and yet opened one more facility in North India. The manufacturing plant which located in south India has successfully completed ten plus years of production with good customer satisfaction. Inside this manufacturing facility there are three different products are manufactured Domestic purpose solar tank, Production of stand parts to house the solar tanks and Commercial purpose solar tank. All these products are manufactured in order to meet the varying demand of the customer. The production lines inside the company are fully busy and utilise the whole available production time of the industry. Based on the working load, all the workers are shifted and shuffled in order to train and maintain the plant efficiency.

The company had earlier tried to implement the 5S concept but it was failed. It gives a serious note for further investigation of this study. Flagging the failure of 5s is the first start of the study which leads to find a huge hidden problem present in the manufacturing environment. The assessment details and study outcomes are discussed further in the following sections.

4.1 5S audit

The present scenario of the company is observed. There are many posters around the factory establishing 5S concepts but not in actual practice. A 5S audit might help to identify the reasons for the 5S implementation failure. Since it is a manufacturing industry and gradually augment their product in the market this audit not only help to find the 5S implementation failure but also various improvements and responsibilities. A broad analysis on literature survey of 5S audit and expert's opinion from the relevant field helps to prepare a 5S questioner. Around 120 questions are prepared comprised of each S and distributed to the various management levels in the company. Then the collected sheets are approximated using Likert scale approximation method. The evaluated weights from the approximation are converted to percentage and projected in the radar chart shown in the Figure 1.

Figure 1 Systematic methodology followed for this case study (see online version for colours)

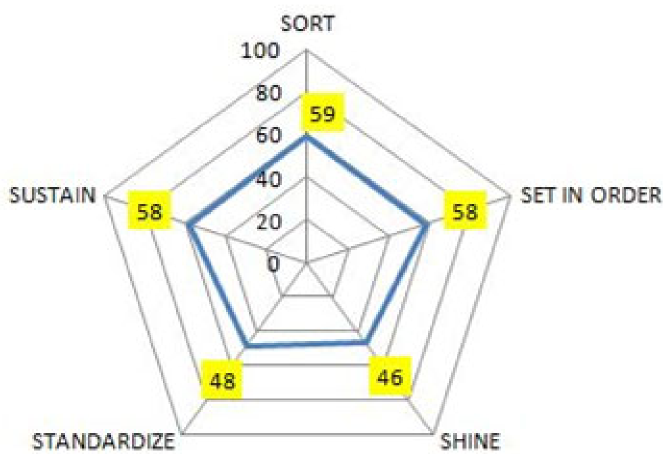


The present state of 5S in the company is revealed by this 5S audit as shown in the Figure 2. It shows many suggestions and improvements and at the same time important loop holes too. From Figure 2, it has been identified that the Standard and shine of 3rd and 4th S has scored poor percentage. The problems of this 5S implementation are reviewed again with an audit questioner. Each S has potential reasons to improve which are listed below.

- Sort
  1 Unneeded items are present in the work place
  2 Materials are not moved in timely manner.
- Set in order
  1 Production standards are not maintained properly
  2 No visible boards are used regarding safety, schedule, and standards
  3 Improper flow of information regarding production schedule.

- Shine
  1. Checklist are not maintained
  2. Walkways are not cleaned properly, marked yellow lines are faded.
- Standardise
  1. Photos and visual controls are not used
  2. Regular audit and documentation are not followed
  3. Safety is not prioritised.
- Sustain
  1. 5S team is not properly created
  2. Lack of awareness program on 5S in middle management
  3. Workers suggestions are not considered properly
  4. Employees are not recognised properly on their 5S efforts
  5. Kaizen (continuous improvement is not followed).

Figure 2 Radar chart result of 5s audit (see online version for colours)



Inference of 5S audit disclosed the actual status of the plant, the interpretation of each S in this audit holds valuable information. From the start of 1S, materials are not moved in timely manner. In 2S, the checklists are not maintained properly like cleaning, material handling, etc. which makes the work place untidy and faded the yellow line drawn inside the manufacturing facility. Likewise each and every single inference from this audit has significance which connects all the major issues inside the plant. If these entire S's are addressed properly and promptly, we can create an efficient and responsible work environment. From Figure 2, the shine and standardise in this audit scored poor when compare to other S's, so prioritising these standard and shine for effective implementation will help to improve the overall 5S achievement.

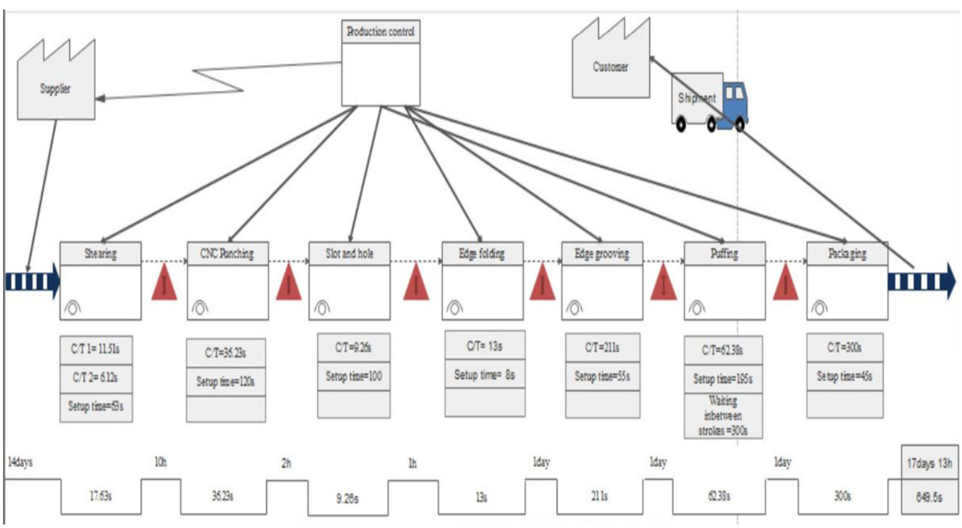
5 Value stream mapping

In this industry, we felt conducting a VSM to know the electrical energy consumption level, after conducting the current state value stream mapping. It gives many hints and hidden problems in the production flow of the industry. In this company they have two different processing structures for their products which are mostly not common to other products. One is commercial use solar water heaters with inner tank as plastic and the second one is domestic and commercial usage tank with inner tank as steel. Plastic inner tanks are imported from other countries, only the steel inner tank and outer layer tanks are manufactured in the company. A value stream is drawn for these two manufacturing processes.

5.1 Current state value stream map (outer layer)

The current state value stream map is drawn and shown in Figure 3 for the solar water heater tank outer layer. Comprises of shearing, CNC punching, slot and hole, edge folding, anti-edging, edge grooving, puffing and packaging processes.

Figure 3 Current state value stream map (inner tank is plastic) [outer layer] (see online version for colours)



From Figure 3, the solar tank outer layer manufacturing process is discussed through VSM. To create an outer layer they use sheet metal as raw material. Process starts from shearing and end at edge grooving. At the end of the edge grooving process an outer layer tank is manufactured. Then the manufactured outer layer and imported plastic inner tank are binding in the puffing process. Once puffing completed, tanks are sending to the packaging section and packed finally.

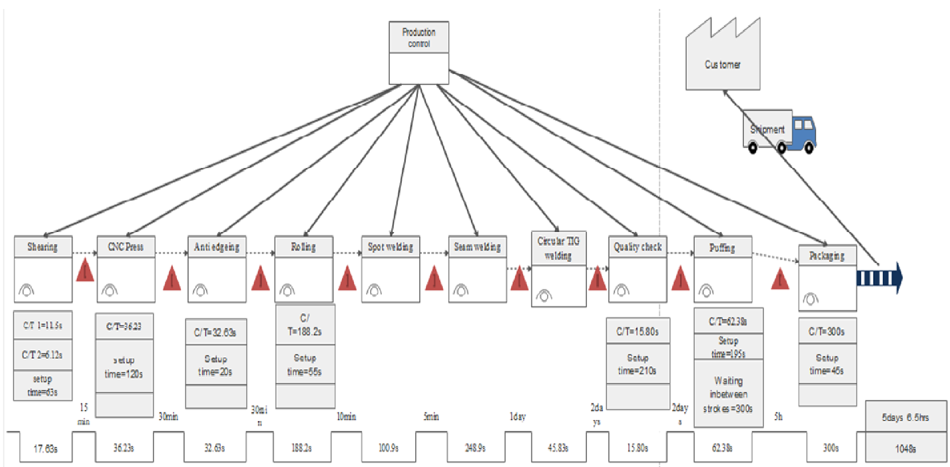
From this VSM, we found out the idle time (work in process inventory) between several production processes are huge. Especially from edge folding to packaging process the idle time is one day each. This increases the lead time of the product, which we identified as *17days 13h*. But the cycle time to create one product is *649.5* s only. Which is the actual value added work. There are several non-value added activities (NVA) present in puffing and packaging process. All are happens because standard work is not practiced in that particular process. This can be improved by providing standard training to the workers.

5.2 Current state value stream map (inner layer)

The next important product they are manufacturing is domestic purpose solar tank with stainless steel inner layer.

The current state value stream map is drawn for this inner layer and shown in Figure 4 which comprises of shearing, CNC punching, anti edging, rolling, spot welding, seam welding, circular TIG welding, quality check, puffing and packaging process.

Figure 4 Current state value stream map (inner tank is steel) [inner layer] (see online version for colours)



From Figure 4, the solar tank inner layer manufacturing process is discussed through VSM. This is an exclusive product having lesser demand when compare to previous product. In this product the inner layer tank is made from sheet metal and combined with outer layer in puffing process. The total lead time of this product is 5 days 6.5 h out of which the value added time is only 1,048 s. The NVA present in this production process are mostly in welding and quality check process. An insufficient skilled labour on welding and lack of quality control team is the reason for higher NVA presence. Due to this problem the inner and outer layer is not moulded together properly in the puffing process. This leads to rework and over processing.

This also further reveals that the workers are little pressurised during the second half of the month. It is because either they cannot meet the demand or their cycle time is not sufficient to meet the demand. From the VSMthe cycle time has been calculated. Takt time will help us to find whether the company have sufficient time to meet the customer requirement or not.

5.3 Takt time

For any manufacturing facility to perform well, it has to maintain the cycle time less than or equal to the Takt time (cycle time ≤ Takt time).

$$Takt\ time = (Available\ production\ time \big/ customer\ demand\ rate) \tag{1}$$

Estimating the available production time of the plant every month

1 Number of working days in a month = 25 days

2 Number of working shifts per day = 1 shift / day

3 Duration of every shift = 8 hours/ shift

Total available production time of the plant per month is = 200 hours

1 Customer demand rate planned is = 1,003 units

2 Now the Takt time is = 717.5 s / unit.

It means at every 717.5 s the plant has to manufacture one unit in order to meet the customer demand. The company has 85–90% of their product demand is on domestic purpose solar water heater tank, which has plastic as the inner tank. The cycle time of this product is 649.5s. It means the cycle time is maintained below the takt time 649.5 < 717.5

From the Takt time concept, we found that the plant has enough capability to meet the customer demand. Further study has been conducted focusing on company's production schedule. The company shared their three months production data starting from corporate planning to production schedule. Once analysing their production data we found that the real problem is with the production schedule. Because the company uses Delphi methods to predict their product demand. The sale of solar water heater is seasonal based, so the Delphi method did not consider the seasonal effects while predicting the future demand. Due to this, the sale of water heaters is not match with their forecasted demand. This was the problem the company cannot prepare their production schedule effectively. There are mathematical models available to forecast the product demand, where the product sale is based on trend and seasonal effects. So forecasting the product demand with suitable mathematical model is the remedial solution for this problem. There are few mathematical models identified and the product demand is forecasted which are discussed in the following sections.

6 Demand forecasting

Analysis of sales data obtained from the industry reveals interesting factors. The sales are not following their forecasted demand pattern. In order to streamline the demand pattern of the company, a suitable forecasting model needs to be identified. From the literature study and expert advice, a suitable forecasting model is identified called Classical multiplied time series forecasting model. To validate the forecasting model at least one year of sales data is required as input, because one year data will contains all seasonal variation in the sales. In this classical multiplied time series forecasting model (CMTSF), it de-seasonalised the sales data and creates a product trend using regression analysis.

Then the future predictions are multiplied with season and trend along with the corresponding time period.

Equation of classical multiplied time series forecasting model

$$Y_t = S_t x I_t T_t \tag{2}$$

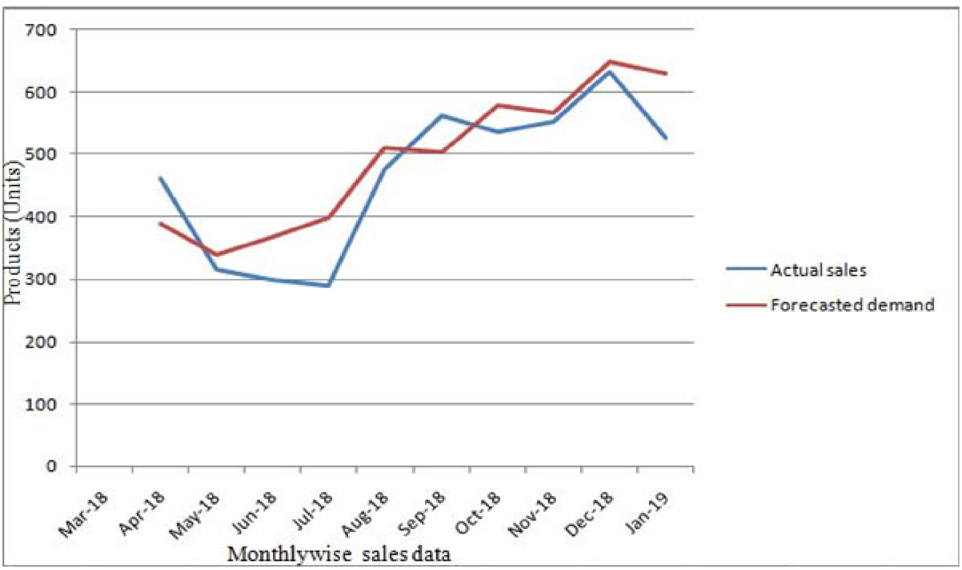
Yt product sales

St seasonal index

It irregular index

Tt trend index.

Figure 5 Product demand forecasted using classical multiplied time series forecasting model (see online version for colours)



The graph in Figure 5 shows the actual sale is plotted between one year sales data (monthly wise) vs. product quantity in units. From the figure, we can observe that the actual sales and forecasted demand curves have huge variations. Especially from the month of March 2018 to august 2018 forecasted demand curve gone beyond the actual sales curve. In September 2018 it is vice versa. The reason for this curve variation is due to incorrect seasonal predictions or regression error. This variation is also called as forecasting error. This forecasting error can be reduced by applying Mean absolute percentage error (MAPE). The variations between actual sales and forecasted demand are evaluated by MAPE in terms of percentage. A good forecasting model should give MAPE less than 5%. If MAPE is maintained below 5% then the forecasted demand will be closer to the sales. Hence, we can avoid stocking more finished goods inventory. The MAPE evaluated for this CMTSF model is 19%. So the forecasted demand with this CMTSF model did not gave the accurate results. There are many other mathematical models available to forecast the product demand. Until to get the desired accuracy, forecasting will continue which are discussed in the following sections.

6.1 Simple exponential smoothing

Exponential smoothing is the mostly preferred forecasting model. This model is widely used for many different industries irrespective of their product nature. This exponential smoothing method has three different methods which are simple exponential smoothing, double exponential smoothing and triple exponential smoothing. To understand the demand of this solar water heater product the forecasting is done under all this three types of exponential smoothing method.

Simple exponential smoothing is the basic model of exponential smoothing method. This model is simplest of all the other exponential smoothing method. Because it does not consider the trend and seasonal impacts while forecasting.

Equation of simple exponential smoothing model

$$Y_{t+1} = \alpha Y_t + \alpha(1-\alpha)Y_{t-1} \tag{3}$$

α smoothing constant

Y_t actual sale

Yt_{-1} previous sale

Y_{t+1} future sale (demand).

6.2 Double exponential smoothing model

This model is superior to simple exponential method. Because, this model considers the product trend component while forecasting.

Equation of double exponential smoothing model

$$Y_{t+1} = \alpha Y_t + \alpha\left(1-\alpha\right)Y_{t-1} \tag{4}$$

α smoothing constant

Y_t actual sale

Y_{t-1} previous sale

Y_{t+1} future sale (demand).

$$T_{t+1} = \beta T_t + \beta(1-\beta)T_{t-1} \tag{5}$$

β trend smoothing constant

T_t trend at present sales

T_{t-1} trend at previous sale

T_{t+1} trend at future sale.

6.3 Triple exponential smoothing model

In this forecasting model, it considers the trend and seasonal factors in sales. The sale of solar water heater depends mainly on these factors so the model might be giving good results as we expected.

Figure 6 Product demand forecasted using simple exponential smoothing model (see online version for colours)

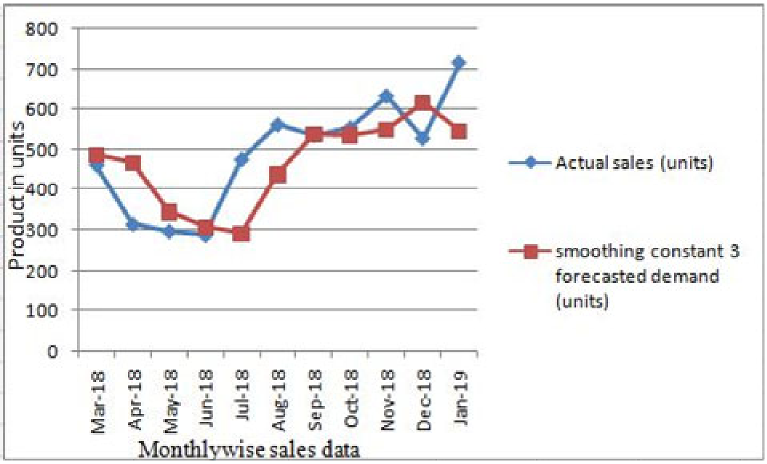
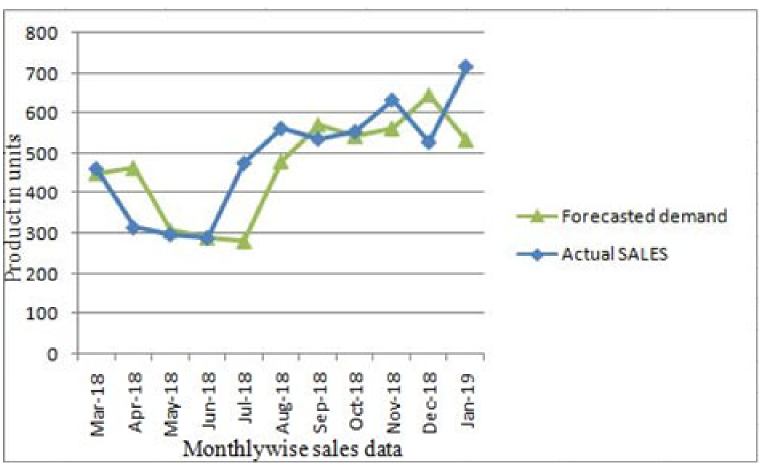


Figure 7 Product demand forecasted using double exponential smoothing model (see online version for colours)



Equation of triple exponential smoothing model

$$Y_{t+1} = \alpha Y_t + \alpha(1-\alpha)Y_{t-1} \quad (6)$$

α smoothing constant

Y_t actual sale

Y_{t-1} previous sale

Y_{t+1} future sale (demand).

$$T_{t+1} = \beta T_t + \beta(1-\beta)T_{t-1} \quad (7)$$

β trend smoothing constant

T_t trend at present sales

T_{t-1} trend at previous sale

T_{t+1} trend at future sale.

$$S_{t+1} = \gamma Y_t + (1-\gamma) Y_{t-1} \tag{8}$$

S_{t+1} seasonal index in future sale

γ seasonal smoothing constant

Y_{t-1} previous sale.

Figure 8 Product demand forecasted using triple exponential smoothing model (see online version for colours)

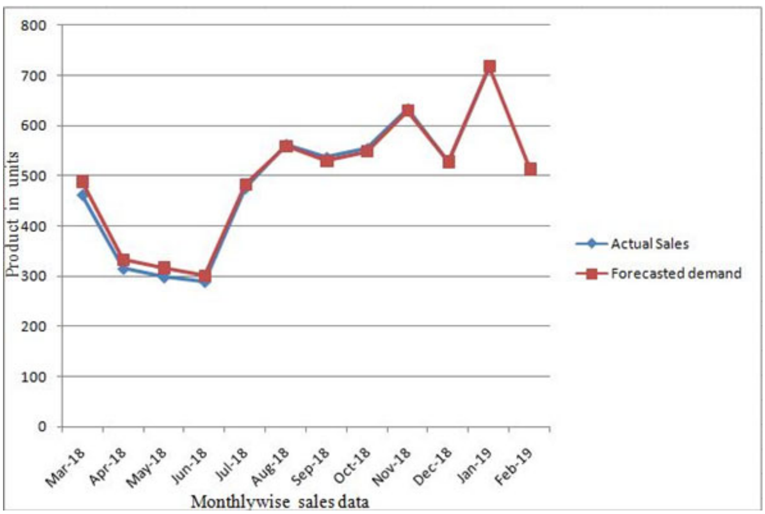


Table 1 Mean absolute percentage error for forecasted models

S. no.	*Forecasted model*	*MAPE (%)*
1	Classical multiplied time series	19
2	Simple exponential smoothing	17
3	Double exponential smoothing	15
4	Triple exponential smoothing	2

Finally, a desired output has been achieved by reducing the MAPE less than 5% in triple exponential smoothing method; Figure 8 shows the sales and forecasted curve. Both these curves are close and more significantly forecasted demand curve is streamlined well with the sales curve. This was the accuracy expected to forecast the future demand. Now, we can forecast the future demand of the company. By using this model the next six months product demand is forecasted from March 2019 to August 2019 shown in the Table 2.

From our previous findings, it has been confirmed that the production schedule is the major bottleneck identified in the industry. The reason for the problem is also stated as improper forecasting method on their product demand. Finally, a demand forecasting technique has been identified with suitable mathematical model and streamlined their future product demand. The next biggest challenge faced by the company is unevenness in production and over burdens caused by the piling up finished goods inventory. 'Heijunka' is the best method to solve this problem which is discussed below.

Table 2 Forecasted product demand

Months (2018–2019)	*Actual sales (units)*	*Forecasted demand(units)*
Mar-18	462	488
Apr-18	315	333
May-18	298	317
Jun-18	289	301
Jul-18	476	482
Aug-18	562	559
Sep-18	536	529
Oct-18	554	548
Nov-18	633	629
Dec-18	528	528
Jan-19	716	717
Feb-19	512	513
Mar-19		485
Apr-19		331
May-19		313
Jun-19		304
Jul-19		501
Aug-19		592

7 Heijunka

Lean manufacturing technique of 'Heijunka' (production smoothing) will help to schedule the production in the form of corrected product volume mix. This technique creates production efficiency and enables dynamic scheduling based on predicted demand. This constant rate of scheduling and production can helps the industry to remove many lean wastes.

To find out an optimum product mix from the demand, it is essential to calculate a production ratio using the following equation which finalises the daily production requirement.

$$Production\ Ratio = \left(Period\ demand\ /\ Lowest\ period\ demand\right) \quad (9)$$

One month product demand of the company has been showed in Table 3.

From the table, we identified the total demand in this month is around 630 units. In order to meet this demand within the available production time, a production ratio needs to be calculated.

Table 3 One month product demand details

Products	*Variants*	*Demand (units)*
A	CRP 100	118
B	CRP 160	20
C	CRP 200	21
D	FRM 100	97
E	FRM 150	69
F	FRM 200	23
G	FRM CR 130	165
H	FRM CR 200	82
I	FRM CR 260	16
J	FRM CR 340	5
K	TB 100	4
L	TB 150	5
M	TB 200	5
	Total	630

Table 4 Daily production ratio

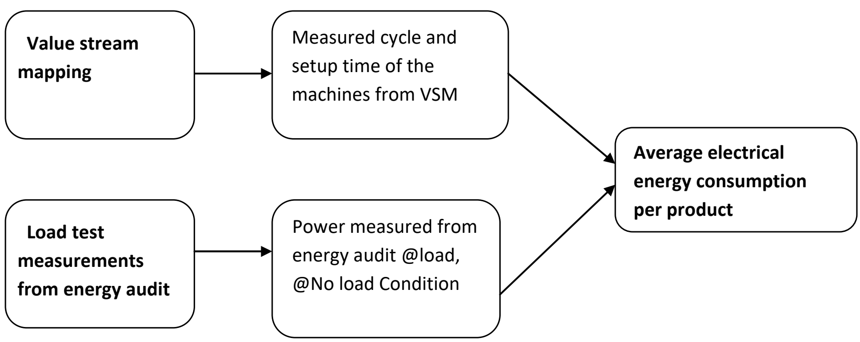
Products	*Variants*	*Demand(units)*	*Daily production ratio (units)*
A	CRP 100	118	5
B	CRP 160	20	1
C	CRP 200	21	1
D	FRM 100	97	4
E	FRM 150	69	3
F	FRM 200	23	1
G	FRM CR 130	165	7
H	FRM CR 200	82	4
I	FRM CR 260	16	1
J	FRM CR 340	5	0
K	TB 100	4	0
L	TB 150	5	0
M	TB 200	5	0
		Total	27

From Table 4, the total daily production ratio calculated is 27 units. The company can manage this production cycle and easy for them to handle it. Because, they can manage up to 40 units /day. Products J, K, L, M shown in Table 4 are zero because of the lesser demand. But it can be added along with the daily requirement of 27 units whenever they face a demand on that product. From the table, the calculated production ratio for daily production cycle in each product is calculated as A = 5, B = 1, C = 1, D = 4, E = 3, F = 1, G = 7, H = 4, I = 1 totally 27/day. This production smoothing technique is dynamic, varying according to the product demand and time period. Now the unevenness in production faced by the company is eliminated. If the industry maintains its daily production cycle based on this technique. Then it will improve the production stability. This product and volume mix of production is easy to adjust and enhance the production facility to face any dynamic demand challenge.

8 Energy audit and energy consumption level of the company

The ultimate aim of this project is to find the energy consumption level of machineries to manufacture one unit of solar tank, and to optimise it. Energy audit is conducted in the company to find out the power consumption level of the machines and the power factor maintenance of the company. By combining both the energy audit and VSM we can estimate an average energy consumption level of the manufacturing products. Which was a novel attempt implemented in this study. To find the energy consumption level, a methodology used in this study has been shown in the Figure 9.

Figure 9 Methodology used to find average energy consumption per product



In Figure 9, the energy audit is integrated into the value stream mapping. Power consumption level of the machines at loading and No loading condition during production is measured in energy audit. From VSM, the cycle time and setup time are measured. By combining these data we can estimate an average amount of energy consumed by the machine to manufacture one unit of product. Formulae used to calculate the energy consumption is shown below:

1 Energy @ No load condition = (Setup time × Power measured in No load) {*kWh*}

2 Energy @ Loading condition = (cycle time × Power measured in load) {*kWh*}

In this study, we found that few machines having issues with capacity utilisation and power factor problems which are discussed in Table 6.

1. Total electrical energy consumed by a machines to produce one unit of solar tank (*inner layer*) = 1.7 kWh

2 Total electrical energy consumed by a machines to produce one unit of solar tank (*Outer layer*) = 0.7819 kWh.

The company is producing solar water heaters under two main categories one is steel as an inner tank and the other is plastic as inner tank.

If a stainless steel tank is made then its production is consist of both the inner and outer layer

So the total average energy consumption by one unit of stainless steel tank is = 1.7 + 0.78 = *2.48 kWh*.

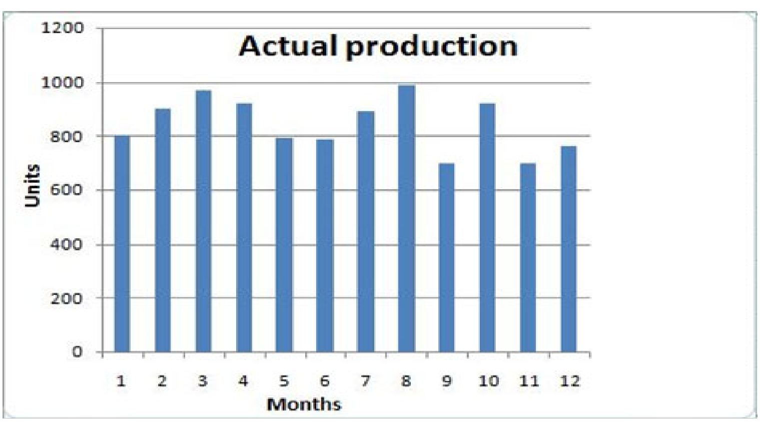
In case of plastic inner tank production, only outer layer is produced so the total average energy consumption by one unit of solar tank with plastic as inner is = *0.78 kWh*.

We finally found our average energy consumption according to the product categories. Let us find the energy consumption by products in the company's monthly production.

Table 5 Load test measurement from energy auditing

S. no.	*Name of the machine*	*Power consumption @load (W)*	*Power consumption @No load (W)*
1	Shearing machine	2280	660
2	Power press machine	4260	1080
3	Seam welding machine	120	60
4	Compressor	23340	5760
5	Puffing machine	3751	3027
6	Edge grooving machine	460	263
7	Circular TIG welding machine	32906	NA
8	Spot welding machine	32906	NA
9	Anti edging machine	197	131
10	Power press machine 2	592	329

Figure 10 Yearly production rate (see online version for colours)



V.s

In Figures 10 and 11, the energy consumption level is plotted corresponding to the monthly production rate of the company. This was the scenario of the company before our study. Once we assess the company, we found there are many finished goods inventory which consumes the revenue of the company. This we have addressed in the previous section and suggested the solutions using demand forecasting and Heijunka techniques. If our suggested techniques are implemented in the company then we can visualise the energy conservation opportunities. Sample calculation is shown below to see the energy conservation opportunity if suggested lean techniques are implemented.

Figure 11 Yearly energy consumption level (see online version for colours)

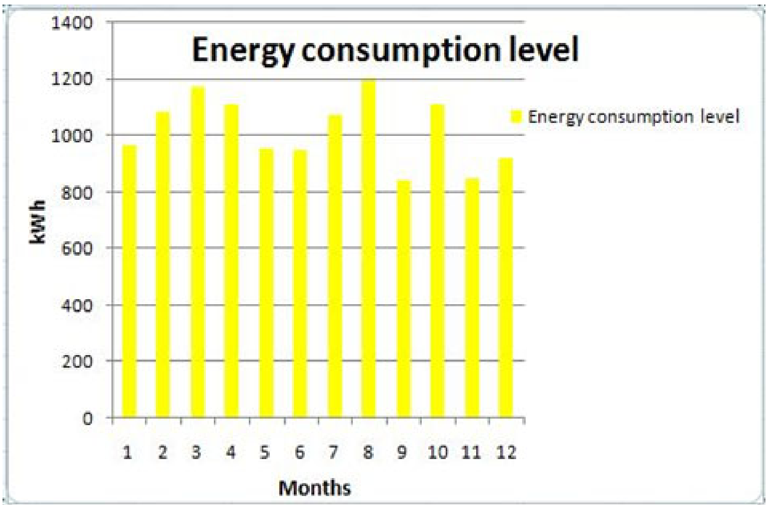


Table 6 Inference and recommendations from energy audit

S. no.	*Machine*	*Inference*	*Recommendations*
1	Shearing machine	Capacity utilisation of the machine is low	Instead of shearing one sheet at a time adding multiple sheet will give you better utilisation
2	Power press machine	Percentage loading is less	Even though the percentage loading is high , since it is an impulse loading it can be neglected now
3	Seam welding machine	Power factor is very low	Need to improve the power factor
4	Compressor	Capacity utilisation is satisfactory	If power factor maintained close to unity then the discount can avail from electricity board.

Sample calculation is shown for the same 10th month.

From Figure 10, the actual production corresponds to 10th month is 990 units.

But from the demand forecasting technique we found the demand on this month is 699 units.

For steel as inner =(699 x0.25) = 175 units, then the energy consumption is (175 × 2.48) = 434 kWh.

For plastic inner = (699 x 0.75) = 525 units, then the energy consumption is (525 × 0.78) = 410 kWh.

In this month, the total average energy consumption of the company to produce 699 units of solar tank is = 434 + 410 = 844 kWh.

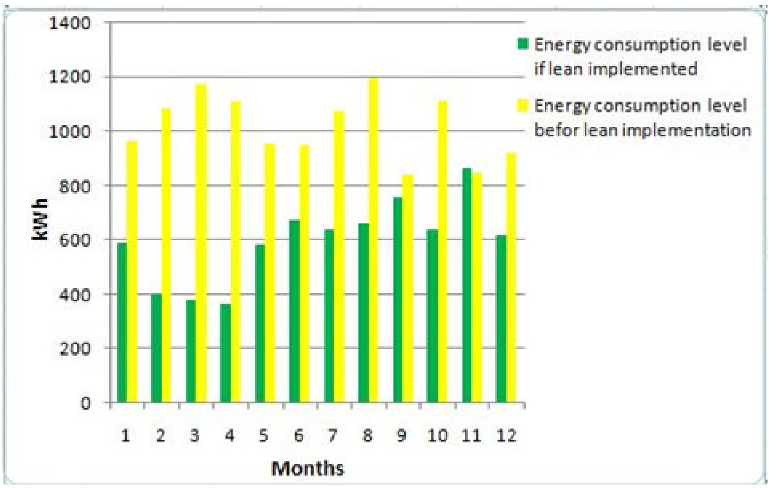
Previously for this same month the energy consumption level is 1,085 kWh.

If lean is implemented in the industry then the energy consumption level will be 844 kWh.

Total energy conserved because of lean implementation in the 10th month is = 1,085 – 844 = 241 kWh.

This energy calculation is done for the whole year and compared with previous energy consumption level, which is shown in the graph.

Figure 12 Energy consumption level before and after implementing lean techniques (see online version for colours)



In Figure 12, energy consumption levels are compared before and after implementing the lean techniques for the whole year. By eliminating the constant non-moving inventory present in the production system, on an average around 30% of energy has been reduced by comparing the previous production rate corresponding raw material and time also conserved.

9 Conclusions

The contribution of this study mainly aims to reduce the operational barrier while implementing the lean energy strategy. Integrating lean and energy audit methods distinctly reduced the managerial and practical implementation implications. The planned assessment inside the manufacturing facility is three-folded approach. Firstly, identification of lean wastes through VSM. Secondly, audit the energy consumption of the machines. Finally, the core objective of this project is to conserve the electrical energy use of the industry by combing lean and energy auditing techniques. These threefold approach was the main strategic implementation aimed to introduce in this study. But few outcomes from VSM assessment lead to further investigation on their demand forecasting methods and introduced suitable mathematical models which are applied to forecast the product demand and then, scheduled the production based on the 'Heijunka' technique. Erstwhile 5S implementation failure in the industry also enquired with RADAR chart development. In case, ignoring the demand management problem identified from the assessment leads to fully spoil the sustainability of this lean energy framework. Therefore, this continuous improvement framework can only be achieved by providing practical engineering and managerial solutions, which are required to wheel this sustainability framework.

If we look into this whole concept of the study, it has many stereotyping techniques like Lean manufacturing, energy auditing, and demand forecasting. The major part of this project is combining all these in a single stretch to visualise the benefits, and the main ingredient of this study is lean manufacturing which binds all together and prevails the end solution.

This study also has the following limitations and hence can be treated as a possibility of future research.

- To improve the market analysis strategy among the sales/marketing team for better input collection and maintain robustness in forecasting.
- Periodic energy audits on machines and maintains quality standards for better utilisation.
- Dynamic production scheduling with optimum production ration calculation based on the essential demand requirements.
- Introducing alternate resources for conservation further aims to enhance the environmental performance and reduce negative impacts.

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