

Implementation of Lean Six Sigma for Production Process Optimization in a Paper Production Company

Adefemi Adeodu¹, Mukondeleli Grace Kanakana-Katumba², Maladzi Rendani¹

¹Department of Mechanical and Industrial Engineering, University of South Africa (South Africa)

²Department of Industrial Engineering, Tshwane University of Technology, Pretoria (South Africa)

engrcharles520ca@gmail.com, KanakanaMG@tut.ac.za, maladm@umisa.ac.za

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Abstract:

Purpose: This study aims at implementing lean six sigma to evaluate the productivity and manufacturing wastes in the production line of a paper company

Methodology/Approach: The study is a case study in nature. The method illustrates how lean six sigma (LSS) is used to evaluate the existing production process in a paper production company with focus on productivity and manufacturing wastes. The study considered a real-time problem of customer's dissatisfaction. Gathered data were based on machine functionality (up time, down time and cycle time); materials and labour flow at every process stage of the production line. The optimization of the production process was based on lean tools like value stream mapping, process cycle efficiency, Kaizen, 5S and pareto chart

Findings: Based on lean six sigma application, it was discovered that the present production performance was below standard and more manufacturing wastes were generated. The present productivity and manufacturing wastes are reported as low process cycle efficiency (23.4 %), low takt time (4.11 sec), high lead time (43200sec), high number of products not conforming to six sigma values, high down time (32.64 %) and excess labour flow (33). After the implementation of the lean six sigma tools for certain periods, there were lots of improvements in the production lines in terms of all the parameters considered.

Research Limitations/ Implications: The study has demonstrated application of lean six sigma in the case of solving real-time problems of productivity and manufacturing wastes which have a direct implication on customer's satisfaction. The lesson learnt and implications presented can still be further modeled using some lean based software for validity

Originality/Value: The study has contributed to the body of knowledge in the field of LSS with focus to process-based manufacturing, unlike most literature in the field which concentrated more on discrete based manufacturing.

Keywords: lean manufacturing, lead time, process cycle efficiency, takt time, value added time

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1. Introduction

Lean popularly known as Lean Manufacturing is a set of principles embraced by industrial organizations in order to improve on production performance and customer's satisfaction at the same time eliminating wastes (Ahmed, Manaf & Islam 2018; Mwacharo, 2013; Saidul Huq, 2018). It is a technique widely in use in manufacturing and supply chain management, but recently gaining implementation in other discrete industrial organizations (Mwacharo, 2013). Maintaining quality and reliable performance have become priority to production industries in order to gain customer satisfaction, as demand for the products increases (Gupta, Jain, Meena & Dangayachi, 2018). Companies have to define, measure, analyze, make improvements and effect control on their existing manufacturing systems to comply with market competition (Gupta et al., 2018). Different methods, approaches and tools are being used for continuous productivity and quality improvements (Gupta et al., 2018). Aside these, each company or production sector is required to use a proper selection or combination of different approaches or tools in its implementation process (Sokovic, Pavletic & Pipan, 2010). Down time and variations are inevitable in the course of production of any product, but the main goal of process management or process capability analysis in any organization is to investigate the causes of the down time during the production process of the product (Pearn & Chen, 1999). This aids manufacturing organizations to monitor and measure the potential of process (Wu, Kuo & Chen, 2004).

Continuous improvement of process is a key concept of total quality management (Chen, Lu, Wang, Jang & Dahlgaard, 2015), but other methodologies like re-engineering or automation, lean manufacturing will also give similar results of improved performance (Gupta et al., 2018).

Lean Manufacturing, a multidimensional production optimization approach that captures various management practices, aimed at wastes reduction and improving operational effectiveness (Roriz, Nunes & Sousa, 2017). The evidence of implementation of the approach in the manufacturing sector is not limited to quality and productivity improvement, but also considers non-tangible change factors such as initiation of supportive learning environment and developing leadership in the organization (Gupta et al., 2018). To this effect, companies now trend strategy for continuous improvements on quality of their products/services to retain customers in order to gain market share (Chen et al., 2015). During the last economic crisis breakout of 2008, there was serious destabilization in the global market as both consumer demand and industrial production fell (Saidul Huq, 2018). Companies, most especially the process related were left with massive quantities of inventories that could not be disposed as a result of the intensity of receding sales (Beacham, 2018), which led to serious reduction in industrial production especially in EU and USA (Saidul Huq, 2018). Figure 1 shows the industrial production volume rates between 2005-2016.

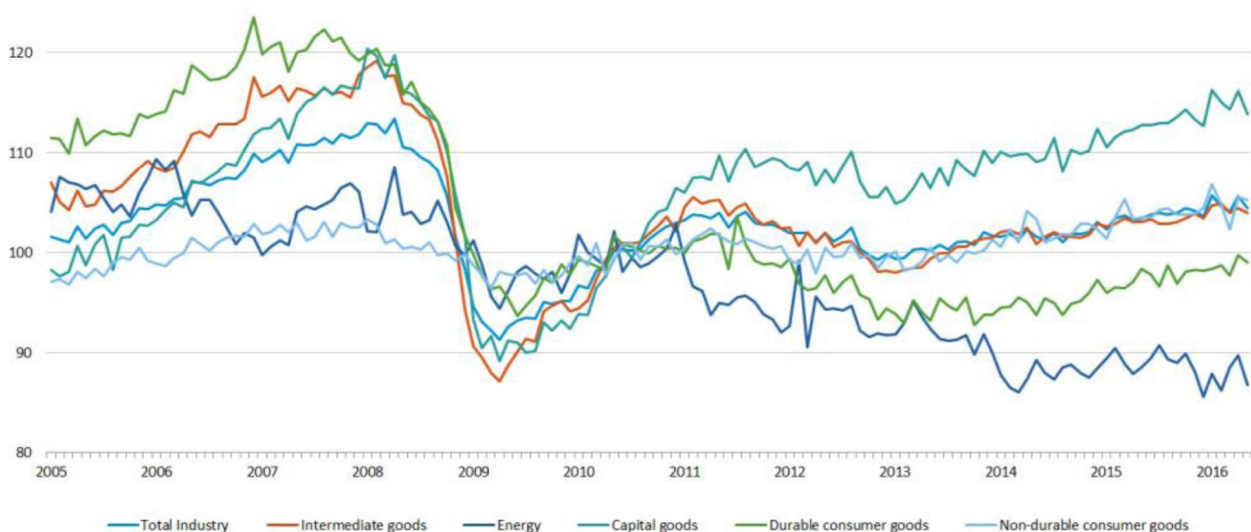


Figure 1. Industrial Production Volume rate between 2005-2016 (Eurosat, 2017)

In the last two years, a gradual rising trend is seen Atradius Conduction Team (ACT) (2018). As a result of the crisis, industrial focus was geared toward cost reduction by some radical means such as facility shutdowns, mergers and even quality reduction (Saidul Huq, 2018), instead of refocusing on production re-engineering with tilt improvement of process and operational characteristics towards Lean mode of production (Saidul Huq, 2018), elimination of wastes and enforcing quality at all stages (Anthony, 2018). Also, before 1980s, process industries were seriously facing the challenge of low productivity as a result of poor work standardization (Sayidmia, 2016). It was discovered that majority of the existing processes of production contained some non-value adding activities which invariably led to prolonged production cycle (Sayidmia, 2016). By eliminating the non-value adding activities from the processes and streamlining the workflow towards the finished product, can significantly optimize productivity (Harrington, 1996; Moser, Isaksson & Seifert, 2017). Due to globalization, customer satisfaction has become more prevalent to manufacturing companies, especially in the area of lead time which defines the time difference between the release of customer's order and delivery. Therefore, success and sustenance of businesses in the global market demand customer satisfaction in terms of short lead time and conformity in quality of products (Gaither, 1994; Moser et al., 2017). LSS model as proposed by Crawford (2004) has presented how Six Sigma can first be applied to improve the processes effectiveness followed by lean to improve the system efficiency. However, it is better to draw on both simultaneously to achieve the idea of integration. To succeed in integrating lean with Six Sigma, organizations need to adopt a holistic improvement method, where lean and Six Sigma mutually reinforce each other. An integrated approach is expected to include the use of a current state VSM as a platform for applying Six Sigma and lean tools, applying Six Sigma to adjust process parameters, integrating lean techniques into DMAIC and using future state VSM as a way to change the structure of the process. The integration of lean and Six Sigma is the solution to overcome the shortcomings of both, as they complete each other. The fusion of the two is the way for organizations to increase their potential improvements (Bhuiyan & Baghel, 2005). The integration of Six Sigma and lean help companies achieve zero defects and fast delivery at low cost. A more detailed description of this integration is needed in order for organizations to succeed in exceeding future customer demands.

There are several works reported on the use of lean six sigma by different authors which are not limited to manufacturing sector. In the study of Madsen, Risvik and Stenheim (2017), lean was implemented in the public sector of Norwegian municipality as a management tool for improving productivity and performance. Chiarini (2012) reported the use of lean six sigma as a tool for risk management and cost reduction of cancer drugs in health services. Furterer and Elshennawy (2011) also implemented lean six sigma in similar health sector to reduce linen loss in an acute care hospital. The use of lean six sigma in in-service sector for the improvement of productivity and performance were reported by Bazrkar, Iranzadeh and Farahmand (2017); Edgeman (2010); Lauren and Antony (2010); Meza and Jeong (2013); Rakusa (2016); Sanchez-Marquez, Guillem, Vicens-Salort and Vivas (2020). Lean six sigma, DMAIC approach was used to address non-compliance in quality of customer's specification in a computer design service system. The DMAIC approach was used to define the problem, measure the extent of the problem, analyze the problem to identify the root cause, find solutions to reduce the effects of the problems and finally sustain the improvements made (Bazrkar et al., 2017; Rameni & Banuelos, 2018). For successful implementation of six sigma, the understanding of barriers and motivations is pertinent (Hekmatpanah, Sadroddin, Shahbaz, Mokhtari & Fadavinia, 2008). Six-sigma is targeted to achieve perfection in every single process of a production (Narula & Grover, 2015). It means having less than 3.4 defects per million opportunities or a success rate of 99.99 %. In view of this, lean six-sigma is a method that permits organizations to review their existing status and guide in improvement decision via analysis of status (Erbiyik & Saru, 2015). This study aimed at assessing the contributions of Lean six sigma to production process optimization in AB Paper company with the objectives of minimizing the process defects in term of manufacturing wastes and optimizing the efficiency of the production process.

2. Methodology

The methodology adopted in the study is case study. This method illustrates how lean six sigma (LSS) is used to evaluate the existing production process in a paper company in Nigeria based on productivity and manufacturing wastes. The study also presented lessons learnt and managerial implications of LSS implementation. The case study method was chosen because it offered flexibility in design and implication by allowing both quantitative and

qualitative analyses, which are more sensitive to organization complexities phenomena (Krueger, Mellat, & Adams 2014; Merriam & Grenier, 2019; Sanchez-Marquez et al., 2020; Sunder & Mahalingam, 2018). A case study method offers a means of investigating complex and critical functions of the value chain (Ingason & Jónsdóttir, 2017; Vinodh, Kumar & Vimal, 2014). Another advantage of the method is it helps to make direct observations, collect data in a natural setting and compare so as to rely on the derived data (Ingason & Jónsdóttir, 2017; Sunder, Ganesh & Marathe, 2019). In this study, a real-time problem of customers' dissatisfaction was considered. The gathered data were based on machine functionality (up time, down time and cycle time), material and labour flow at every process stage of the production line. The assessment and optimization of the production process of the company were based on Lean tools like Value Stream Mapping (VSM), Process Cycle Efficiency (PCE), Kanban, Poka-Yoke, 5S, Pareto chart and analysis. These tools are valuable for diagnosing and resolving set of organizational problems (Bazrkar et al., 2017; Sunder et al., 2019). Qi Macros application embedded in Microsoft Excel is used to design the value stream mapping for the process value chain. The overview of the lean tools is presented thus:

2.1. Value Stream Mapping (VSM)

It is a Lean Manufacturing tool suitable for the analysis and design of the flow of materials/ information that is required to deliver products to customers (Roother & Shook, 2003). Also, it can assist in significant wastes reduction during production

2.2. Process Cycle Efficiency (PCE)

It is defined as the ratio of value-added time to total time of a process (Ying, 2011). This is expressed as equation 1

$$PCE = \frac{VDT}{TT} \times 100\% \quad (1)$$

Where:

PCE is the Process Cycle Time (sec)

VDT is the Value-Added Time (sec) (2)

TT is the Total Lead Time = VDT+NVDT

2.3. Takt Time

This is defined as time required to produce a sellable unit quantity of product (Rajenthirakumar, Mohanram & Harikarthik, 2011). This matches production against customer's demand. It is expressed as equation 2

$$T = \frac{T_a}{T_d} \quad (3)$$

Where;

T is the Takt Time (work time between two or more consecutive time t) (sec)

T_a is the Net time available to work

T_d is the Time demand (customer demand)

Note: net available time is the amount of time available for work to be done, which excludes the break time and other foreseen shutdown like scheduled maintenance, staff briefing and training.

2.4. Kaizen

This is a form of continuous improvement measure adopted by early Japanese companies which includes Kanban that can be termed as just-in-time (JIT) and POKA-YOKE

2.5. 5S

This is a workplace standardization philosophy by Japanese companies with 5 different words starting with S. These describe arrangement of workplace efficiency by identifying, sorting of items, maintaining the work area and sustaining the new order (David, 2010). The meaning of the 5S is stated below:

1. Sorting: Examine and eliminate all unnecessary tools, parts, and instruction
2. Setting in order: Arrangement of tools and machine parts in such a way that the needed ones are easily seen
3. Sweep: Make the workplace clean of any form of hazardous materials or event that can contribute to hazard.
4. Standardizing: Let there be a standard or general work procedures for all kinds of jobs
5. Sustenance: find the best way of maintaining and reviewing standard.

2.6. Pareto Chart and Analysis

This is a statistical technique that determines which few actions or processes contributed to the majority of the outcomes (Shingo, 1989; David, 2010; Dash, 2020). The data analyzed is then translated into bars arranged in either ascending or descending order using excel software (Hart & Hart, 1989).

3. Case-Study Background

This case study was undertaken in a paper production company managed as Private Limited Liability Company. The organization was established in 2015 as a printing and publishing company, located in the South-West province in Nigeria. The company is made up of five (5) functional Departments namely; Central Account, Production, Marketing, Logistics and Procurement with a total of seventy (70) staff. The production Department takes about 50 % of the entire labour force of the organization. The company receive, process and make deliveries of orders on a daily basis, up to an average of fourteen thousand (14, 000) pieces/order. Figure 2 shows the value chain of the production line. Value chain gives idea that a production system comprises of other subsystems, each with input, transformation process and their respective output (Michael, 1985; Sayidmia, 2016). It is a systematic approach to examine the development of competitive advantage (Sayidmia, 2016). The stages that represent the value chain of AB production line are described below:

1. Concept Visualization: this is the conceptual design of the text and graphic, which involves strategic and creative work, as well as finalization of the idea and approval of the conceptual design.
2. Design/ Plate cutting: this involves the creation of the image and text in the real form on the plate using software.
3. Printing: this is the impression of the text and image from the plate to a paper in hard form.
4. Cutting /Trimming: this is the removal or dressing of the offset of the printed paper in preparation for folding.
5. Folding: this is the arrangement of the printed sheet pieces in pages.
6. Stitching/Gluing: this involves the bringing together of the printed sheet piece in pages. It can also be bond adhesive.
7. Finishing: this is the final stage of book development where the book is examined for any process error from the previous stages and preparation for delivery.

The case organization shows little or no compliance to lean manufacturing, thus providing opportunity for academia-Industry collaboration (Sunder & Mahalingam, 2018).

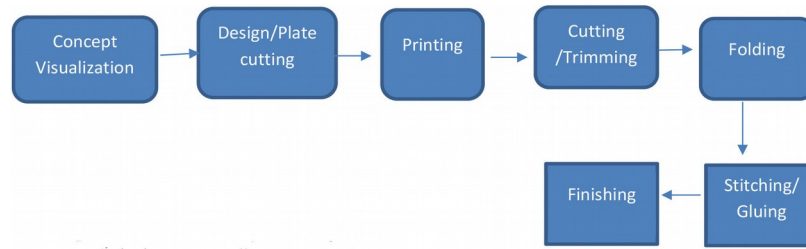


Figure 2. Value Chain of AB Production line

3.1. Business Case

In the bid to maintain a good customer-client relationship by the management of the organization, there is a need to improve on the production process efficiency, lead time and takt time. Also reduce the manufacturing wastes in terms of percentage down time, number of non-conforming products and degree of labour flow. The management decided to engage lean six sigma practitioners to evaluate the current production process of the company. The lean six sigma team comprise] a post-doctoral researcher that specialized on quality management and a senior lecturer in the University who is also a Black Belt certified. The team engaged in company’s document review and one-on-one interview with some selected customers and staff from the production Department. These were further supported by self-observation on the production floor for a period of three months to understudy the production processes.

4. Results

This section presents the results of the lean six sigma assessment of the company before and after implementation of Lean six sigma tools.

4.1. Present Value Stream Mapping of AB Production Line

The existing Value Stream Mapping of AB production line is revealed from different activities which emanated from different stages of operations. The data necessary to develop the existing Value Stream Mapping were presented in Tables 1 and 2 with other important data like number of operators (O), assistant operator (AO), and staff (S) were presented. The estimation of the completion of the existing Value Stream Mapping involved the introduction of timeline at the tail end of the map, recording the value added and non-value-added time. Consideration was given to machine running operations.

The present Value Stream Mapping of AB production line shows the flow of order, raw materials, labour, information, Value-Added Time and Non-Value-Added Time. It aids in the computation of the required processes and their respective cycle time, up time, customer order and batch sizes. By examining the present Value Stream Mapping of the production line, the question of number of labour required at each unit, levels of value added time, non-value-added time and any improvement measure to be carried out should be asked as these would help to determine Process Cycle Efficiency, lead time and takt time. Figure 3 shows the present Value Stream Mapping of AB paper production line which was actually managed by three (3) representatives. Orders were received from customers for production to commence. As observed, there are so many Non-Value-Added Time reflected from each unit of the production line which are quantified in the form of up and down time. The implementation of lean tools and six-sigma are expected to improve on the Non-Value-Added Time while the total labour also cut down.

Run	Design/ Plate Cutting			Printing			Cutting/Trimming			Stitching/Gluing		
	UT	CT	DT	UT	CT	DT	UT	CT	DT	UT	CT	DT
1	2250	2880	630	1764	2880	1116	3346	4680	1334	2064	2880	816
2	1980	2880	900	1680	2880	1200	2880	4680	1800	1980	2880	900

Note: CPT Machine speed: 750 rpm; Curd 64 and G70 Machine speed are 500 and 245 rpm respectively; Cutting machine speed: 100 pieces/min; 3,500 pieces/batch

Table 1. Existing Down Time, Cycle Time, and Up Time (All time in seconds)

S/N	Processing Stage	Average VDT (Sec)	Average NVDT (Sec)
1	Concept Visualization	1000	25000
2	Design/Plate Cutting	900	2500
3	Printing	1780	350
4	Cutting/Trimming	2400	720
5	Folding	50	1300
6	Stitching/Gluing	1500	1100
7	Finishing	2500	2100
	Total	10130 (23.4%)	33070 (76.6%)

Table 2. Existing Value Added and Non-Value-Added Time of the production line

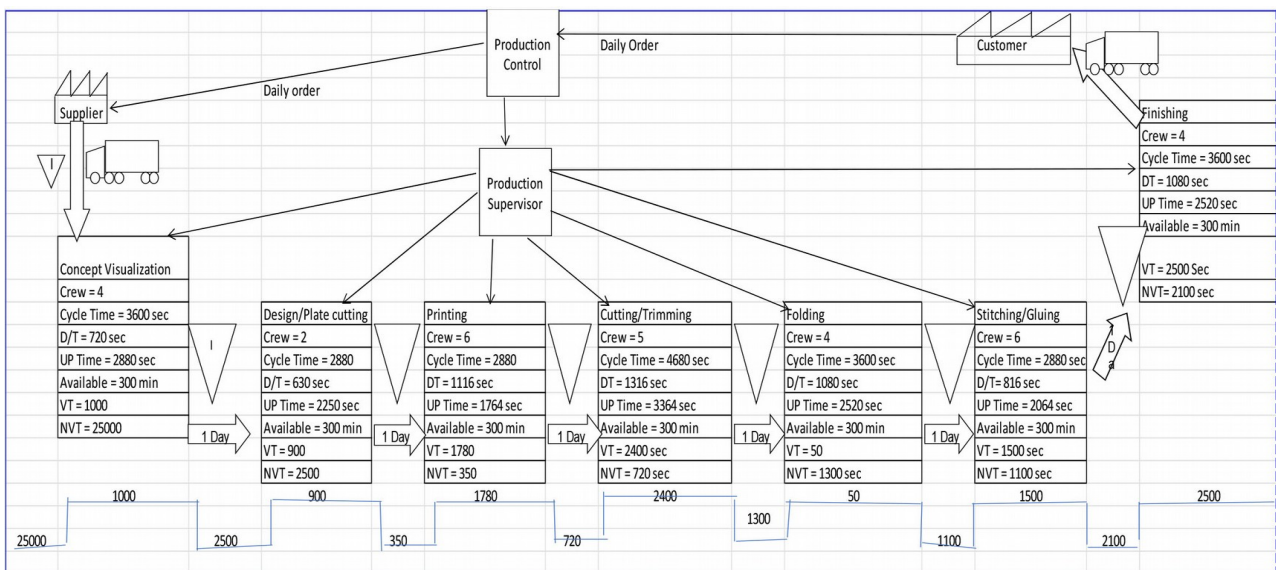


Figure 3. Present Value Stream Mapping of AB Production line

4.2. Present Process Cycle Efficiency of AB Paper Production Line

Value Added Time = 10130 seconds

Non-Value-Added time = 33,070

$$\text{Present Lead Time} = \text{Value Added Time} + \text{Non-Value-Added time} \tag{4}$$

$$= 10130 + 33070 = 43200 \text{ seconds} \tag{5}$$

$$\text{Process Cycle Efficiency} = \frac{\text{Value Added Time}}{\text{Lead Time}} \times 100\% = 23.4\% \tag{6}$$

From the above calculation, it is estimated that production cycle efficiency (PCE) is 23.4 % which falls below benchmark of 25 % (Ying, 2011), while the present lead time is very high.

4.3. Present Takt Time of AB Paper Production Line

The present takt time of the production line was calculated to be 4.11 sec/piece i.e, production of salable unit of product takes 4.11 sec. This is presented in the Table 3 which is expected to increase by implementation of lean tool and six-sigma.

S/N	Description	Time (min)
1	Working shift/day	2 shifts
2	Hours/shift	10 hours
3	Available time/ shift	600 min
4	Set up time/shift	30 min
5	Lunch time/shift	30 min
6	Planned shut down time/shift	60 min
7	Net-working time /shift	480 min
8	Net available time/day	57600 seconds
9	Customer demand/day	14000 pieces/day
	Takt Time	4.11 sec/piece

Table 3. Present Takt time of AB Paper Production line

4.4. Present Manufacturing Waste in the AB Production Line

Three major wastes were observed in AB production line namely: non-conforming products, waste of time (down time) and undue motion of labour.

4.4.1. Estimation of Non-Conforming Products

The estimation of non-conforming products is presented in Table 4. The basis of the estimation is based on the conformity of the production six sigma standard. The consideration was given to machine running process stages.

Process Stage	Total order Pieces	No piece/ day	No Pieces/ batch	Rejected piece/ batch	Average Rejection/ day	Rejection/Mi llion opportunities	Gap at six sigma Level $x \leq 34,000 \leq 6^s$
Design/Plate cutting	380000	14000	3500	150	155	43400	-9400
				160			
				140			
				170			
Printing	380000	14000	3500	190	228	63840	-29840
				250			
				230			
				240			
Cutting/Trimming	380000	14000	3500	25	47	13160	20840
				50			
				72			
				40			
Gluing/Stitching	380000	14000	3500	100	122	34160	-160
				120			
				128			
				140			

Table 4. Estimation of Non-Conforming Products

From Table 4, the total customers' orders were 380000 pieces for a given period in a month, which was reduced to 14000 pieces per day. Four batches in two shifts were taken per day to give 3500 pieces per batch. Data on non-conforming products per batch was collected for the machine processing stages. From the estimation of

rejection per million opportunities, all production stages were non-compliant to six sigma standard except that of trimming/cutting stage. The production from the printing section shows the highest degree of non-compliance with gap of 29840 pieces per million while gluing/stitching section had the least degree of rejection with a six-sigma gap of just 160 pieces per million.

4.4.2. Estimation of Percentage Down-Time in AB Production Line

The estimation of present down time in AB production line is presented in Table 5 which revealed the total idle time in a given period of a month for the production of customers’ orders. Consideration is also given to machine running process stages.

Unit	Causes of the Down time	Down Time (sec)	Average Down Time	Cycle Time (sec)	% Down Time	Machine
Design/Plate Cutting	Plate Damage	630	765	2880	26.6	Computer-To-Plate
	Poor Impression on plate	900				
Printing	Plate Misalignment	1116	1158	2880	40	Curd 64/G70
	Ink Wetting	1200				
Cutting/Trimming	Machine break down due power source	1334	1567	4680	33.5	Minabmda
	Job Misalignment	1800				
Gluing /Stitching	Skipped Stitches	816	858	2880	30	Polar-Motta 90
	Variable Stitch Density	900				
	Overall Down Time		4348	13320	32.64	

Table 5. Estimation of Percentage Down-Time in AB Production line

The percentage down time in AB production line is 32.64 %. Which means about one-third of the production cycle time goes into idle time which also contributed to very low process cycle efficiency.

4.4.3. Pareto Analysis of Down-Time in AB Production Line

Figure 4 presents the Pareto Chart of the down time of AB production line. From Figure 4, it can be deduced that about 90 % of the down time of the production line was as a result of ink wetting. Plate misalignment and job misalignment contributed between 80-90 % of the down time, poor printing impression and variable stitch density also contributed about 70 %, machine breakdown due to power failure and skipped stitches contributed 60 % to the down time, while about 50 % of the down time was caused by plate damage.

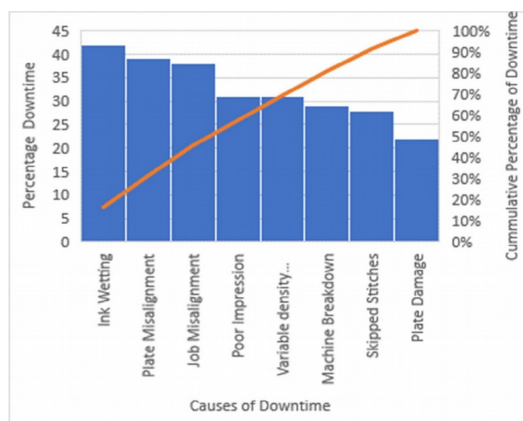


Figure 4. Pareto Chart of the Down Time of AB Production Line

4.4.4. Estimation of Present Labour in AB Production Line

The data presented for present labour force in AB production line is shown in Table 6. According to lean manufacturing principle, over flowing of labour in the production line is termed as waste.

From table 6, the total labour in the production line is 33, where printing and stitching section has the highest number of work with staff strength of 6.

S/N	Production Stage	No of Operator (O)	No of Assistant Operator (AO)	No of Co-Worker (CW)
1	Concept Visualization	1	1	3
2	Design/ Plate cutting	1	1	1
3	Printing	1	1	4
4	Cutting/ Trimming	1	1	3
5	Folding	0	0	4
6	Gluing /Stitching	1	1	4
7	Finishing	0	0	4
	Total	5	5	23

Table 6. Present Labour of AB Production line

4.5. Implementation of Lean Tools in AB Production Line

There are some improvements points which differ by production stages in the present Value Stream mapping. Delay and sometimes insufficiency of raw materials were reported by the production supervisor thereby increasing the non-value-added time. Kaizen in terms of Kanban and POKA-YOKE as continuous improvement measures was recommended. At every stage of the production processes was 5S recommended due to high level of non-value-added times observed due to poor standardization, lack of proper arrangement of tools and machine parts. Sorting and sweeping of the shop floor to eliminate all unnecessary tools and parts or hazardous materials were not properly done. The present value stream mapping of AB production line with improvement points is presented in the Figure 5.

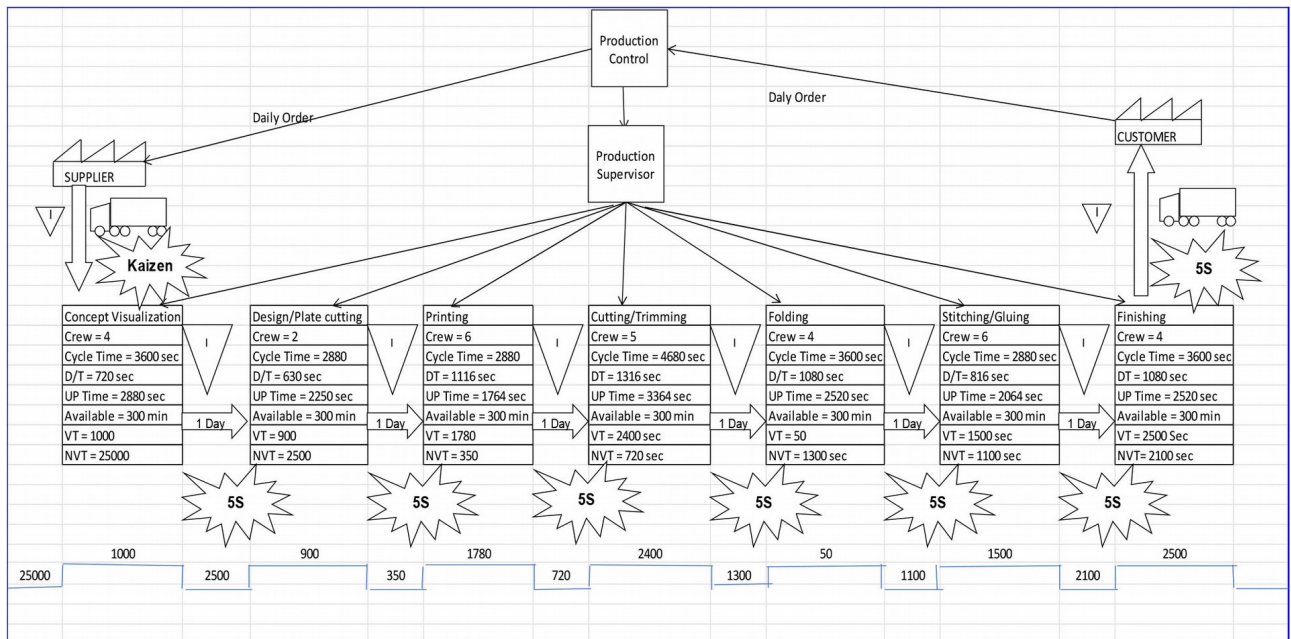


Figure 5. Present VSM of AB Production line with Improvement Point

4.6. Improved Value Stream Mapping of AB Production Line

The future value stream mapping of AB production line, after careful observation and implementation of some lean appropriate tools reflected improvements in Value Added time and Non-Value-Added time. This is presented in Table 7.

From Table 7, there is a decrease in non-value-added time to approximately 60 %. Figure 6 shows improved value stream mapping of AB production line

S/N	Processing Stage	Average VDT (Sec)	Average NVDT (Sec)	% Reduction in NVDT
1	Concept Visualization	1000	12500	50
2	Design/Plate Cutting	900	1250	50
3	Printing	1780	175	50
4	Cutting/Trimming	2400	144	80
5	Folding	50	268	80
6	stitching/Gluing	1500	220	80
7	Finishing	2500	428	80
	Total	10130(40.3 %)	14985(59.7 %)	

Table 7. Future Value Added and Non-Value-Added Time of the production line

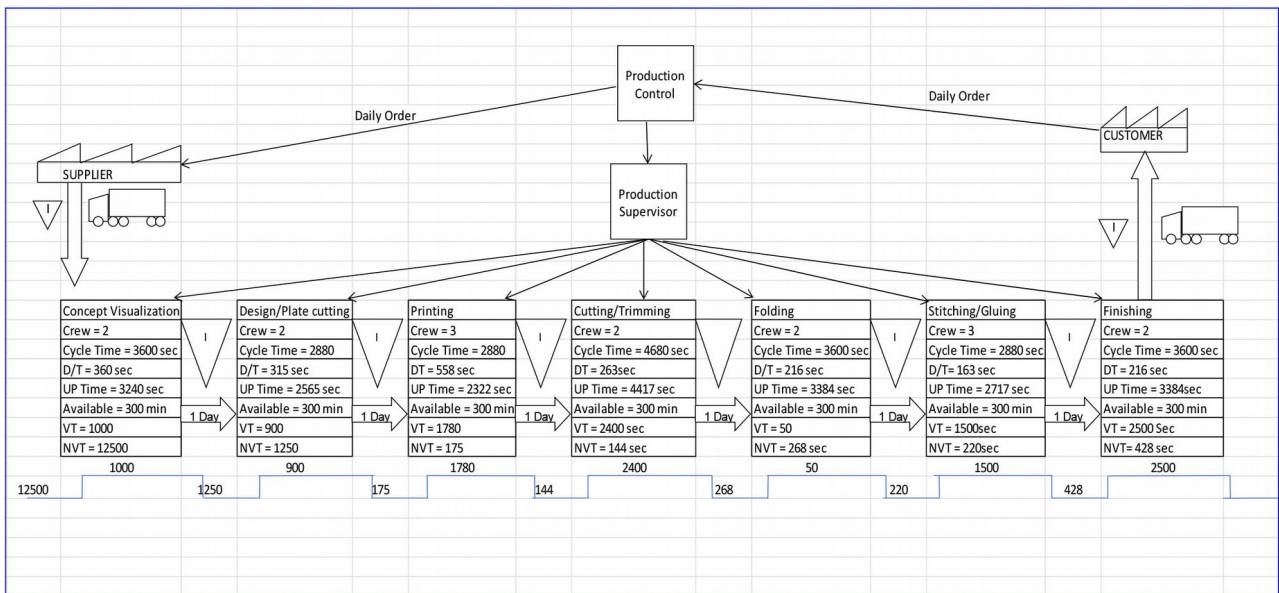


Figure 6. Improved Value Stream Mapping of AB Production Line

4.7. Improved Process Cycle Efficiency (PCE) of AB Production Line

The process cycle efficiency of AB production line after proper implementation of lean tools and six sigma methodologies is estimated to be approximately 40 %. This also impacted on the lead time to drastically reduce to 25115 seconds.

Value Added Time = 10130 seconds

Non-Value-Added time = 14985

Improved Lead Time = Value Added Time + Non-Value-Added time

(7)

$$= 10130 + 14985 = 25115 \text{ seconds} \quad (8)$$

$$\text{Process Cycle Efficiency} = \frac{\text{ValueAddedTime}}{\text{LeadTime}} \times 100\% = 40\% \quad (9)$$

4.8. Improved Takt time of AB Production Line

The takt time of AB production line after the implementation of lean tools and six sigma approaches is seen to increase from 4.11 seconds/piece to 4.71 seconds/piece. Table 8 shows the improved takt time.

S/N	Description	Time (min)
1	Working shift/day	2 shifts
2	Hours/shift	10 hours
3	Available time/ shift	600 min
4	Set up time/shift	10 min
5	Lunch time/shift	10 min
6	Planned shut down time/shift	30 min
7	Net-working time /shift	550 min
8	Net available time/day	66000 seconds
9	Customer demand/day	1,000 pieces/day
	Takt Time	4.71 sec/piece

Table 8. Improved Takt time of AB Production line

4.9. Improved Manufacturing Wastes in the AB Production Line

The three (3) wastes that were observed in AB production line after implementation of lean tools and six sigma approaches were non-conforming products, down time and undue motion of labour.

4.9.1. Improved Estimation of Non-Conforming Products

The improved estimation of non-conforming products is presented in the Table 9. The basis of the estimation is based on the conformity of the production to six sigma standards. The consideration was given to machine running process stages.

Observations from Table 9 showed that rejection piece per batch of non-conforming products have reduced to the barest minimum after the implementation of the lean tools and six sigma methodologies. The table showed that all the machine running processes now conformed to six sigma standard as their rejection per million opportunities are less than 340000 pieces.

Process Stage	Total order Pieces	No piece/ day	No Pieces/ batch	Rejected piece/ batch	Average Rejection/ day	Rejection/ Million opportunities	Gap at six sigma Level $x \leq 34000 \leq 6^{\sigma}$
Design/Plate cutting	380000	14000	3500	70	75	21000	13000
				79			
				70			
				80			
Printing	380000	14000	3500	92	113	31640	2360

Process Stage	Total order Pieces	No piece/day	No Pieces/batch	Rejected piece/batch	Average Rejection/day	Rejection/ Million opportunities	Gap at six sigma Level $x \leq 34000 \leq 6^{\sigma}$
				125			
				116			
				118			
Cutting/Trimming	380000	14000	3500	25	47	13160	20840
				50			
				72			
				40			
Gluing/Stitching	380000	14000	3500	20	25	7000	27000
				24			
				26			
				28			

Table 9. Improved Estimation of Non-Conforming Products

4.9.2. Improved Estimation of Down Time in AB Production Line

The improved estimation of down time is presented in the Table 10. The consideration was given to machine running process stages.

The percentage improvement in the down time in the production line is approximately 11 %.

Unit	Causes of the Down time	Down Time (Sec)	Average Down Time	Cycle Time (sec)	% Down Time	Machine
Design/Plate Cutting	Plate Damage	315	383	2880	13.3	Computer-To-Plate
	Poor Impression on plate	450				
Printing	Plate Misalignment	558	579	2880	20	Curd 64/G70
	Ink Wetting	600				
Cutting/Trimming	Machine break down due power source	267	314	4680	6.7	Minabmda
	Job Misalignment	360				
Gluing /Stitching	Skipped Stitches	163	172	2880	5.9	Polar-Motta 90
	Variable Stitch Density	180				
	Overall Down Time					

Table 10. Estimate of Improved Down Time in AB Production Line

4.9.3. Improved Estimation of Labour in AB Production line

The data presented for improved labour force in AB production line is shown in Table 11. According to lean manufacturing principle, over flowing of labour in the production line is termed as waste (Sayidmia, 2016).

From Table 11, the total labour in the production line has reduced to 16 after the implementation of lean tools and six sigma methodologies. Printing and stitching section have the highest number of works with staff strength of 3 each.

S/N	Production Stage	No of Operator (O)	No of Assistant Operator (AO)	No of Co-Worker (CW)
1	Concept Visualization	1	1	0
2	Design/ Plate cutting	1	1	0
3	Printing	1	1	1
4	Cutting/ Trimming	1	0	1
5	Folding	0	0	2
6	Gluing /Stitching	1	1	1
7	Finishing	0	0	2
	Total	5	4	7

Table 11. Improved Labour of AB Production line

4.10. Gap Analysis between Present and Improved States

The gap analysis of the present and improved states of the AB production line, after the implementation of lean tools and six sigma methodologies was carried out through brainstorming session by the LSS team. The root causes and effects analyses of the problems was done using Ishikawa Diagram as presented in Figure 7, so as to design improvements and subsequent controls (Gupta et al., 2018; Roriz et al., 2017; Sokovic, 2010). The causes were grouped into four main categories, namely: work organization, machine, method and man.

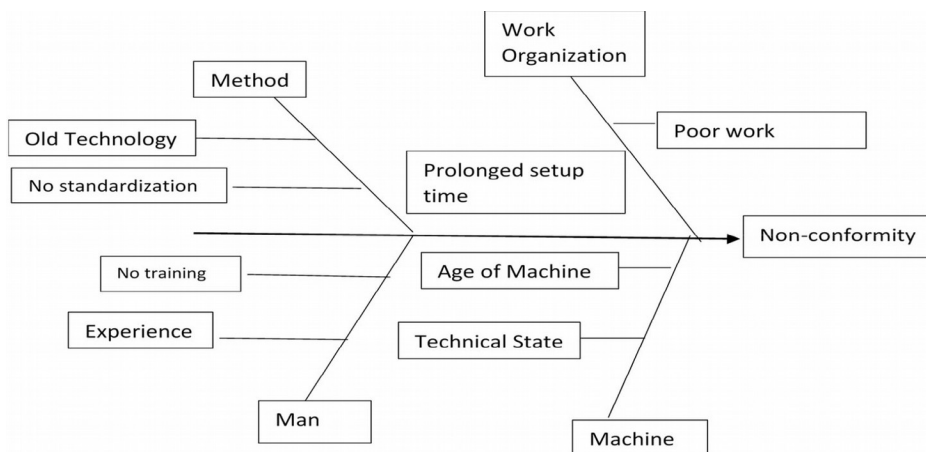


Figure 7. Root Causes and Effects Diagram of the Problems in AB production Line

5. Results Discussion and Lessons Learnt

The detailed analyses of the root causes of the problems, improvements strategies and lessons learnt were discussed in this section.

5.1. Analysis on Process Cycle Efficiency (PCE)

It is deduced from the results that PCE before implementation of lean six sigma (LSS) was 23 %, which improved to 40 % after the implementation of LSS. This is linked to too many non-value-added time incurred most especially during non-machine running operations like concept visualization, design/plate cutting and finishing. The excess non-value-added time did prolong the production lead time which invariably impacted the PCE negatively below the minimum standard of 25 %. The problem of low PCE is traced to process method and work organization. It is observed that operators handling the processes used wrong methods due to less experience on the job. Also, insufficient implementation of control system was found in the organization. The poor control system resulted in attitudinal behavior of the operators. The improvement of PCE was achieved by implementation of kaizen (continuous improvement) on all the processes. It is systematic approach to improving efficiency and quality by gradual or incremental changes (Michael, 1985; Fled, 2000). The implementation of kaizen reduced unnecessary

inventory, reduced production lead time and non-conforming products in the production floor. Also, implementation of kaizen involves intermittent training and re-training of the operators for skills and multi-skills on the job. Operators were made to understand the importance of team work. Another lean tool implemented to improve PCE in AB production line is work standardization. It is used to organize the production processes in such a way that they were being executed in the most effective way (Ahmed et al., 2018) by achieving accurate line balancing, minimizing undue work in process and serious reduction in non-value-added activities especially in the non-machine running processes (Belokar, Kumar, & Khars, 2012). The strategic framework for Kaizen implementation is shown in Figure 8, which was basically designed for 5S implementation. It required good management vision which involved plan of constituting team.



Figure 8. Strategic Framework for Kaizen Implementation

5.2. Analysis on Takt Time

Takt time as described by Rajenthirukumar et al. (2011) is the time required to produce a sellable unit quantity of the product, which is a function of net available time to work. Comparing table 3 and 8, which show the estimations of takt time before and after implementation of LSS, it was observed that takt time before and after LSS was 4.11 and 4.71 sec/piece, respectively. This shows more net available time to meet up with customers' demands after implementation of LSS. The problem of low takt time can be linked with three (3) factors of setup time/shift, lunch time/shift and planned shutdown time/shift especially on the machine running processes. These were all traceable to poor work organization as root cause. It was observed that the operators spent more time than necessary on these three factors, which constituted more non-value-added times and invariably impacted on the net available time to meet up with customers' demands. Low productivity of the operators especially with machine running processes is observed to be too much time allocated for planned shutdown and other factors. This is traceable to predisposition of the workers linked to motivation at work. This reflected on the number of product piece per shift. The improvement on the takt time was achieved by implementation of LSS tools of Total Productive Maintenance (TPM), 5S and Single Minute Exchange of Die (SMED) (Bhadury, 2000; Sayidmia, 2016). The TPM was useful in minimizing setup time and planned shutdown time which were purposely designed for

change-over of production order, corrective and preventive maintenance (Sayidmia, 2016). The lean tools and six sigma approaches encouraged maintenance by all operators involved with machines (Decentralized Maintenance). Its took care of the reliability of the equipment on the production floor (Sayidmia, 2016). Therefore, implementation of LSS reduced unnecessary down time of operation. Figure 9 show strategic framework to total productive maintenance which may involve training of operators and staff, decentralization of duties and other components of total productive maintenance must be implemented at all stages of production, most especially machine running processes. There should be monitoring and evaluation team on ground to ensure proper implementation and also giving feedback.

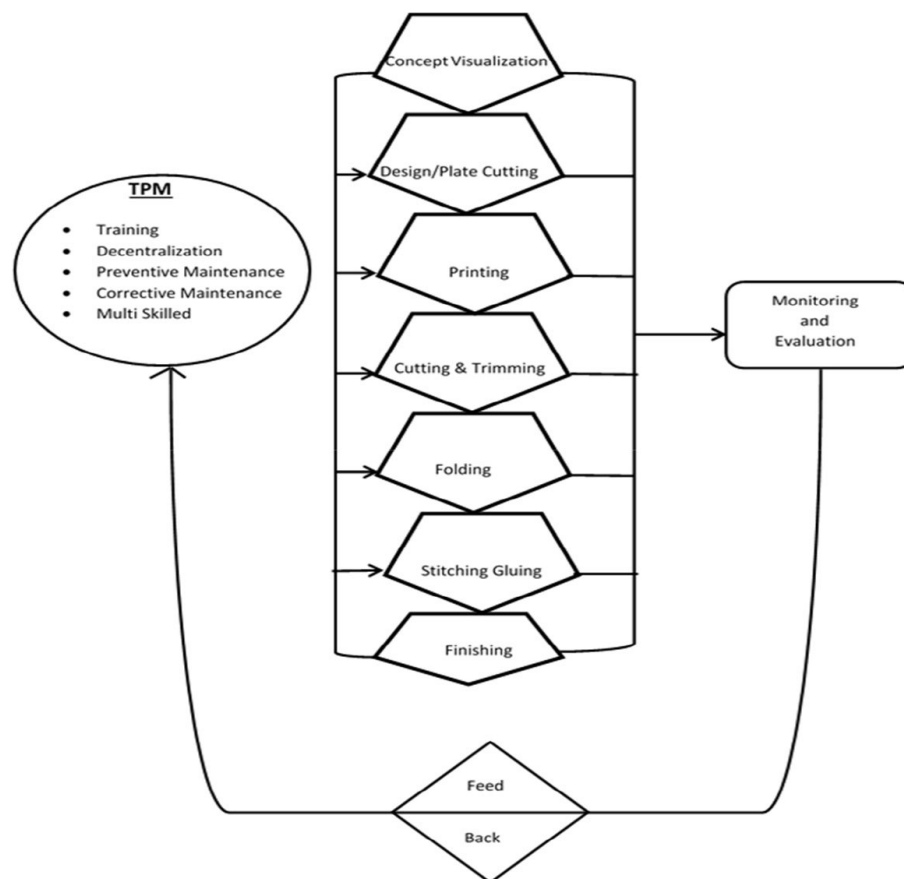


Figure 9. Strategic Framework for Total Productive Maintenance for AB production Line

5.3. Analysis of Manufacturing Wastes

The three major production wastes to be discussed are: non-conforming products, percentage downtime and over flowing labour as presented in Tables 4, 5 and 6, respectively. The improvements in the manufacturing wastes after implementation of LSS is presented in Tables 9, 10 and 11, respectively. Comparing Tables 4 and 9, it was observed that high quantity of non-conforming products existed before implementation of LSS in all the machine running operations with printing section having the most defected pieces. Also, percentage down time before and after implementing LSS were estimated as 32.64 % and 11 %, respectively as presented in Tables 5 and 10 in which printing section contributed the highest percentage down time. The third category of manufacturing waste was the overflowing labour which was estimated at 33 and 16 for before and after LSS, respectively. The major sources of the problems of manufacturing wastes in the production line emanated from the printing section and it can be linked to machine, man, method and work organization as the root causes. The technical state or depreciation levels of the machines were diagnosed. This caused generation of defected pieces and incessant breakdown of the machines, adding to frequency of down time and prolonged production cycle time, especially for G70 machine. Lack of standard procedure or clear instruction and manual guide on the usage

of the machines for operators majorly affected G70 machine. Deficiency in the technical know-how of the operators of Curd 64 machine contributed to the frequency of defective pieces as it required specialized skills. Operators needed to be guided on how to choose formats of orders to make processes much more effective. No special training for operators except some verbal obligatory safety advice. The improvement on the manufacturing wastes was achieved by implementation of LSS approaches of TPM, kaizen, standardization of work, inventory management, 5S and six sigma methodology of DMAIC. TPM is a suitable approach for the improvement problem because it's a man-machine based problem in production. TPM is a holistic approach to maintenance that involves three components namely; preventive, corrective and maintenance prevention (Sayidmia, 2016; Abdulmalek, Rajgopal & Needy, 2006). This actually take care of the unnecessary down time and prolonged shutdown of machines. Kaizen, 5S (sort, setting, sweep, standardize and sustenance) implementation take care of high rate of defective products. Work standardization and inventory management monitor and control the inventory of staff to curtail over staffing.

6. Conclusion and Implications

This article has contributed towards the implementation of lean methodology in process industry. Application of LSS in this case has been able to solve real-time problems of productivity and manufacturing wastes which have direct implications on customers' satisfaction. It has also presented some theoretical and empirical implications by establishing a lean frame work for process industries when it has to do with improvement of real-time lean problems as listed:

1. Challenge of poor process cycle efficiency or productivity is improved from 23 to 40 % by implementation of Kaizen and work standardization.
2. Challenge of manufacturing wastes is solved by improving on quantities of non-conforming products to conform to six sigma standard, reduced the level of down time from 32.6 to 11 %, and over staffing from 33 to 16 thereby saving cost on labour inventory by implementation of total productive maintenance (TPM), work standardization, inventory management and six sigma methodologies like 5S, DMAIC and DMADV.
3. The application of LSS in the presented case-study is an indication that it can be successfully adapted to other process metrics like quality, responsiveness, total turnaround time and so on.
4. Involvement of an expert with black Belt certified alongside with University Faculty resource and quality management students was a leverage during the execution of the project. In view of this, academic-industry collaboration is encouraged.

6.1. Limitations

1. This article has practically and in no doubt contributed to the body of knowledge in the field of LSS with focus to manufacturing sector. Nevertheless, it presents a single case organization which may not be substantial for generalization.
2. The lesson learnt and implications presented can still be further validated using some lean based simulation software.

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