E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 186–195.

Paper Type: Research Paper

Implementation of Lean Six Sigma Methodology in a Refractory Company

Ayyappan Solaiyappan[1,*]

[1] Department of Mechanical Engineering, Government College of Technology, Coimbatore-641013, Tamilnadu, India; ayyappansola@gmail.com.

Citation:

Solaiyappan, A. (2023). Implementation of lean six sigma methodology in a refractory company. *Journal of applied research on industrial engineering, 10*(2), 186-195.

Received: 29/11/2021 Reviewed: 03/01/2022 Revised: 10/02/2022 Accept: 18/03/2022

Abstract

To enhance the manufacturing process capability of a refractory company, the scope for implementing the Lean Six Sigma (LSS) methodology is analyzed in this work. The DMAIC methodology of Six Sigma is used in this project to determine the Critical To Quality (CTQ) characteristics, defining the possible causes, identifying the variation in sources, establishing the variable relationships, and implementing the control plans. It was found from the DMAIC approach that the quality of Raw Crude, Water Content, and the frequency of using temperature Calibration equipment are the main factors responsible for lowering productivity in Shaft kiln. To improve the productivity of kiln, it was suggested to process the raw crude free of mud, remove the moisture content present in the magnesite stones and take action on changing the frequency of measuring the oil feeding calibration equipment.

Keywords: Lean six sigma, DMAIC, Refractory, Kiln Shaft, Lean manufacturing.

1 | Introduction

Six Sigma methodology includes a set of process improvement techniques and tools which was introduced by Engineer Bill Smith at Motorola Company in 1986. Six Sigma seeks to improve the quality of the product/process by identifying and minimizing the causes of defects and minimizing the variability in manufacturing and business processes. It mainly uses a set of quality management methods such as empirical and statistical tools. Each Six Sigma project is carried out with an organization following a defined sequence of steps and specific targets. Achieving a Six Sigma level means to have a process that generates outputs with 3.4 Defects Per Million Opportunities (DPMO) [1], [2]. Six Sigma is now widely accepted as a high-performing strategy for driving out the defects from the company's quality system. Lean Six Sigma (LSS) concept is the integration of two quality management tools such as Lean Manufacturing (LM) and Six Sigma [3]. LSS attempts to reap the scope and size of improvements that can be achieved by both concepts together.

Therefore, it is an integrated system of LM and Six Sigma. However, some would perceive LSS as two different concepts which are adapted in parallel [4]. The integration between the two quality management concepts varies depending on applications, tools, ideas, and philosophies. Therefore, it

Corresponding Author: ayyappansola@gmail.com

https://doi.org/10.22105/jarie.2022.317347.1403

leads to many theories on how LM and Six Sigma could be integrated. LM focuses on the reduction of non-value-added activities in production while Six Sigma focuses on the reduction of process variation [5]. The integration would take into account the strength and weaknesses of each concept to make a better concept. The Define, Measure, Analyze, Improve and Control (DMAIC) methodology is used to express the quality performance data expressed as the percentage defect rate that can be converted into a wide range of vital Six Sigma metrics for the development of the company's quality system [6], [7]. In this line, Lean and Six Sigma tools have been successfully implemented in various organizations to reduce its operating costs and increase productivity [8], [9]. Six Sigma methodology was applied successfully to reduce the bearing end plate reworks in a machining process [10]. This methodology was also implemented in the pulp drying process to reduce the dry content variation [11]. The different industrial sectors that include aviation, iron ore manufacturing, printing, rubber gloves manufacturing, extrusion process, grinding, automotive, oil and gas sectors, etc. were experimented with LSS tools and found successful [12]-[21]. Health care, educational industries, IT, and financial sectors also benefitted from this tool [22]-[30]. But no report exists on the implementation of LSS in refractory companies. This motivates to explore the application of LSS to determine the significant process factors capable of obtaining better productivity. LSS utilizes the DMAIC methodology to achieve effective results.

2 | Need for a Case Study in a Refractory Company

The case organization is the small-medium refractory enterprise. It operates in the entire value-chain from the extraction of raw crude (Magnesium Carbonate) from the mines to the finished Magnesium Oxide (MgO) Crystal powders and fire-resistant bricks that are exported to the various needy industries. The main aim is to improve the productivity of the Shaft kiln. In this context, the productivity of the kiln alternatively refers to the conversion of Magnesite (Magnesium Carbonate) bricks to get converted into lightly calcined magnesite. The factors that contribute to the decrease in productivity of the Kiln are analyzed crucially by implementing the LSS framework and the study is continued in the following sections.

3 | Need for a Case Study in a Refractory Company

3.1 | Define Phase

This phase focuses on process understanding of the current reality. Based on the analysis of historical data and assessment of the present situation of the company, the following problems were identified:

I. The decreased productivity of Shaft kiln in the works department due to the various factors is identified as the main problem.
II. Raw crude that comes from the mines is mixed with mud of nearly 25%-30%.
III. More time is consumed due to man-power loading and unloading.

Table 1 shows the statistical capability of the process of the company. It was assessed based on the past functioning of the company. These details are set as the statistical target for the present study.

Table 1. Statistical capability of the process.

Factors	Statistical Quantity
Maximum production capacity	27.5 Tons/day
Current production capacity	14.0 Tons/day
Current defects rate	7.693Tons/day
Opportunity of the defect (per unit)	1
DPMO	549500
Sigma Level	1.376

3.1.1 | Voice of customer

To determine the Critical to Quality Characteristics (CTQs) of this process, the Voice of Customer (VOC) tool was used. Raymond Mill is their important internal customer. The responses from the Raymond mill are observed as a part of the VOC study. The objective was to identify the parameters for low productivity in the kiln that aims to deliver good quality MgO crystals to Raymond mill. The details of VOC outcomes are presented in *Table 2*. Thus, the factors which emerged out of VOC were raw crude extracted from the mines, man-power loading and unloading time, rain duration, water/moisture content, temperature, and oil feeding calibration equipment.

Table 2. VOC outcomes.

Customer	Observations	Key CTQs	Relevancy to the Project
Shaft kiln	Mud mixed Magnesite crude coming from the mines	20-30% Mud mixed crude	Yes
Raymond mill	Time to load and unload the magnesite stones into the kiln	Loading and Unloading time	Yes
Raymond mill	High variation in moisture content	2-2.2% moisture content	Yes
Raymond mill	It is important to note the temperature and oil feeding at regular intervals to monitor the Kiln temperature.	Need for temperature and oil feeding calibration equipment	Yes

3.1.2 | SIPOC model for process mapping

In this phase of the research, the key metrics of the project were identified, the data collection process was developed and executed. This was done to understand the process in detail. This includes the macro as well as the micro-level of process mapping. The macro-level mapping was done using Suppliers, Inputs, Process, Output, Customers (SIPOC) concept. SIPOC provides important inputs to monitor products and services provided for customer satisfaction. The VOC outcomes are shown in *Fig. 1*.

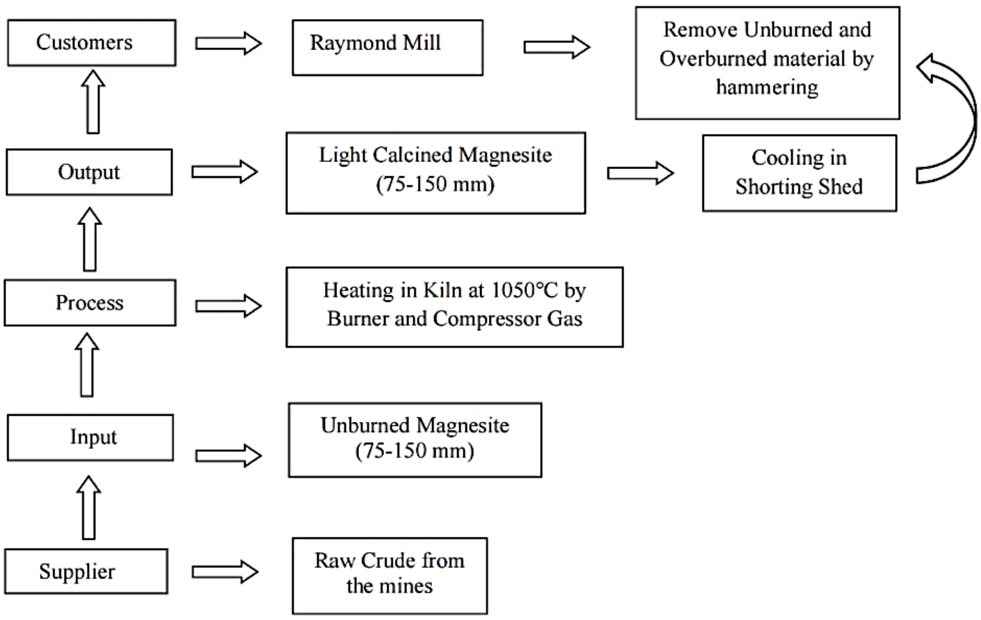

Fig. 1. Schematic diagram of process mapping chart.

3.2 | Measure Phase

In this phase, a standard measuring system is to be established to set the specification limits for the factors that contribute to low productivity in the Kiln. To decide the levels and factors, the measuring

Solaiyappan | J. Appl. Res. Ind. Eng. 10(2) (2023) 186-195

system needs to be established. The deliverables (Y) and potential causes or suspected factors (X) are shown in *Table 3*.

Table 3. Identifying the deliverables and causes.

Major Deliverables (Y's)		Specification Limit	Data Type
1	Production time	Depending on the factors below considered in this study.	Continuous
2	Temperature	Depending on the factors below considered in this study.	Continuous
3	Quality	Depending on the factors below considered in this study.	Ok/ Not Ok (Discrete)
Identified Causes (X's)–2 Level		**Specification Limit**	**Data Type**
1	Raw crude	20%-30%	Continuous
2	Moisture content	2%-2.2%	Continuous
3	Loading time	520-754 min	Continuous
4	Mounting above kiln	0-150 min	Continuous
5	Unloading time	240-320 min	Continuous
6	Temperature calibration equipment	110-160 min	Continuous
7	Oil feeding calibration equipment	280-380 min	Continuous

3.3 | Analysis Phase

3.3.1 | Defining possible causes

The Cause and Effect (CE) analysis technique was used to identify all the causes as shown in *Fig. 2*. The CE matrix was used to prioritize the potential causes. Failure Mode and Effect Analysis (FMEA) was also used in capturing potential causes. This was the outcome of a brainstorming session of the concerned managers. Based on the above steps, the major causes were identified in the CE diagram. The major causes are: raw crude from the mines, oil flow rate, Man-power loading and unloading time, Moisture content, mounting above the kiln, Temperature, and oil feeding calibration equipment.

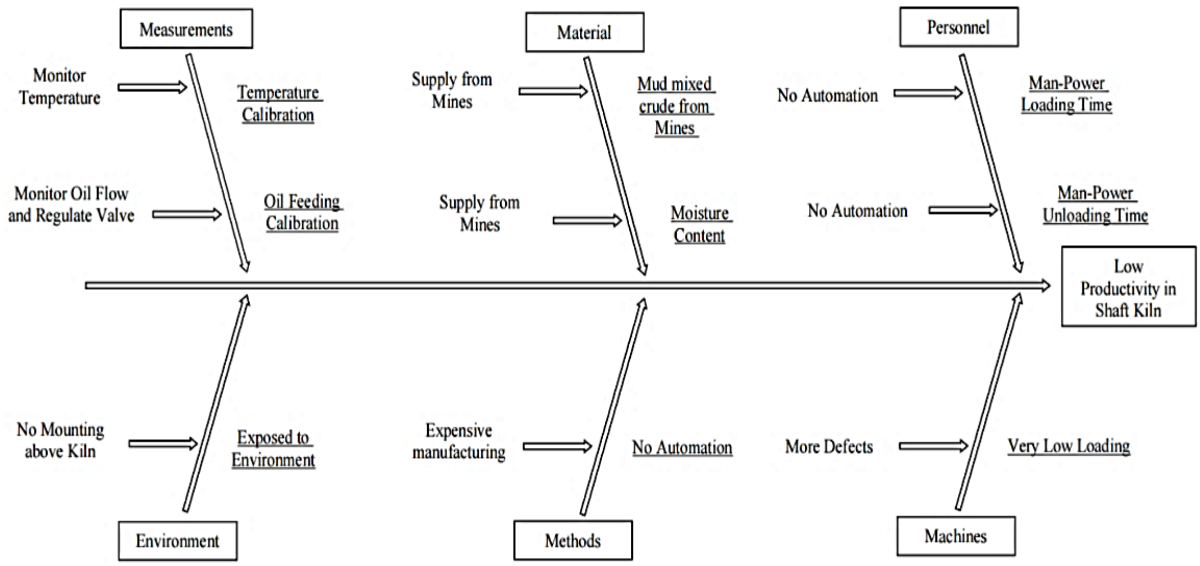

Fig. 2. CE diagram for low productivity in kiln.

A two-level CE matrix is shown in *Table 4*. There are seven factors listed on the input side as listed below and three factors listed on the output side. As the productivity of the Kiln has a higher impact on temperature, it is rated as number (5) in the CE matrix. The next impact is on the production time and, thus, is rated number (4). As productivity has a lower impact on quality, it is rated as number (3). If the influence of input on the output is more, a higher rating of 5 is given and if the influence is low, a lower rating of 1 is given. Based on the subtotal obtained in the CE matrix, a Pareto analysis chart is drawn to analyze the root cause for low productivity in Kiln.

Table 4. CE Matrix (2-level matrix).

Category	Input	Output Production Time (4)	Quality (3)	Temperature (5)	Subtotal
1	Raw crude	4	5	5	56
		16	15	25	
2	Man power loading time	3	2	3	33
		12	6	15	
3	Moisture content	2	3	2	27
		8	9	10	
4	Mounting above kiln	1	1	1	12
		4	3	5	
5	Man power unloading time	3	2	2	28
		12	6	10	
6	Temperature calibration Equipment	4	2	2	51
		16	15	20	
7	Oil feeding calibration equipment	5	4	4	52
		20	12	20	
Total		84	66	105	

3.3.2 | Pareto analysis chart

Pareto analysis is a tool to make decisions based on possible impact and importance to customer satisfaction and bottom-line results. It is an 80:20 rule that means that 80% of the problems come from 20% of the process. The Pareto chart is a bar chart showing attributes of the problem on the X-Axis and frequency of occurrence on the Y-Axis. *Fig. 3* shows the Pareto analysis of this process.

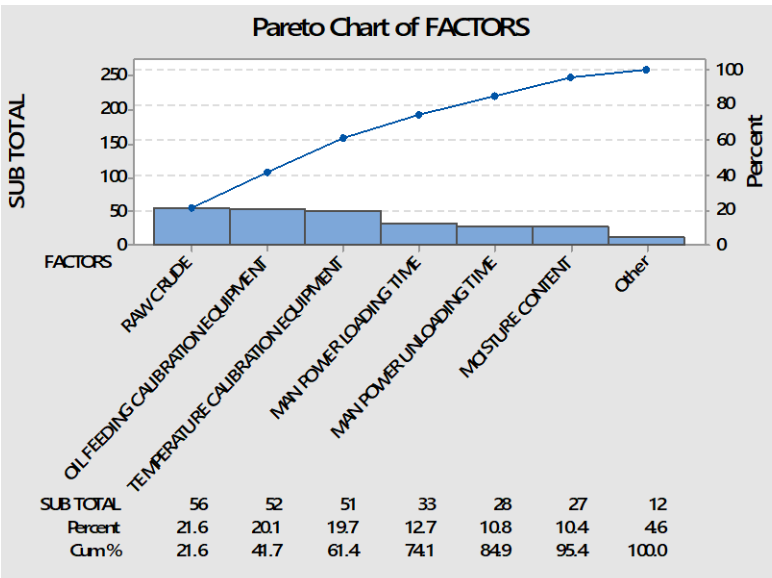

Fig. 3. Pareto chart for low productivity in Kiln.

It lists attributes such as causes of defects or factors with the highest occurrence listed on the left side. Pareto analysis is a great tool to discover the primary causes of a defect quickly for an LSS team to focus on maximizing the results. After the completion of the Pareto analysis, it would be easy for anyone to sort out the contribution of each factor to the output.

3.4 | Improve Phase

3.4.1 | Factors and level setting

This phase concentrates on improving and optimizing the factors like raw crude, man-power loading and unloading time, moisture content, mounting above Kiln, temperature, and oil feeding calibration equipment that impact the temperature values. In this phase of the project, Design of Experiments (DOE) is conducted by considering Full Factorial Design (FFD) with 2K Model i.e. 2-levels and K-factors. The selected factors and the levels are shown in *Table 5*. As FFD has higher accuracy than Taguchi or Response Surface Methodology (RSM), it is adopted as a DOE strategy. According to FFD for 2 levels and 7 factors, 128 experiments were carried out.

Table 5. Factors and their levels.

Symbol	Factors	Unit	Level	
			-1	+1
RC	Raw crude	%	20	30
MPLT	Man power loading time	min	520	754
WC	Moisture/water content	%	2	2.2
RD	Rain duration	min	0	150
MPUT	Man power unloading time	min	240	320
TCE	Temperature calibration equipment	min	110	160
OFCE	Oil feeding calibration equipment	min	280	380

At the predefined set conditions in the above table, the humidity level of the infrared thermometer *Fig. 4* is set as 0.76. Then a laser light from the infrared thermometer falls on the desired point to give the values of the temperature at the specified point. The values of temperature are observed according to specified conditions of FFD.

Fig. 4. Infrared thermometer for temperature calibration.

3.4.2 | Analysis of variance for process factors

For the experimental observations, the variance is analyzed based on the factors like Degree of Freedom (DF), Sum of Squares (SS), Mean Squares (MS), F-Value, and P-Value. The significance of each factor can be identified from the corresponding P-Value. As Level-of-Significance (LoS) is taken as 0.05 in this case, the factors having LOS less than or equal to 0.05 are considered significant. The Analysis of Variance (ANOVA) parameters are tabulated in *Table 6*.

Table 6 ANOVA for the output of kiln temperature.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	28	109138	3898	74.87	0
RC	1	698	698	13.41	0
MPLT	1	254	254	4.87	0.030
WC	1	201	201	3.86	0.052
RD	1	4	4	0.07	0.795
MPUT	1	64	64	1.22	0.271

Solaiyappan | J. Appl. Res. Ind. Eng. 10(2) (2023) 186-195

Table 6. Continued.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TCE	1	11	11	0.22	0.643
OCE	1	2403	2403	46.16	0
RC*MPLT	1	1992	1992	38.27	0
RC*WC	1	1269	1269	24.37	0
RC*RD	1	188	188	3.61	0.061
RC*MPUT	1	74	74	1.41	0.238
RC*TCE	1	0	0	0	0.971
RC*OCE	1	3210	3210	61.66	0
MPLT*WC	1	508	508	9.76	0.002
MPLT*RD	1	8	8	0.14	0.705
MPLT*MPUT	1	51	51	0.98	0.324
MPLT*TCE	1	4	4	0.08	0.779
MPLT*OCE	1	111	111	2.12	0.148
WC*RD	1	11	11	0.21	0.651
WC*MPUT	1	59	59	1.14	0.289
WC*TCE	1	3	3	0.07	0.798
WC*OCE	1	549	549	10.54	0.002
RD*MPUT	1	22	22	0.42	0.518
RD*TCE	1	42	42	0.8	0.373
RD*OCE	1	29	29	0.56	0.457
MPUT*TCE	1	6	6	0.11	0.742
MPUT*OCE	1	8	8	0.14	0.705
TCE*OCE	1	1	1	0.03	0.874
Error	99	5154	52		
Total	127	114292			

The coefficient of determination (R^2) value of 93.4% confirms the prediction quality of the developed model as in *Eq. (1)* representing process factors and Kiln temperature.

$$\begin{aligned}
\text{TEMP} = {} & 1734 + 11.39 \ast \text{RC} - 0.292 \ast \text{MPLT} - 167.2 \ast \text{WC} - 0.421 \ast \text{MPUT} - \\
& 2.080 \ast \text{OCE} - 0.00674 \ast \text{RC} \ast \text{MPLT} - 6.30 \ast \text{RC} \ast \text{WC} - 0.00323 \ast \text{RC} \ast \text{RD} - \\
& 0.00379 \ast \text{RC} \ast \text{MPUT} + 0.02003 \ast \text{RC} \ast \text{OCE} + 0.1703 \ast \text{MPLT} \ast \text{WC} + 0.000135 \ast \\
& \text{MPLT} \ast \text{MPUT} + 0.000159 \ast \text{MPLT} \ast \text{OCE} + 0.170 \ast \text{WC} \ast \text{MPUT} + 0.414 \ast \text{WC} \ast \\
& \text{OCE} + 0.000304 \ast \text{RD} \ast \text{TCE}.
\end{aligned} \tag{1}$$

The residual plots in *Fig. 5* confirm the prediction ability of the developed regression equation and it can be used for further analysis.

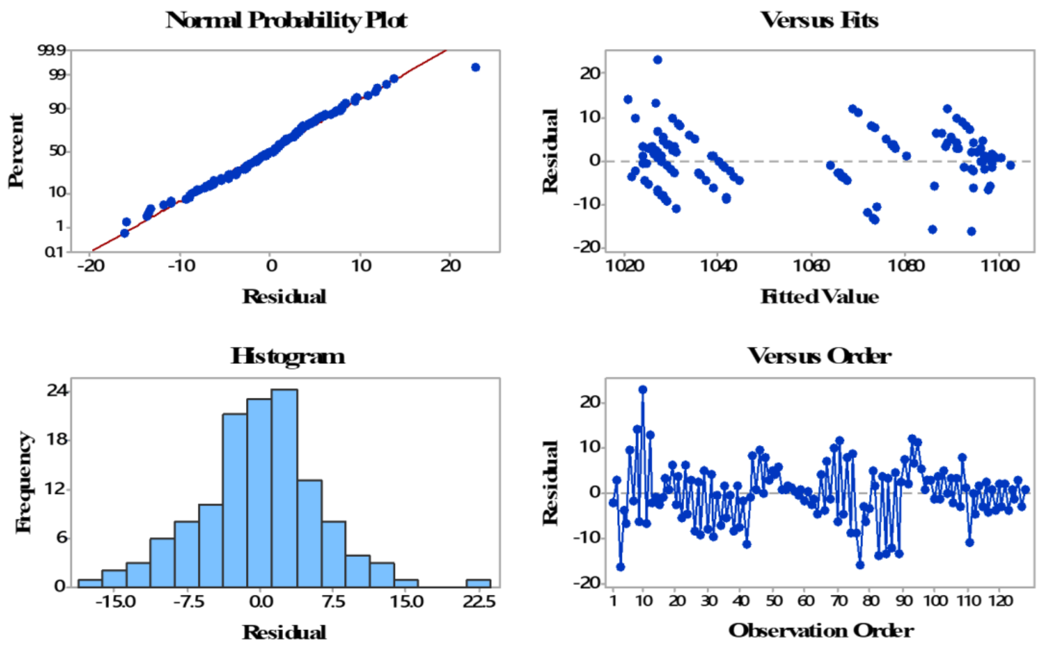

Fig. 5. Residual plots for kiln temperature.

The main effects plot for Kiln mean temperature variation versus all the factors is shown in *Fig. 6*. It can be observed from the figure that 20% raw crude has a higher mean temperature than 30% raw crude and the slope is quite large for Oil feeding and Calibration Equipment (OCE). Also, OCE used at 280 minutes intervals, has a higher mean temperature than equipment used at 380 minutes intervals. The main effect plot for other factors can also be related similarly.

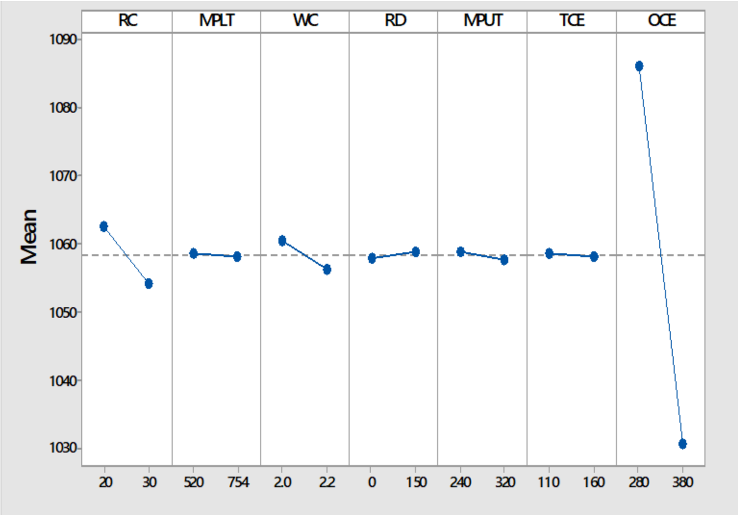

Fig. 6. Main effects plot for kiln temperature (data means).

Interaction plots are most often used to visualize interactions during ANOVA or DOE. The plot as in *Fig. 7* indicates the interaction between the factors within themselves. It can be noted that if OCE interval time is varied between 280-380 minutes, the 20% raw crude has a higher mean temperature than 30% raw crude at 280 minutes interval, while at 380 minutes interval both 20% and 30% raw crudes have same mean temperature. In such a way, the interaction of each factor can be analyzed well in the depicted graphs.

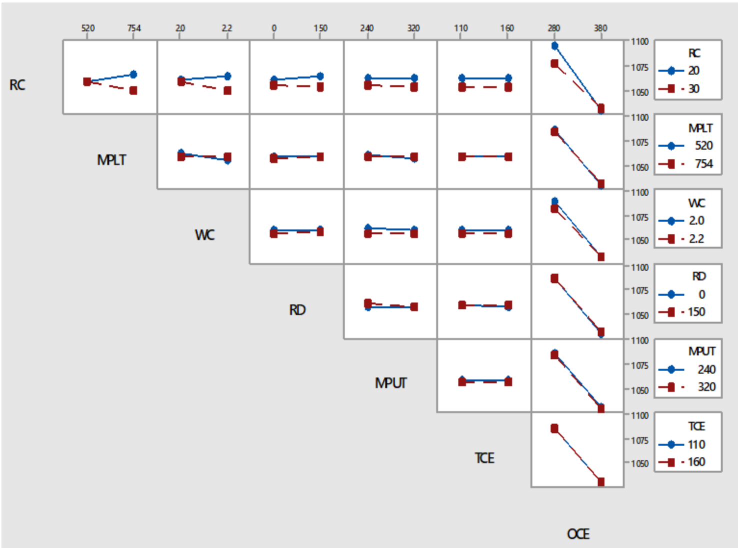

Fig. 7. Interaction plot for kiln temperature (data means).

3.5 | Control Phase

This control phase in the DMAIC process ensures that the process continues to work well, produces desired output results, and maintains the quality level. The X-bar, and R-Chart for the residuals are constructed as in *Fig. 8* to ensure that these residuals are in control within the desired process.

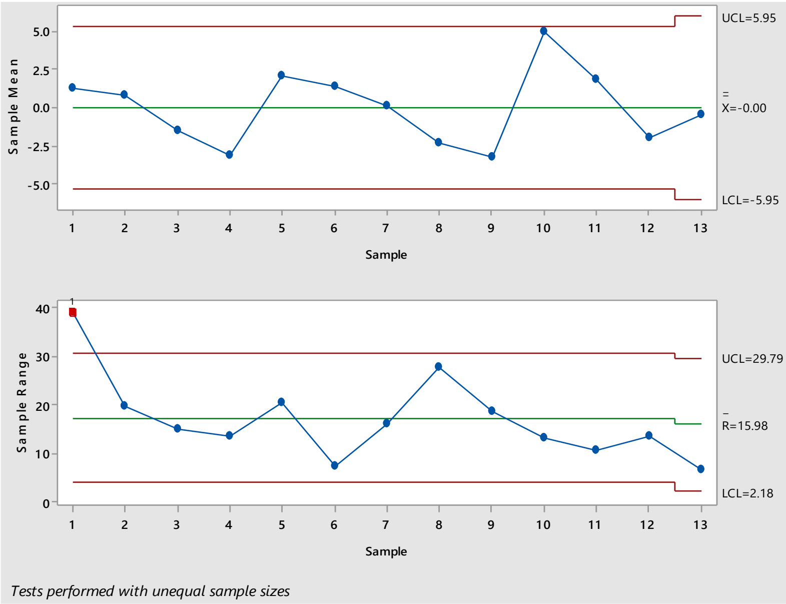

Fig. 8. X-bar and R-charts for residuals.

4 | Conclusion

It is concluded from the application of the DMAIC approach as part of the LSS process in the Refractory Company that raw crude comes from the mines, moisture content in the raw crude, and frequency of using Temperature calibration equipment are the main factors responsible for lowering the productivity in Shaft Kiln. As the crude is mixed with mud, more heat energy is needed to heat the raw crude which, in turn, decreases the productivity of Kiln. Therefore, to improve the productivity of Kiln, the raw crude coming from the mines (mud mixed) must be changed. Secondly, it is suggested to change the frequency of measuring these oil feeding calibration equipment to increase productivity. Finally, the moisture content present in the magnesite stones needs to be decreased to increase productivity.

Acknowledgments

The author would like to thank Mr. Shankar Balaji, M.E. (CAD), Government College of Engineering, Salem - 636011, Tamilnadu, India for his assistance in the collection of data.

References

[1] Arcidiacono, G., & Pieroni, A. (2018). The revolution lean six sigma 4.0. *International journal on advanced science, engineering and information technology*, *8*(1), 141-149.

[2] Tampubolon, S., & Purba, H. H. (2021). Lean six sigma implementation, a systematic literature review. *International journal of production management and engineering*, *9*(2), 125-139.

[3] Kowang, T. O., Yew, L. K., Hee, O. C., Fei, G. C., & Long, C. S. (2019). Lean six sigma implementation: does success means sustainability. *International journal of academic research in business and social sciences*, *9*(6), 907-914.

[4] Assarlind, M., Gremyr, I., & Bäckman, K. (2013). Multi-faceted views on a lean six sigma application. *International journal of quality & reliability management*, *29*(1), 21-30.

[5] Drohomeretski, E., Gouvea da Costa, S. E., Pinheiro de Lima, E., & Garbuio, P. A. D. R. (2014). Lean, six sigma and lean six sigma: an analysis based on operations strategy. *International journal of production research*, *52*(3), 804-824.

[6] Singh, J., Singh, H., Singh, A., & Singh, J. (2020). Managing industrial operations by lean thinking using value stream mapping and six sigma in manufacturing unit: case studies. *Management decision*, *58*(6), 1118-1148.

[7] Wyrwicka, M. K., & Mrugalska, B. (2017). Mirages of lean manufacturing in practice. *Procedia engineering*, *182*, 780-785. https://doi.org/10.1016/j.proeng.2017.03.200

[8] Moya, C. A., Galvez, D., Muller, L., & Camargo, M. (2019). A new framework to support lean six sigma deployment in SMEs. *International journal of lean six sigma*, *10*(1), 58-80.

[9] Tortorella, G., & Fettermann, D. (2018). Help chain in companies undergoing a lean implementation: the impact of critical success factors on quality and efficiency performance. *International journal of lean six sigma*, *9*(1), 113-132.

[10] John, B., & Areshankar, A. (2018). Reduction of rework in bearing end plate using six sigma methodology: a case study. *Journal of applied research on industrial engineering*, *5*(1), 10-26.

[11] John, B., & Chowdhury, K. K. (2021). Minimizing the dry content variation in the pulp drying process using six sigma methodology. *Operations research forum*, *2*, 1-21. https://doi.org/10.1007/s43069-021-00110-y

[12] Hill, J., Thomas, A. J., Mason-Jones, R. K., & El-Kateb, S. (2018). The implementation of a lean six sigma framework to enhance operational performance in an MRO facility. *Production & manufacturing research*, *6*(1), 26-48.

[13] Indrawati, S., & Ridwansyah, M. (2015). Manufacturing continuous improvement using lean six sigma: an iron ores industry case application. *Procedia manufacturing*, *4*, 528-534.

[14] Garza-Reyes, J. A., Al-Balushi, M., Antony, J., & Kumar, V. (2016). A lean six sigma framework for the reduction of ship loading commercial time in the iron ore pelletising industry. *Production planning and control*, *27*(13), 1092–1111.

[15] Albliwi, S. A., Antony, J., & halim Lim, S. A. (2015). A systematic review of lean six sigma for the manufacturing industry. *Business process management journal*, *21*(3), 665-691.

[16] JJie, J. C. R., Kamaruddin, S., & Azid, I. A. (2014). Implementing the lean six sigma framework in a small medium enterprise (SME)—a case study in a printing company. *Proceedings of the 2014 international conference on industrial engineering and operations management Bali* (pp. 387-395), Indonesia. http://ieomsociety.org/ieom2014/pdfs/86.pdf

[17] Jirasukprasert, P., Garza-Reyes, J. A., Kumar, V., & Lim, M. K. (2014). A six sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process. *International journal of lean six sigma*, *5*(1), 2-21. https://doi.org/10.1108/IJLSS-03-2013-0020

[18] Ketan, H., & Nassir, M. (2016). Aluminium hot extrusion process capability improvement using six sigma. *Advances in production engineering & management*, *11*(1) 59-69.

[19] Gijo, E. V., Scaria, J., & Antony, J. (2011). Application of six sigma methodology to reduce defects of a grinding process. *Quality and reliability engineering international*, *27*(8), 1221-1234.

[20] Nascimento, D. L. D. M., Goncalvez Quelhas, O. L., Gusmao Caiado, R. G., Tortorella, G. L., Garza-Reyes, J. A., & Rocha-Lona, L. (2019). A lean six sigma framework for continuous and incremental improvement in the oil and gas sector. *International journal of lean six sigma*, *11*(3), 577-595.

[21] Vinodh, S., Gautham, S. G., & Ramiya R., A. (2011). Implementing lean sigma framework in an Indian automotive valves manufacturing organisation: a case study. *Production planning & control*, *22*(7), 708-722.

[22] Barnabé, F., Giorgino, M. C., Guercini, J., & Bianciardi, C. (2016). Performance enhancement and continuous improvement in healthcare: how lean six sigma "hits the target". *International journal of business and social science*, *7*(5), 21-35.

[23] Brown, R., Grehan, P., Brennan, M., Carter, D., Brady, A., Moore, E., Teeling, S. P., Ward, M., & Eaton, D. (2019). Using lean six sigma to improve rates of day of surgery admission in a national thoracic surgery department. *International journal for quality in health care*, *31*(1), 1421. https://doi.org/10.1093/intqhc/mzz083

[24] Elbermawy, M. F., Al Manhawy, A. A., & Ibrahim, H. E. A. (2014). Implementation of lean six sigma for improving supply chain processes in a pharmaceutical industry. *International journal of scientific & engineering research*, *5*(8), 519-529.

[25] Furterer, S. L. (2011). Applying lean six sigma to reduce linen loss in an acute care hospital. *International journal of engineering, science and technology*, *3*(7), 39-55.

[26] Kremcheeva, D. A., & Kremcheev, E. A. (2019). Implementation of the six sigma method in the educational process. *Journal of physics: conference series*, *1384*(1), 012022. https://iopscience.iop.org/article/10.1088/1742-6596/1384/1/012022/pdf

[27] Li, N., Laux, C. M., & Antony, J. (2019). How to use lean six sigma methodology to improve service process in higher education: a case study. *International journal of lean six sigma*, *10*(4), 883-908.

[28] Maleszka, A., & Linke, M. (2016). Improvement of management process by using lean six sigma tools in some big organisation of food industry. *Polish journal of natural sciences*, *31*(1), 101-112.

[29] Kundu, G., & Murali Manohar, B. (2012). Critical success factors for implementing lean practices in it support services. *International journal for quality research*, *6*(4), 301-312.

[30] John, B., & Parikh, P. (2020). Improving the insurance claim processing process using six sigma methodology. *International journal of six sigma and competitive advantage*, *12*(4), 348-368.