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Artículo original

Impact of lean tools on energy consumption

Impacto de las herramientas lean en el consumo de energía

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Abstract

Lean principles are mainly used for increasing productivity, reducing lead time, and eliminating waste. Energy impacts can also be assessed by using the lean principles. The objective of this paper is to measure the impact of Lean Manufacturing tools on energy consumption, with the base assumption that they should help decrease it. The methodology assesses and documents the energy utilization as a part of VSM. A pilot application in an industrial setting is presented.

Resumen

Los principios de Lean Manufacturing se usan principalmente para mejorar la productividad, reducir el tiempo de entrega y eliminar desperdicios. Los impactos en consumo de energía también se pueden estimar usando principios de Lean.

El objetivo de este artículo es el de medir el impacto del uso de herramientas de Lean Manufacturing en el consumo de energía, partiendo del supuesto de que su aplicación debería reducirlo. La metodología evalúa y documenta la utilización de la energía como parte de la elaboración de Mapas de la Cadena de Valor. Finalmente se presenta una aplicación piloto en una empresa industrial.

This paper is derived from a Non-Thesis Project presented to the Graduate Faculty of The University of Texas at San Antonio in partial fulfillment of the requirements for the Degree of Master of Science in Advanced Manufacturing Enterprise Engineering.

I. Introduction

In today's competitive world, companies focus on eliminating waste to ensure customer satisfaction and maintain their profit growth. Among various types of wastes in manufacturing, energy waste is gaining attention nowadays. Organizations must comply with federal rules and regulations towards environmental-friendly manufacturing where energy plays a key role. It has been proven in many types of industries and different areas of manufacturing that lean implementation results in highly efficient production systems, and one of the several benefits is the significant environmental and energy gains.

The objective of this study is to pinpoint the contribution of lean implementation in energy saving to achieve a better environmental performance of production systems. This project focuses on the analysis of the impact of selected lean tools on energy consumption in a manufacturing company. An application of the methodology in a cylinder valve regulator manufacturing company is introduced. Using value stream mapping, the current state of operations and energy consumption in the shop floor can be evaluated. Based on the seven types of waste commonly used by lean practitioners, the opportunities for waste reduction and their expected impacts are identified. A future state value stream map is created to show the use of selected lean tools and their impact on productivity and energy consumption. A comparison study between the current and future state maps details the contributions of lean tools in energy reduction. It is concluded that implementing lean principles can result in significant energy reduction, and different lean tools can help in energy savings in different types of operations.

2. Background

These days U.S manufacturers face an increasingly competitive environment, where they are looking for opportunities to reduce the production costs without any negative effect to their productivity. Whereas, uncertain energy prices in today's market place negatively affect the predictable earnings (Galitsky & Worrell, 2008). A September 2005 poll taken by the National Association of Manufacturers (NAM) revealed that 93% of directors from small and medium-sized manufacturing companies believe that higher energy prices are having a negative impact on their bottom line (United States Environmental Protection Agency [EPA], 2007). It is known fact that reduction in the energy wastes can significantly reduce the production costs. Manufacturing sector has significant opportunity in reducing energy waste compare to any other sector in U.S. economy. Energy consumption by various key sectors in U.S is shown in Figure 1 below. Encouraging cost effective investment in energy efficiency methods and technologies may give good results of maintaining high quality product with reduced cost. This is main reason that all the organizations focused on Toyota Production System (TPS) or otherwise called as Lean manufacturing. It is a production system that focused on eliminating the wastes and other non-value adding activities. Lean is a world leading strategy that has proved its worthiness in industrial environments over a long period of time (Moreira, Alves, & Sousa, 2010). Several authors identified that lean has significant environmental gains. The main goal of the present study is to enlighten the contribution of Lean for achieving better or improve energy savings with improved quality, reduced waste using a Value stream map. Three main reasons for Integrating Lean and energy efficiency efforts are (a) Cost savings (b) Climate change and Environmental Risk (c) Competitive advantage.

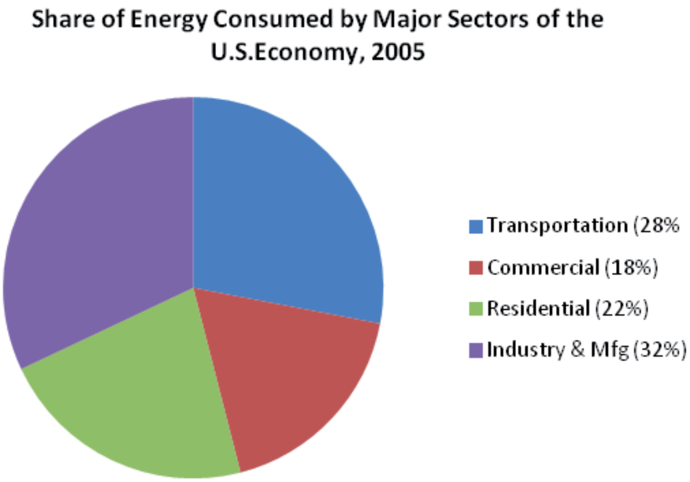

Figure 1. Share of Energy in US Economy (EPA, 2007)

2.1. Relationship between Lean and Energy use

According to EPA (2007), "substantial energy savings typically ride the coattails of lean. By eliminating manufacturing wastes such as unnecessary processing and transportation, business also reduce the energy needed to power equipment, lighting, and cooling." Without explicit consideration of energy wastes, however, Lean may overlook significant opportunities to improve performance and reduce costs. Energy is a vital input to most production processes and value streams. By thinking explicitly about unnecessary energy use as another "deadly waste", Lean implementers can significantly reduce costs and enhance competitiveness, while also achieving environmental performance goals. Energy wastes increase the costs of business. The energy use hidden in lean wastes is shown in Table 1.

Nowadays, energy waste should also be linked with the economy of organization. All the organizations and their management are in tremendous pressure to increase productivity and reduce energy waste. Companies view energy waste as an obstacle

Waste Type	Energy Use
Overproduction	More energy consumed in operating equipment to make unnecessary products
Inventory	More energy used to heat, cool, and light inventory storage and warehousing space
Transportation and Motion	More energy used for transport More space required for work in process (WIP) movement, increasing lighting, heating, and cooling demand and energy consumption
Defects	Energy consumed in making defective products More space required for rework and repair, increasing energy use for heating, cooling, and lighting
Overprocessing	More energy consumed in operating equipment related to unnecessary processing Use of right-sized equipment often results in significant reductions in energy use per unit of production
Waiting	Wasted energy from heating, cooling, and lighting during production downtime.

Table 1. Energy Use Hidden In Lean Wastes (EPA, 2007)

in achieving profits, so they are encouraging to improve energy performance of their facilities.

2.2. Lean Tools and their impacts on energy consumption

Seryak, Epstein, and D'Antonio (2006) believe that all the lean tools are not energy saving tools. While there are a great deal of lean tools, six tools that are frequently used to implement lean and can be used to greatly reduce energy consumption have be identified. These tools are: Standard Work, Visual Workplace, Error Proofing, TPM, Quick Changeover, and Right-Sized Equipment (Kuriger & Chen, 2010). In the following paragraphs we show how the different tools mentioned above can play a significant role in the reduction of energy consumption:

- » • Standard work: Standard work is a set of work procedures that establish the best and most reliable method of performing a task or operation. Work procedures maintained at each work station incorporating energy reduction best practices can reduces the energy waste. For instance:
    - • Building energy reduction best practices into training materials, standard work for equipment operation and maintenance.
    - • Adding energy reduction practices into 5S checklists.

» Visual Controls: Visual Workplace provides visual indicators so that goals and current status of the workplace can be easily identified. These indicators can include energy usage goals, which can help workers and managers to be conscious of energy use and opportunities for energy reduction (Kuriger & Chen, 2010).

» Mistake-proofing: Mistake proofing refers to procedures that are used to prevent defects and processing errors. Reducing the errors or completely eliminating the errors or defective parts reduces the energy consumption per unit of good parts.

» Total Productive Maintenance (TPM): Systematic care and maintenance of the equipment increases the life of machines and reduces machining downtime. With proper equipment and system maintenance, facilities can reduce manufacturing process defects and save an estimated 25 percent in energy cost. Different strategies that can be adopted for integrating Energy-Reduction Efforts into TPM are:

  • Integrate energy reduction opportunities into autonomous maintenance activities.

  • Train employees on how to identify energy wastes and how to increase equipment efficiency through maintenance and operations

  • Conduct energy kaizen events to make equipment more efficient.

  • Build energy-efficiency best practices into systems for management of safety, health, and environmental issues.

» Quick Changeover is a procedure to reduce the setup and changeover time for a process. This tool reduces the time the line is down. It also reduces the energy used to make the changeover and provide light and heat during non-productive time (Kuriger & Chen, 2010).

» Right-Sized Equipment: It is a method that ensures that the appropriate machines and equipment are used to complete a process step. Selecting equipment that has just enough capability and speed to satisfy the flow of a production cell can provide energy savings over an outdated machine that has much more capacity than it is required.

3. Methodology

3.1. Energy Value Stream Mapping

Integrating energy utilization into VSM is one way to understand the energy consumption in a shop floor. Addition of energy information into the VSM makes everyone to be able to easily understand the complete impact that the value stream has on the operational performance, energy efficiency (Kuriger & Chen, 2010). Having the energy use of the process along with lean related metrics like cycle time, changeover time and others helps the experts to have better understanding of the process and its energy concerns. It also helps the VSM team to brainstorm and make necessary improvements for the proposed "future state". Adding the average energy use of all the processes to the process data boxes in the VSM helps to identify the bottlenecks or key areas for improvement.

3.2. Pilot application: Valve regulator manufacturing company

The objective of this section is to calculate the energy utilization of various types of equipment at each particular work station and incorporate it with VSM. Current state VSM and Future state VSM are shown in this section. This section also describes the calculation of energy usage at each work station of the manufacturing company.

A company that produces Liquid Petroleum Gas (LPG) cylinder valves regulators is considered in this pilot application. The process involves extrusion, metal cutting, and lathe machining process, assembly, painting and inspection. For this study, the extrusion process is not taken into consideration due to insufficient data availability.

3.2.1: Company and process background: The company presented in the application produces the valve regulators that are primarily used for Liquid petroleum gas cylinder valves. The focus of this VSM is on one product family with three types of products: Regulator pin, supporting pins, and washers. Average customer demand was estimated at 52,000 parts per month. The processes for this product family start with a blast furnace where on a daily basis raw material is charged in the furnace. The melted raw material is then extruded into the required shapes. The shapes obtained are cooled and placed in the storage area. As it requires very high maintenance, the aforementioned extrusion process works four days every two weeks. As there is no sufficient data regarding the machinery and their energy consumption rate, the extrusion process is not taken into consideration for energy calculations. After the extrusion and storage processes, metal cutting and processing on the lathe take place. This continues with assembly, painting and inspection. At the assembly station each regulator pin requires two supporting pins and three washers. Different operations are performed on two different lathes in order to manufacture the three different parts. Once the assembly process is complete, the part enters the painting station where the company name and batch numbers are painted and finally the assembled part reaches the inspection station. Once inspection is completed, the finished goods are placed at the warehouse and customer orders are dispatched once a day.

At the facility, the business planning department receives orders from the customer every 15 days. When an order is received by the business planning department, it is entered into the planning system and an estimate of the completion date is generated. The system produces a rough schedule of orders on the production units on a weekly basis. Next, they affix a routing to the order and assign a plan week to it. This schedule on the operating side becomes the basis to monitor day to day increments against how closely they are in accordance with the schedule. Schedules can be updated as needed. This facility uses trucks as its mode of transportation. Orders are dispatched to the customers on a daily basis. The plant works for eight hours a day, five days a week.

3.2.2. VSM: current state map. All the data for the current state map were collected according to the approach recommended by Rother and Shook (1999). The data collection started from the shipping department, working backwards all the way to metal cutting work station. Figure 2 shows the current state map that was constructed. The small

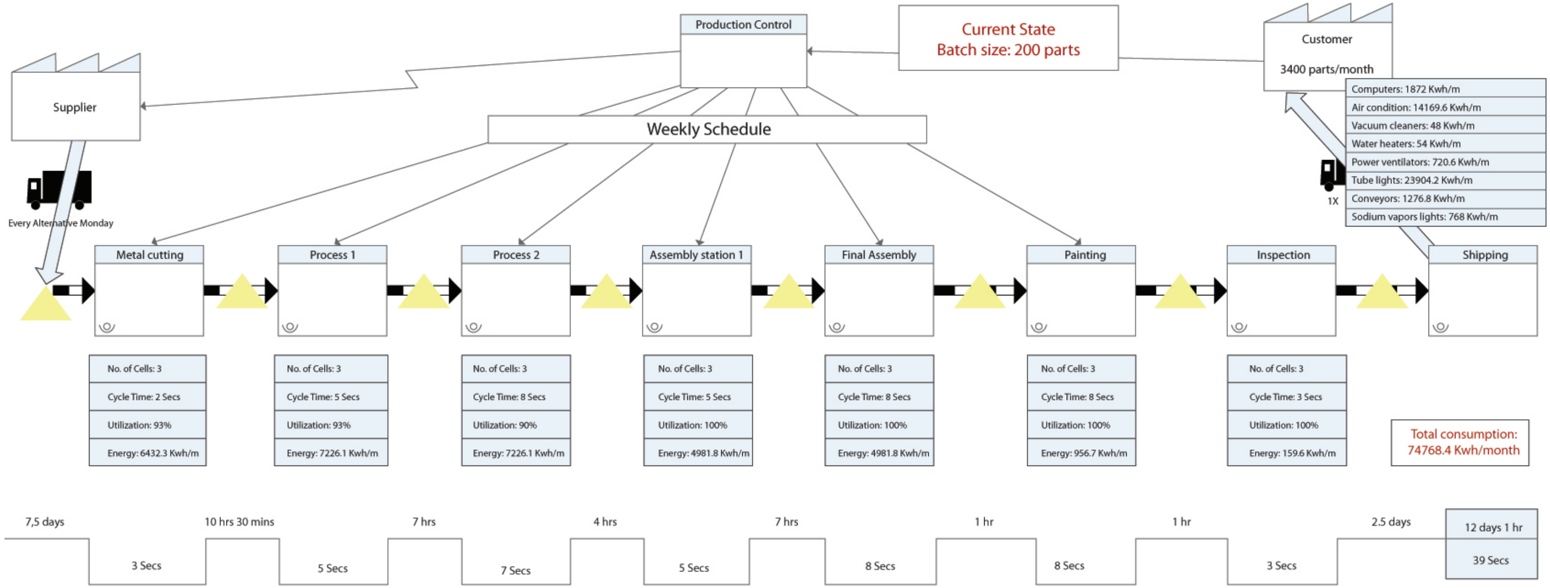

Figure 2. VSM, Current state map

boxes in the map represent the process, and the number inside the box is the number of workers at each process. Each process has a data box below, which contains its cycle time, machine utilization and energy consumption at that particular work station. The triangles before each station show the waiting time at that particular station. The timeline at the bottom of the current state shows the total lead time of the component, which signifies the non-value added time in the product manufacturing. The other component is the processing time which is otherwise called as value added time.

3.2.3. Energy use in the current state. Energy use in the shop floor has a major impact on the production cost of the manufacturing companies. According to EPA (2007), industry and manufacturing sectors consume more energy than any other sector, such as transportation, commercial, and residential. Calculating the energy usage at each particular workstation provides significant opportunities to identify bottlenecks in terms of energy. It helps to identify improvement areas and to decrease operating costs.

In this application, energy consumption of the machinery and all the other equipment that use power were calculated based on their rated power. All the energy calculations in this company were made in kilowatt-hours. Table 2 shows the total number of pieces of every type of equipment that are consuming energy in the current state of the shop floor.

Based on the pieces of equipment that are consuming energy, the total energy consumption in the shop floor is 74786.4 Kw-h per month. All the calculations for the current state consumption are presented in Tables 3, 4 and 5. Based on the value

s.no	Equipments	Quantity	Rated Power(watts)	Energy Consumption (Kwh)
1	Tube lights	840	60	23904.0
2	Computers	10	300	2520.0
3	Lathe	6	10260	12927.6
4	Lathe (metal cutting)	3	9000	5670.0
5	Sodium vapour lights	12	200	768.0
6	Conveyors	20	760	3351.6
7	Robots	12	250	202.5
8	Air compressors	6	6840	7296.0
9	Power tools	6	2280	3078.0
10	Sprayers	3	100	67.5
11	Air condition	15	1440	14169.6
12	Vacuum cleaners	4	200	48.0
13	Power Ventilators	4	380	729.6
14	Water heaters	2	300	54.0
			Grand Total:	74786.4

Table 2. Summary of energy consumption in the current state

Energy consumption at Inventory room of Raw Materials								
Equipments	Quantity	No. of equipments running		No. of hours running		Power consumption		
		shift	off shift	shift	off shift	cap(watts)	For 15 days (KWH)	
Air conditioner	3	3	2	8	16	1440		2419.2
Tube lights	200	200	120	8	16	60		6336
Sodium vapour light	6	8	0	8	0	200		384
computers	2	8	0	8	0	300		576
Conveyors	3	3	0	7	0	760		478.8
							Total	10194

Table 3. Energy consumption at Inventory Room of Ray Materials

Energy consumption in shop floor								
Equipments	Quantity	No. of equipments running		No. of hours running		Power Consumption		
		shift(8 hrs)	off shift	Shift	Off Shift	cap(watts)	For 15 days (KWH)	
Metal Cutting								
Lathe Machines	3	3	0	7	0	9000		5670
Tube lights	60	60	30	8	16	60		1728
Computers	3	3	0	8	0	300		216
Conveyor belt	3	3	0	7	0	760		478.8
Robots	3	3	0	3	0	250		67.5
Process 1								
Lathe Machines	3	3	0	7	0	10260		6463.8
Tube lights	60	60	30	8	16	60		1728
Computers	3	3	0	8	0	300		216
Conveyor belt	3	3	0	7	0	760		478.8
Robots	3	3	0	3	0	250		67.5
Process 2								
Lathe Machines	3	3	0	7	0	10260		6463.8
Tube lights	60	60	30	8	16	60		1728
Computers	3	3	0	8	0	300		216
Conveyor belt	3	3	0	7	0	760		478.8
Robots	3	3	0	3	0	250		67.5
Assembly station1								
compressors	2	2	0	8	0	6840		3283.2
powertool	3	3	0	7.5	0	2280		1539
Tube lights	40	40	20	8	16	60		1152
Conveyor belt	1	1	0	7	0	760		159.6
Assembly station2								
compressors	2	2	0	8	0	6840		3283.2
powertool	3	3	0	7.5	0	2280		1539
Tube lights	40	40	20	8	16	60		1152
Conveyor belt	1	1	0	7	0	760		159.6
painting station								
compressors	2	2	0	8	0	1520		729.6
sprayers	3	3	0	7.5	0	100		67.5
Tube lights	40	40	20	8	16	60		1152
Conveyor belt	1	1	0	7	0	760		159.6
Inspection station								
Tube lights	40	40	20	8	16	60		1152
Conveyor belt	1	1	0	7	0	760		159.6
Common equipment								
Computers	10	10	0	8	0	300		720
Air conditioner	9	9	9	8	16	1440		9331.2
Vaccum cleaners	4	4	0	2	0	200		48
water heaters	2	2	0	3	0	300		54
powerventilators	4	4	2	8	16	380		729.6
							total	52639.2

Table 4. Energy consumption at the shop floor

Energy consumption at Inventory room of Finished goods								
Equipmen	Quantity	. of equipments runn		No. of hours running		Power consumption		
		shift	off shift	shift	off shift	cap(watts	For 15 days (KWH)	
Air condit	3	3	2	8	16	1440		2419.2
Tube light	300	300	120	8	16	60		7776
Sodium va	6	8	0	8	0	200		384
computer	2	8	0	8	0	300		576
conveyors	5	5	0	7	0	760		798
							Total	11953.2

Table 5. Energy consumption at Inventory Room of Finished Goods

stream map, the shop floor is producing around 67500 parts per month, in which 10% of the stock are maintained as safety stock.

Findings in the current state:

- Over production of 375 parts per day.
- High energy consumption in the form of lighting and air conditioning for the inventory at the warehouse.
- Unnecessary movement of products due to high WIP.
- High consumption of energy in terms of energy per correct part produced as there is high defect rate.
- Energy waste in form of waiting of the parts due to several machine breakdowns at various stations.

Formulae used to calculate energy consumption:

$$Power\ Consumption\ (Kwh) = \frac{Rated\ power\ (watts) * Hours\ per\ shift}{1000} * 30\ days * quantity$$

Example (Lathe):

$$Power\ Consumption\ (Lathe) = \frac{9000 * 7}{1000} * 30 * 3 = 5670\ {}^{kwh}/_{month}$$

Example: Air conditioning at Finished Goods Inventory Room:

$$Total\ Power\ Consumption\ = Consumption\ during\ work\ shifts + consumption\ during\ off\ shifts$$

$$Consumption\ during\ work\ shifts = \frac{1440 * 8}{1000} * 30 * 3 = 1036.8\ kwh/month$$

$$Consumption\ during\ off\ shifts = \frac{1440 * 16}{1000} * 30 * 2 = 1382.4\ kwh/month$$

$$Total\ consumption = 1036.8 + 1382.4 = 2419.2\ kwh/month$$

3.2.4. Energy use in Future State: The process of defining and describing the future state map starts while developing the current state map, where target areas for improvement start to show up. Looking at the current state map several things stand out: over production, high inventory, unnecessary movement of components due to high WIP and occupying more space.

From the findings in the current state we can see that there are a lot of opportunities in order to decrease the energy consumption of the shop floor. In this case all the energy wastages that are going on in the current state are related with seven wastes of the lean. The relationships between energy waste and seven wastes of lean are discussed below.

» Overproduction: From the current state VSM, it is identified that the shop floor is producing around 67,500 parts per month, in which 10% parts are maintained as safety stock. The actual customer demand is around 52,000 parts per month. This means that the shop floor maintains a lot of storage. Thus, overproduction is consuming energy providing air conditioning and lighting to all the extra floor space required.

» Inventory: Due to the push character of the system, there are high amounts of WIP at all the stations, with long waiting times. Energy is wasted to provide light and air conditioning to the space occupied by the WIP.

» Defects: Due to poor working conditions with no proper checklists and guidelines at the assembly lines, there is a defect rate of around 10%. This is causing the products to require rework. If there is an assembly defect there is less waste than when a machining defect happens. An assembly defect can be reworked, whereas a machining defect has to be melted and processed again beginning as raw material. Melting and reworking consume a considerable amount of extra energy.

» Waiting: Waiting of parts takes place at different work stations due to machine breakdowns. In the current state there is on average 53 minutes of waiting time due to various breakdowns. Some of the breakdowns are robot failures, lathe machines breakdowns due to scrap winding, cams and gears failure of lathe due to lack of basic maintenance, compressor leakages etc.

s.no	Wastage	Lean tool applicable
1	Overproduction	Pull, Kanban cards
2	Transportation	Manufacturing cell, Work load balance, Poka Yoke
3	Inventory	Pull system, Kanban
4	Defects	Standardized work, Visual control, Poka Yoke
5	Waiting	TPM (autonomous maintenance activities)
	Motion	Kanban

Table 6. Different Lean tools applied for reducing the energy wastages

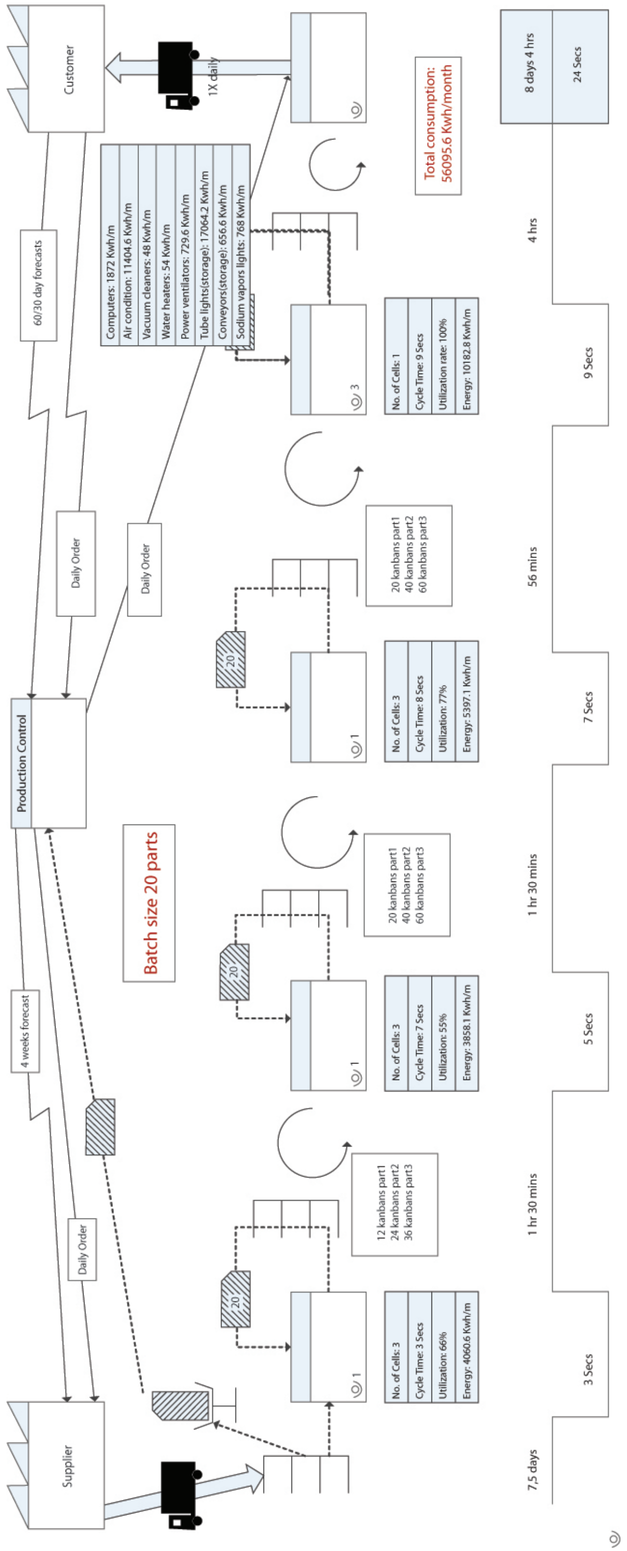

Figure 3. VSM, Future state

3.3. Comparison between Current state and future states

3.3.1. Overproduction: (Lean tool applied: Pull). **Pull system:** Pull system is an alternative to scheduling individual processes, in which the customer process withdraws the items it needs from a "supermarket" (buffer), and the supplying process produces to replenish what was withdrawn (Rooney & Rooney, 2005). Table 7 shows the comparison of the energy consumption in current and future state.

Energy consumption at stations	Equipment affected due to Pull	Current state (Kw-h/month)	Future state (Kw-h/month)
Metal cutting	Lathe	6432.3	5379.3
Process 1	Lathe	7226.1	4609.8
Process 2	Lathe	7226.1	6148.8
Assembly station1	no equipment	4981.8	4981.8
Final assembly	no equipment	4981.8	4981.8
Painting station	no equipment	956.7	956.7
Inspection station	no equipment	159.6	159.6
Total		31964.4	27217.8

Table 7. Overproduction: Comparison between current and future state consumption

3.3.2. Transportation: (Lean tool applied: Manufacturing cell, Work load balance, Poka Yoke)

- Manufacturing cell: An arrangement of people, machines, materials and equipment in which the processing steps are placed right next to each other in sequential order and through which parts are processed in a continuous flow. The most common cell layout is a U shape (Rooney & Rooney, 2005).
- Poka Yoke: It is also called mistake proofing. It is a process that is used to prevent errors from occurring or to immediately point out a defect as it occurs. If defects are not passed down an assembly line, throughput quality improves (Rooney & Rooney, 2005).
- Workload balance: A process in which work elements are evenly distributed and staffing is balanced to meet the takt time (Rooney & Rooney, 2005).
- Takt time: The rate of customer demand, takt time is calculated by dividing production time by the quality of the product the customer requires in that time. Takt, the heartbeat of a lean manufacturing system, comes from the German word taktzeit, which means cycle time (Rooney & Rooney, 2005).

For this case, manufacturing cell is applied to the assembly stations, painting and inspection stations in order to reduce the long waiting of the products and uneven utilization of the operators at each workstation. Cell formation eliminated the transportation problem between various stations.

Energy consumption	Current state (Kw-h/month)	Future state (Kw-h/month)
Machining process	1436.4	1292.76
Assembly stations	638.4	0
Ware house	1276.8	1149.12
Total	**3351.6**	**2441.88**

Table 8. Transportation consumption in current and future state

3.3.3 Inventory: (Lean tool applied: Kanban). **Kanban:** A communication tool in Just-in-Time that authorizes production or movement. Kanban, from a Japanese word for a visible card or record, was developed by Taiichi Ohno at Toyota. It is a small card or signboard (or any authorizing device) attached to boxes of specific parts in the production line signifying the delivery of a given quantity (Rooney & Rooney, 2005).

In this case, one Kanban is used for a batch of 20 regulator pins. No. of Kanban between each station is calculated is using the formulae N= dl+s/c where N= Number of Kanban, d: demand units, L: Lead time (time to replenish an order, expressed in the same time as expressed in demand), S: Safety stock (as a percentage of demand during lead time), based on service level and variance of demand during lead time. C: no. of parts for each container. Based on the demand rate of the production line the number of Kanban that are calculated between the manufacturing cell and process 2 is 20; between processes 2 and 1 is 20 Kanban; and 12 Kanban are maintained between process 1 and metal cutting. Coming to energy consumption, Kanban helps in reducing the work in progress in the shop floor with very few batches between the stations. Due to the use of the Kanban system, the WIP in the shop floor reduced from 21,300 to 6,240. The utilization of shop floor for WIP was reduced to one fifth of what it was in the current state. Energy reduction due to inventory takes place in form of lighting and cooling. Table 9 shows the energy consumption by the lights and air-condition in current state and future state.

Energy consumption	Current state (Kwh/month)	Future state (Kwh/month)
Storage area	38073.6	32716.8

Table 9. Energy consumption due to Lighting and cooling in current and future state

3.3.4. Defects: (Lean tools applied: standard work, visual control, Poka Yoke).

In the current state it is identified that there are two different types of errors, namely operator errors and machining errors. Different operator errors are as follows.

At the assembly line:

» Damaging the threads

» Forgetting assembly washers, bearing balls,

» Order of the assembly

At the painting station:

» Mistake in mixing the colors

» Wrong color to wrong part

» Mistake in painting occupied space

» Identifying leakages of compressing cylinder

Machining process:

» Wrong sequence of processing

Machine Faults:

» Incorrect cutting parameters

» Dull cutting tool

» Unsecured work piece

Different types of lean tools applied to decrease the defects are Standardized work, Visual control, and Poka Yoke.

» Standardized work: A lean manufacturing tool that enables operators to observe the production process with an understanding of how assembly tasks are to be performed. It ensures the quality level is understood and serves as an excellent training aid, enabling replacement or temporary individuals to easily adapt and perform the assembly operation.

» Visual control: Any devices that help operators quickly and accurately gauge production status at a glance. Progress indicators and problem indicators help assemblers see when production is ahead, behind or on schedule. They allow everyone to see the group's performance and increase the sense of ownership in the area. Table 10 shows the energy wastages in current state and percentage chances of reduction and energy consumption in the future state due to defects in the manufacturing process.

3.3.5 Waiting: (Lean tool: TPM)

Different types of critical shut downs causing waits in the shop floor are:

» Robot failures due to software program

» Lathe breakdown due to scrap winding

» Tool breakages due to irregular shape of mat

» CAMS and gears failure of the lathe due to lack of basic maintenance

Errors due to operators and machine faults	Energy consumption in current state (Kw-h)	Energy waste (Kw-h)	%Energy waste reduction	Energy recovered	Energy consumption in Future state (Kw-h)
Assembly line	9963.6	996.36	25%	249.1	9714.5
Painting station	956.7	47.835	20%	9.567	947.1
Machining process	20884.5	1044.2	25%	325.8	20623.4
Machine faults	20884.5	2088.5	50%	1303.4	19840.3
Total	52689.3	4176.9		1564.0	51125.4

Table 10. Energy reduction due to defects in the production process

- Conveyor failures
- Compressor leakages
- Water wash failure
- Spray gun failures

Total Productive Maintenance (TPM): Systematic care and maintenance of the equipment increases the life of machines and reduces downtime. With proper equipment and system maintenance, facilities can reduce manufacturing process defects and save an estimated 25 percent in energy cost (Rooney & Rooney, 2005).

Different strategies that can be adopted for integrating Energy-Reduction Efforts into TPM

- Integrate energy reduction opportunities into autonomous maintenance activities.
- Train employees on how to identify energy wastes and how to increase equipment efficiency through maintenance and operations

Table 11 shows the energy consumption in the form of lighting, cooling due to waiting in the production line. The average breakdown in the current state is around 53 minutes and it is around 14 minutes in the future state.

Avg. production down time in current state	Energy consumption during down time(Kwh)	Avg. production down time in future state	Energy consumption during down time (Kwh)
53.34 min.'s per day	1145.743	14.05 min.'s per day	301.8584

Table 11. Energy consumption due to waiting

3.3.6. Motion (Lean tool: Kanban)

Motion waste is due to unnecessary movement of conveyors in the warehouse and machining area due to high WIP in the current state. Kanban cards used to reduce the inventory and WIP in the shop floor brought WIP down from 21,300 to 6,240. This reduction helped in reducing the movement of conveyors at the ware house and shop floor. Table 12 shows the energy savings due to saved motion.

From tables 13, 14 and 15 we can see the energy consumption in the current state and future state for one month of all the equipment in the factory. Excess energy in

WIP in shop-floor (current state)	Energy consumption (Kwh)	WIP in shop-floor (future state)	Energy consumption (Kwh)
21300	1630.8	6240	633.6

Table 12. Energy consumption due to motion in current and future states

Lean Wastage	Lean tool applicable	Energy consumption in current state (KW-h/month)	Energy consumption in future state (KW-h/month)	% Reduction
Overproduction	Pull system	31964.4	27217.8	26.8%
Transportation	Manufacturing cell	3351.6	2713.2	36.4%
Inventory	Kanban	38073.6	32716.8	30.9%
Defects	Visual control, 5S, Standard work, Poka yoke	4176.9 (This is amount of energy wastage due to various reasons)	2612.94 (initial improvement)	34.9%
Waiting	TPM	1145.7	301.9	73.7%
Motion	Pull, Manufacturing cell	1630.8	633.6	66.8%

Table 13. Percentage energy reductions by applying different lean tools

s.no	Equipments	Quantity	Rated Power(watts)	Energy Consumption (Kwh)
1	Tube lights	685	60	17064.0
2	Computers	23	300	1872.8
3	Lathe	6	10260	9233.5
4	Lathe (metal cutting)	3	9000	4050
5	Sodium vapour lights	12	200	768.0
6	Conveyors	17	760	1210.6
7	Robots	12	250	135.0
8	Air compressors	6	6840	6348.4
9	Power tools	6	2280	3078.0
10	Sprayers	3	100	67.5
11	Air condition	15	1440	11404.8
12	Vacuum cleaners	4	200	48.0
13	Power Ventilators	4	380	729.6
14	Water heaters	2	300	54.0
Grand Total				56095.3

Table 14. Summary of energy consumption in future state

Current state energy consumption (Kwh)	Future state energy consumption (Kwh)	%Reduction
74786.4	56095.3	25%

Table 15. Overall comparison of current and future states energy consumption

the current state is due to various wastes like overproduction, high inventory, defects, waiting, motion and transportation. There is a 25% reduction in the total consumption if the lean improvements are implemented for the future state. In the long run, the reduction will not be the same, as there would be some shutdowns in the processes due to overproduction.

In order to make a clear understanding of the reduction in the energy consumption, per part consumption of energy is calculated. Table 16 shows the energy calculation per part.

No. of parts produced in current state per month	Energy consumption for one month in current state (Kw-h/Month)	Current state energy consumption per part (Kw-h/ part)	No. of parts produced in future state per month
67,500	74,786.4	1.10	60,000

Energy consumption for one month period in future state (Kwh/ month	Future state energy consumption per part (Kwh/part)	% Reduction
56,095.3	0.93	15.6%

Table 16. Energy consumption per part in current and future states

From the table 16, it is observed that energy consumption per part is decreased by 15.6% which is a significant reduction.

Conclusions and further work

In this study, the contribution of lean implementation in energy saving for achieving a better environmental performance of production systems was carried out. An industrial application in a cylinder valve regulator manufacturing company was taken and its current state was assessed. Lean concepts were implemented in the shop floor and then the future state map was compared with the current state map. This resulted in 25% (including machinery, conveyors, robots, lights) decreased energy utilization, decreased WIP from 21,300 to 6,240 parts per day and decreased space utilization of the shop floor. Energy consumption per part decreased by 15.6%. The proposed manufacturing cell at the assembly line resulted in reduced transportation between the assembly, painting and inspection stations, which in-turn resulted in decreased energy consumption. This project has highlighted the importance of lean implementation in the shop floor and its impact on energy consumption. This model can be further improved by considering water utilization, carbon emissions, material consumption etc. S&T

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