Prioritization of enablers supporting deployment of Lean Six Sigma with sustainability considerations: An ISM based approach

Ben Ruben R
Assistant Professor
Department of Mechanical Engineering
Sri Krishna College of Engineering and Technology
Coimbatore, Tamil Nadu, India
*ben.ruben21@gmail.com

Srikant J, Thirumurugan S, Venkata Krishnan R and Sai Deepesh J
Under Graduate Students
Department of Mechanical Engineering
Sri Krishna College of Engineering and Technology
Coimbatore, Tamil Nadu, India
srikantjayasankaran@gmail.com , thiruu2107@gmail.com , r.venkatakrishna1010@gmail.com , sai2871999@gmail.com

Abstract

This article aims at prioritizing and analyzing the enablers that supports implementation of Lean Six Sigma with sustainability considerations. 10 such crucial enablers were identified and an integrated Interpretive Structural Modeling (ISM) and MICMAC (Matriced' Impacts Croisés Multiplication Appliqués à un Classement) approach was applied for prioritizing the enablers. Based on the analysis, the most dominant and dependent enablers that enables LSS adoption with sustainability considerations were identified. The enablers, namely, "Availability of proper defect monitoring system, Availability of well designed roadmap for sustainable LSS Implementation and Effective in-bound and out-bound communication", occupy the base segment of the ISM hierarchy; the enabler, namely, "A supportive Leadership", occupy the top level of the ISM hierarchy. The study helped in identifying and prioritizing the enablers that supports LSS adoption with sustainable considerations arrived using a mathematical approach. This approach will be helpful for practitioners and implementation experts to focus on enabling the key dominant enablers and to deploy LSS adoption with sustainable considerations.

Keywords
Lean Six Sigma, Sustainable Manufacturing, Structural Model, Enablers, MICMAC Analysis

1.0. Introduction
Lean Six Sigma (LSS) is a data-driven methodology that combines two effective business improvement methodologies, Lean Manufacturing and Six Sigma, to improve a company's performance by eliminating wastes and lowering process variation (Zhang et al., 2012; Sreedharan et al., 2018). Sustainable manufacturing is defined as the production of manufactured goods using cost-effective procedures that reduce negative environmental consequences while preserving energy and natural resources (Moktadir et al., 2018; Malek and Tushar., 2019; Sony and Naik, 2020). Employee, community, and product safety are all improved by sustainable production. Six Sigma is a well-known problem-solving methodology in the manufacturing business. The DMAIC paradigm, which consists of five steps: Define, Measure, Improve, and Control, was developed by Motorola in the 1980s and has achieved widespread adoption in industry. The DMAIC approach provides a framework for improving a current process' capabilities by reducing variance, faults, and even costs. Manufacturing firms have started to deploy both LSS and Sustainable Manufacturing strategies to attain integrated benefits. The three dimensions of sustainability i.e Environment, Economy and Society have a direct correlation with LSS strategies as both aims at improving the productivity of the

organization. While deploying such integrated strategies, it is important for the manufacturing organization to study about the factors that supports such integration (Ben Ruben et al., 2018; Parmar et al., 2020). This helps the manufacturing organizations to well plan the implementation process and to complete the deployment without any difficulties. In this article, 10 such enablers are being identified from the literature and are being prioritized using ISM technique.

2.0.Identification of Enablers

Based on the literature and expert opinion, the enablers for LSS adoption with sustainability considerations were identified. As shown in Table-1, ten enablers have been found.

Table 1. Selected Enablers

Enablers	Description
A Supportive Leadership (Laureani and Antony, 2017)	Building trust, inspiring others, and assisting colleagues in overcoming obstacles are all components of supportive leadership. Leaders who want to be more supportive of their teams should encourage teamwork, pay attention to member relationships, and demonstrate commitment.
Adequate Training (Pepper and Spedding, 2010)	Adequate facilities, a diverse range of work, supervision, and training are required for the apprentice or trainee to successfully complete the apprenticeship or traineeship and complete the training contract.
Availability of proper defect monitoring system (Ben Ruben et al., 2018)	Defect tracking assists you in ensuring that errors discovered in the system are corrected. It's great for testers and developers to talk about the problem and work together to solve it. If the problem is resolved quickly, that's fantastic! Perhaps it isn't necessary to log it.
Availability of well designed roadmap for sustainable LSS (Erdil et al., 2018)	The strategy is to review existing literature on lean and Six Sigma, including road maps and critical success factors (CSFs), in order to create an in-house, quantitative survey instrument. The survey's goal was to assess employees' perspectives on the significance of LSS CSFs in the successful implementation and sustainability of a continuous improvement initiative. Based on the literature and data collected, an LSS reference guide - in the form of a road map - was designed to facilitate the implementation and sustainability of LSS.
An Engaged Sponsor (Laureani and Antony, 2017)	Sponsorship entails making key investment decisions and providing top-level support for a project's rationale and objectives. The sponsoring group may occasionally take on the role of project board. The sponsoring group is made up of senior executives who are in charge of making key investment decisions.
Availability of Infrastructure (Ben Ruben et al., 2018)	A system's or organization's basic structure. Any system's basic, fundamental architecture (electronic, mechanical, social, political, etc.) determines how it functions and how adaptable it is to future requirements.
Enhanced Focus on Sustainable Process (Erdil et al., 2018)	Sustainability focuses on meeting the needs of the present without jeopardizing future generations' ability to meet their own needs. The concept of sustainability is built on three pillars: economic, social, and environmental—also commonly known as profits, planet, and people.
Effective Designing of Implementation Process (Timans et al., 2012)	"Design implementation" really implies doing the labour to transform the idea (design) into a real thing. The design process will take common steps including the collection of needs, the identification of possible solutions, the analysis of such solutions, etc.
Frequent Amelioration of processes (Ruben et al., 2018)	Continuous improvement is the continuous improvement of products, services or processes by incremental and breakneck improvements sometimes called continuous improvement. These initiatives may seek "incremental" improvement over time or "breakthrough" improvement all at once. Continuous improvement methods, such as Six Sigma, lean, and total quality management, emphasise employee participation and teamwork, work to measure and systematise processes, and reduce variation, defects, and cycle times.

Effective Inbound and Outbound communication (Laureani and Antony, 2019)	Inbound commercial communications are two ways, enabling the consumer to respond; outbound marketing communications are one-way so that a message can be sent to potential customers but no direct reactions can be facilitated.

Research studies that have been carried out to identify lean, six sigma and sustainable manufacturing enablers separately were selected to the identify the enablers. Based on the frequency of use, conformity to the subject, the enablers were identified. To the best of the authors' knowledge, ISM has not been used to prioritize enablers for LSS implementation with sustainability in mind. The present study was conducted in view of this gap.

3.0 Interpretive Structural Modeling

ISM is a proven technique which is applied to analyze the interactions and contextual interrelationships of the elements that define a system. It is also applied for systems that has more complexity and creates a hierarchical model as an output for categorization of factors (Farris and Sage, 1975).

- To identify the variables that constitute the system to be defined. In the present case, the variables are the enablers affecting LSS adoption with sustainability considerations.
- After recognizing the enablers, a contextual relationship is arrived in between them. This is done by creating a structural self-interaction matrix (SSIM) with reference to pairwise comparison among the identified enablers.
- A reachability matrix is constructed with respect to SSIM, where the symbols (V, A, X, O) are replaced using binary digits (0 and 1) and its transitivity is checked. The transitivity rule implies that if enabler X affects enabler Y and enabler Y affects enabler Z, then enabler X necessarily affects enabler Z
- Level partitioning is done in line with the obtained reachability matrix, to determine various levels in the model
- Based on the final reachability matrix, a digraph is constructed through nodes and arrow lines and its transitivity links are deleted
- The resultant digraph is later transformed into an ISM model by substituting enabler nodes with statements

3.1 Data Collection

To analyze the identified enablers for implementation of LSS with sustainability considerations, an expert team was formed. The team comprises of academicians and industrial expertsThe expert team included purchase managers, manufacturing engineers, quality engineers, R&D managers, marketing executives and maintenance engineers who are involved in the process of deploying LSS concepts with sustainability insights. The contextual relationship of each enabler is to be determined by the experts. After multiple discussions and iterations, the contextual relationship between for all enablers that supports LSS adoption with sustainability considerations is assigned. This relationship is based on “leads to type” which means that how the effect of one enabler leads to the effect on another enabler.

3.2 Development of Structural self-interaction matrix development

The contextual relationship is determined by examining the relationship between the two enablers (i and j) and their direction. To symbolize directions, four symbols have been utilized, and each symbol denotes a unique relationship based on the direction. The four symbols are:

(1) V: enabler i will lead to enabler j.
(2) A: enabler i will be achieved by enabler j.
(3) X: enabler i and enabler j will facilitate to achieve each other.
(4) O: enabler i and enabler j are not related.

Based on the contextual relationship between enablers, SSIM has been configured. Table 2 explains the usage of symbols V, A, X and O in creating SSIM.

Table 2. Structural Self-Interaction Matrix

	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	V	V	V	V	V	V	V	V	V	1
2	V	V	X	V	X	O	O	O	1	
3	O	A	X	A	X	A	X	1		
4	O	O	A	O	A	A	1			
5	V	V	V	V	V	1				
6	X	X	X	X	1					
7	X	X	X	1						
8	X	V	1							
9	X	1								
10	1									

3.3 Initial reachability matrix

The developed SSIM is transformed to a binary matrix after transforming V, A, X and O by 1 and 0 according to a given case. The resultant matrix is the initial reachability matrix as shown in Table 3. The replacement of 1 and 0 is based on the following rules (Malone, 1975):

If (i, j) entry in the SSIM is V, then (i, j) entry in the reachability matrix changes to 1 and the (j, i) entry changes to 0.
If (i, j) entry in the SSIM is A, then (i, j) entry in the reachability matrix changes to 0
and the (j, i) entry changes to 1.
If (i, j) entry in the SSIM is X, then (i, j) entry in the reachability matrix changes to 1
and the (j, i) entry also changes to 1.
If (i, j) entry in the SSIM is O, then (i, j) entry in the reachability matrix changes to 0
and (j, i) entry also changes to 0**.**

Table 3. Initial Reachability Matrix

	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	0	0	0	1	0
3	0	0	1	***0***	1	0	1	1	0	0
4	0	0	0	0	0	0	1	1	0	0
5	1	1	1	1	1	1	1	1	0	0

6	1	1	1	1	1	***0***	1	1	1	0
7	1	1	1	1	1	0	0	1	0	0
8	1	1	1	1	1	***0***	1	1	1	0
9	1	1	***0***	1	1	0	0	1	0	0
10	1	1	1	1	1	0	0	0	0	0

3.4 *Final Reachability Matrix*

Based on the initial reachability model, the final reachability matrix is to be developed after checking for transitivity. Transitivity is a significant part of ISM where relationships are made on assumptions. Transitivity indicates that if there are three variables X, Y and Z and if variable X is related to Y and variable Y is related to Z, then variable X is necessarily related to Z. Using this relationship, transitivity is validated for the initial reachability matrix. After imposing transitivity, the final reachability matrix is developed as depicted in Table 4 and transitivity relationships are indicated by 1*. In the present study, variables denote the different enablers and transitivity is being checked for all relationships configured

Table 4. Final Reachability Matrix

	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
1	1	1	1	1	1	1	1	1	1	1	10
2	1	1	1	1	1	0	0	0	1	0	6
3	0	0	1	*1*	1	0	1	1	0	0	5
4	0	0	0	0	0	0	1	1	0	0	2
5	1	1	1	1	1	1	1	1	0	0	8
6	1	1	1	1	1	*1*	1	1	1	0	9
7	1	1	1	1	1	0	0	1	0	0	6
8	1	1	1	1	1	*1*	1	1	1	0	9
9	1	1	*1*	1	1	0	0	1	0	0	6
10	1	1	1	1	1	0	0	0	0	0	5
	8	8	9	9	9	4	6	8	4	1	

3.5 Level Partitions

To determine the hierarchy amongst the enablers, level partitions are being performed. The reachability and antecedent set for every Enabler is to be identified after analysing the final reachability matrix. The enablers that have identical reachability and antecedent sets are specified in the top position in ISM hierarchy. The enablers at top-level of the hierarchy do not enable in achieving any other Enabler located at top of its own level. On recognizing the top-level enablers, they are deleted from next consecutive iterations and the same method is done successively leading to the attainment of lower level. The hierarchy levels helped in developing the final ISM model. Level partitioning of the reachability matrix consisting of all iterations and Enabler levels is shown in Table 5.

Table 5. Level Partitioning

Iteration 1				
Enabler	**Reachability**	**Antecedent**	**Intersection**	**Level**
1	{1,2,3,4,5,6,7,8,9,10}	{1}	{1}	
2	{2,6,7,8,9,10}	{1,2,6,8}	{2,6,8}	
3	{3,4,6,7,8}	{1,3,4,5,6,7,8,9}	{3,4,6,7,8}	I
4	{3,4}	{1,3,4,5,6,8}	{3,4}	I
5	{3,4,5,6,7,8,9,10}	{1,5,6,8}	{5,6,8}	
6	{2,3,4,5,6,7,8,9,10}	{1,2,3,5,6,7,8,9,10}	{2,3,5,6,7,8}	
7	{3,6,7,8,9,10}	{1,2,3,5,6,7,8,9,10}	{3,6,7,8,9,10}	
8	{2,3,4,5,6,7,8,9,10}	{1,2,3,5,6,7,8,9,10}	{2,3,5,6,7,8,9,10}	
9	{3,6,7,8,9,10}	{1,2,5,6,7,8,9,10}	{6,7,8,9,10}	
10	{6,7,8,9,10}	{1,2,5,6,7,8,9,10}	{6,7,8,9,10}	I
Iteration 2				
Enabler	**Reachability**	**Antecedent**	**Intersection**	**level**
1	{1,2,5,6,7,8,9,}	{1}	{1}	
2	{2,6,7,8,9}	{1,2,6,8}	{2,6,8}	
5	{5,6,7,8,9}	{1,5,6,8}	{5,6,8}	
6	{2,5,6,7,8,9}	{1,2,5,6,7,8,9}	{2,5,6,7,8,9}	II
7	{6,7,8,9}	{1,2,5,6,7,8,9}	{6,7,8,9}	II

8	{2,5,6,7,8,9}	{1,2,5,6,7,8,9}	{2,5,6,7,8,9}	
9	{6,7,8,9}	{1,2,5,6,7,8,9}	{6,7,8,9}	II
Iteration 3				
Enabler	**Reachability**	**Antecedent**	**Intersection**	**level**
1	{1,2,5,8,}	{1}	{1}	
2	{2,8}	{1,2,5,8}	{2,8}	III
5	{5,8}	{1,5,8}	{5,8}	III
8	{2,5,8}	{1,2,5,8}	{2,5,8}	III
Iteration 4				
Enabler	**Reachability**	**Antecedent**	**Intersection**	**level**
1	{1,}	{1}	{1}	IV

3.6 *Development of ISM model*

The obtained structural model is derived based on the final reachability matrix and is designated as digraph. The digraph shows the relationship among enablers and is represented by arrows. Later after eliminating the transitivity and by substituting nodes with factor statements, the digraph is transformed into the ISM model as depicted in Figure1.

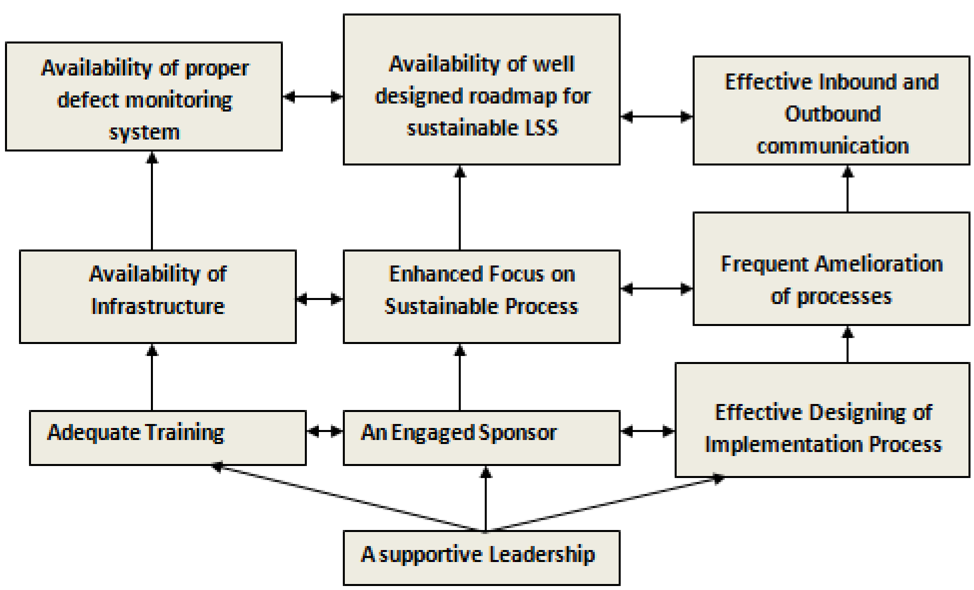

Figure 1. Developed ISM model

4.0 Conclusion

Ten enablers affecting LSS adoption with sustainable considerations were identified from the literature and their interrelationships were obtained based on expert opinion from the case organization consisting of practitioners and academicians. Based on the ISM methodology, the model was built which consists of four levels. The first level consists of three enablers namely 'Availability of proper defect monitoring system', 'Availability of well designed roadmap for sustainable LSS Implementation' and 'Effective in-bound and out-bound communication'. These three enablers possess maximum driving power and are considered as the most crucial enablers in adopting LSS with sustainable considerations. The enablers 'Availability of infrastructure' 'Enhanced focus on sustainable process' 'Frequent amelioration of processes', 'Adequate training', 'An engaged sponsor', 'An engaged sponsor' and 'Effective designing of implementation process' occupy the second and the third levels. The first level enablers have an influence on these enablers and support them. 'A supportive Leadership' is at fourth level. These enablers possess strong dependence powers and weak driving powers. The firm must take necessary mitigating actions to remove these identified enablers in order to make LSS adoption process with sustainable considerations without any hurdles. The developed ISM model is further analyzed based on the Enabler's driving and dependence power in order to create clusters of enablers. Based on results of ISM analysis, the enablers are categorized into autonomous, dependent, linkage and independent clusters as indicated in Figure 2.

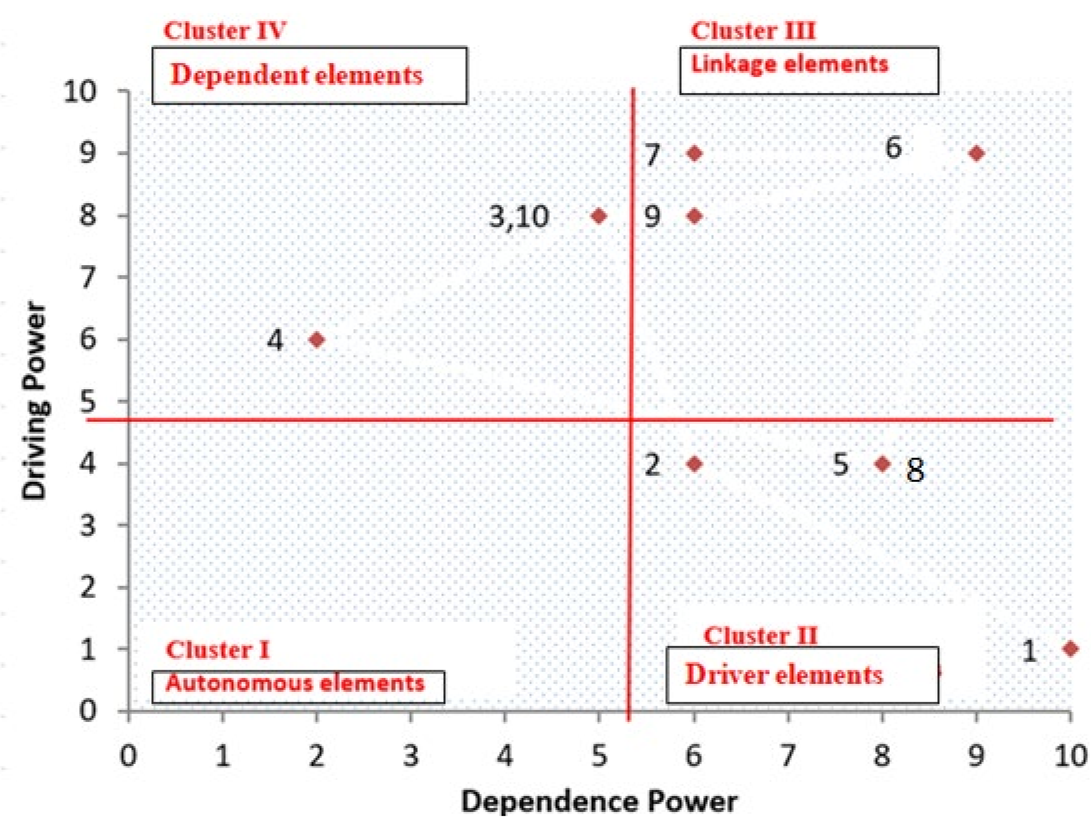

Figure 2. Classification of Enablers

MICMAC principle is based on multiplication properties of the matrices. The purpose of MICMAC analysis is to interpret the driving power and dependence power of the enablers. This is performed to identify the key enablers that drive the system in various categories. Based on their driving power and dependence power, the enablers in the present case have been classified. The enablers 'A Supportive Leadership', 'Adequate Training' and 'An Engaged Sponsor' and 'Effective Designing of Implementation Process' are considered as the driver elements. These enablers are dependent on their own and are considered as the powerful enablers for integrated implementation of LSS with Sustainability considerations. The enablers 'Availability of Infrastructure', 'Enhanced Focus on Sustainable Process' and 'Frequent Amelioration of processes' were identified as the linkage enablers. These enablers possess strong dependence and driving powers. These enablers are influenced by lower level enablers and are not stable. These enablers have a greater impact on other enablers and significantly affect the LSS adoption with sustainable considerations. The enablers 'Availability of proper defect monitoring system', 'Availability of well designed roadmap for sustainable LSS' and 'Effective Inbound and Outbound communication'. The developed ISM model and clustering of enablers will be useful for implementation managers for planning the deployment activities systematically. One of the limitations of the study is that about the contextual relationship among the enablers. The obtained relationship is based on the brainstorming conducted by the expert panel and were finalized based on the practical validity. In future to make the model more competitive, the number of enablers can be increased and the relationship can be justified using a statistical model. Further, a structural equation modeling approach can be used for validating the model statistically.

References

Ben Ruben., S., V. and P., A., "ISM and Fuzzy MICMAC application for analysis of Lean Six Sigma barriers with environmental considerations", International Journal of Lean Six Sigma, Vol. 9 No. 1, pp. 64-90, 2018.

Erdil, Nadiye O., Can B. Aktas, and Omid M. Arani. "Embedding sustainability in lean six sigma efforts." *Journal of Cleaner Production*, Vol.198, pp. 520-529, 2018

Farris, D. R., and Andrew P. Sage. "On the use of interpretive structural modeling for worth assessment." *Computers & Electrical Engineering* 2, no. Vol.2-3, pp.149-174, 1975.

Laureani, Alessandro, and Jiju Antony. "Leadership and Lean Six Sigma: a systematic literature review." *Total Quality Management & Business Excellence* , Vol.30, no. 1-2, pp.53-81, 2019.

Laureani, Alessandro, and Jiju Antony. "Leadership characteristics for lean six sigma." *Total Quality Management & Business Excellence, Vol.* 28, No. 3-4, pp.405-426, 2017.

Malek, Javed, and Tushar N. Desai. "Prioritization of sustainable manufacturing barriers using Best Worst Method." *Journal of Cleaner Production, Vol.* 226, pp.589-600, 2019..

Malone, David W. "An introduction to the application of interpretive structural modeling." *Proceedings of the IEEE* , Vol.63, No. 3, pp.397-404, 1975.

Moktadir, Md Abdul, Towfique Rahman, Md Hafizur Rahman, Syed Mithun Ali, and Sanjoy Kumar Paul. "Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh." *Journal of Cleaner Production, Vol* 174, pp. 1366-1380. 2018.

Parmar, Pranay Sureshbhai, and Tushar N. Desai. "Evaluating Sustainable Lean Six Sigma enablers using fuzzy DEMATEL: A case of an Indian manufacturing organization." *Journal of Cleaner Production, Vol.* 265, pp.121802, 2020

Pepper, Matthew PJ, and Trevor A. Spedding. "The evolution of lean Six Sigma." *The International Journal of Quality & Reliability Management, Vol.* 27, No. 2, pp.138, 2010.

Ruben, R. Ben, S. Vinodh, and P. Asokan. "Lean Six Sigma with environmental focus: review and framework." *The International Journal of Advanced Manufacturing Technology, Vol.* 94, No. 9, pp. 4023-4037, 2018.

Sony, Michael, and Subhash Naik. "Green Lean Six Sigma implementation framework: a case of reducing graphite and dust pollution." *International Journal of Sustainable Engineering, Vol.* 13, No. 3, pp. 184-193, 2020.

Sreedharan V, Raja, and Vijaya Sunder M. "Critical success factors of TQM, Six Sigma, Lean and Lean Six Sigma: a literature review and key findings." *Benchmarking: An International Journal* , Vol.25, No. 9 pp. 3479-3504, 2018.

Timans, Werner, Jiju Antony, Kees Ahaus, and Rini van Solingen. "Implementation of Lean Six Sigma in small-and medium-sized manufacturing enterprises in the Netherlands." *Journal of the Operational Research Society* Vol. 63, No. 3, pp. 339-353, 2012.

Zhang, Qun, Muhammad Irfan, Muhammad Aamir Obaid Khattak, Xiaoning Zhu, and Mahmood Hassan. "Lean Six Sigma: a literature review." *Interdisciplinary Journal of Contemporary research in business*, Vol. 3, No. 10, pp.599-605, 2012.

Biographies

Srikant J is currently a final year mechanical Engineering student at Sri Krishna College Of Engineering and Technology . His area of interests include Quality, continuous improvement, Production planning and operations management

Thirumurugan S is a final year Mechanical Engineering Undergraduate student at Sri Krishna College of Engineering and Technology. His area of interest includes Production & Operations Management, Lean Manufacturing, Six Sigma and Industry 4.0.

Venkata Krishnan R is currently a final year mechanical Engineering student at Sri Krishna College Of Engineering and Technology. His area of interests include Fundamentals of Data Analysis, Production Management and Agile Manufacturing

Sai Deepesh J is currently a final year mechanical Engineering student at Sri Krishna College Of Engineering and Technology. His area of interests include Production planning and operations management

Ben Ruben R is currently working as Assistant Professor in the Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore. He completed his Ph.D. in Lean and Sustainable Manufacturing from National Institute of Technology, Trichy. He has also worked in a DST (Department of Science and Technology, New Delhi) sponsored project that focuses on extending lean tools for sustainable development. He has published research articles and book chapters in renowned International Journals and has attended various International Conferences. He also holds a Black Belt in lean Six Sigma and has worked on collaborative projects with various manufacturing firms. His area of interests include Lean 4.0, Six Sigma, Life Cycle Assessment and Circular Economy**.**