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Lean Manufacturing Towards Sustainability: A Grey Relational Framework

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ABSTRACT

This paper intends to capture the attention of the lean researchers towards a shift of priorities of the various techniques implemented in lean and its journey of 40 years in the global scenario. In particular, the paper focuses on the implementation of lean techniques in India under the banner of sustainability. The paper focuses on three industries, a textile industry representing industrial revolution 1.0, an automotive spare parts industry representing industrial revolution 2.0, and an electrical/electronics industry representing industrial revolution 3.0, named 'A', 'B', and 'C', respectively, and analyses the priorities of the eight best techniques of lean in the sustainability phase. The techniques are Kaizen, Poke-Yoke, 5S, Kanban, Just-in-Time, Jidoka, Takt-Time, and Heijunka. The industries 'A' and 'C' have Poke-Yoke as the most critical technique and have been ranked one whereas in industry 'B' 5S emerges as the most prolific technique in the Indian context of these industries.

KEYWORDS

Framework, Grey Analysis, Lean, Lean Phases

1. INTRODUCTION

The methodology and operational aspects of production in the industrial world has changed over time. With the transition from hand production methods to new machines and processes, the first industrial revolution (1760-1840) marked the dominance of textile industries in the world scenario. The second industrial revolution began in 1850's with the advent of steel. (First form of mass production). The industrial revolution 3.0 (1969) saw the emergence of nuclear energy, electronics, telecommunication and computers. The industrial revolution 1.0 improvised water and steam to improvise production, the second introduced electricity to invoke mass production and industry 3.0 automated production by incorporating electronics and information technology. During the second industrial revolution, automotive industry also came into picture beginning with craft production followed in succession by mass production improvised by Henry Ford around 1900.

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In 1937, Toyota made its way into the automotive sector but soon failed to establish itself due to several indigenous problems and constraints, one being the nuclear destruction of World War II. To solve the problem of this Japanese automotive company its owner Sakichi Toyoda and his production genius Taiichi Ohno started a simple approach to solve their problems. These set of smart rules were perfectionized in over 30 years of shear hard work and diligence which eventually came to be known as 'Lean Production' (John Kraafcik, 1988). This new generation operation philosophy consisted of its own tools, techniques and practices blending it into an art to do the work with best performance, quality and productivity. Figure 1 illustrates the tools and techniques framework in developing 'Lean'. Since 1990, with the publishing of the book "The Machine that changed the world" [Womack, Jones and Roos] lean has transformed work styles and lifestyles throughout the world. Under the paradigms of sustainability involving the pillars of social, economic and environmental dimensions, lean can be a game changer to bring out the best of these critical dimensions of survival that govern the industrial world. Lean can be applied to reduce human effort, inventory, work space and simultaneously increase the variety and diversity of products with a very short time frame. The feature of lean as the "warrior philosophy'" can bring about the change with limited resources and workforce with magical elegance to transformation of clean, green and prosperous society of modern times. This paper intends to concentrate on the ranking of the best eight techniques in previous six phases of lean with respect to the seventh phase called "Sustainability" using the Grey Relational Analysis Technique.

The paper is organised into seven sections: The second section comprises Literature review where an in depth literature review depicting the seven phases of lean with deep implications and emphasis on identifying the eight best techniques for lean implementation. The framework that follows show the position of techniques in the scientific method paradigm and helps to visualize the structure of strategies, principles and practices in accordance with lean. The methodology used, being the fourth section, is represented and the scale used is mentioned. The fifth section of survey and analysis comprises the expert opinions and rank prediction is established. In the sixth section of result and discussion, the ranks and their implications in the chosen industries A, B and C are highlighted. The paper concludes providing an overall discussion of results, limitations of the paper, managerial implications and future scope of research.

1.1 Literature

Though the process of lean production started in 1950's, yet it took fifteen years to establish itself to maturity through relentless and consistent effort in the Toyota automotive industry. The literature was not given a drive until 1971 when Peter Drucker delved into the Japanese management principles in his manuscript. It was a general view on Japanese work-philosophies and did not specifically deal with lean production. In 1990, Womack, Jones and Roos for the first time came up with a book " The Machine that changed the world" which explained lean work philosophy and its competence in crisis situation and how it can be a game changer in turning a company into number one status in the automotive industry. The book was a result of five years of research of all the automotive industries around the world at that point of time and the comparative account of fading mass production to emerging lean production was clearly evident. The term "lean" also was suggested by a researcher, John Kraafcik (1988) in MIT's International Motor Vehicle Program (IMVP). It conferred the idea of "less of everything" in terms of work space, human effort, speed of production, quantity, quality and variety of products produced and resources utilized in achieving these attributes. This literature review filters all research papers which contain the involvement of techniques in various dimensions of lean.

1.1.1. Phases of Lean

Over the last forty years, lean has been studied and implemented in various dimensions called phases. Till date, seven phases are identified with the seventh one continuing. We have considered twenty eight scholarly articles to find out the best eight techniques of Lean. The literature surveyed is tabulated in Table 1.

Table 1. Phases of Lean and best 8 techniques identification literature used

Lean Phases	Period	Literature
Phase of Discovery	1970-1990	Kraafcik(1988a) Drucker (1971) Sugimori et al. (1977)
Phase of Dissemination	1991-1996	Warneckea and Huser(1995) Berkley (1992) Womack and Jones (1997)
Phase of Implementation	1997-2000	Kippenberger (1997) Cappeli and Rogovsky(1998) Green (1999) Yingling et al. (2000) Spear and Bowen (1999)
Phase of Enterprise	2001-2006	Fairris and Tohyama(2002) Hines (2004) Liker (2004) Doolen and Hacker(2005)
Phase of Performance	2006-2009	Takeuchi et al. (1986) Graff (2007) Baines et al. (2006)
Phase of Quantification	2009-2014	Vinodh et al. (2012) Achanga et al. (2012) Ramachandran et al. (2013)
Phase of Sustainability	2014- 2019	Cherrafi et al. (2016) Hartini et al. (2015) Vanichchinchai (2019) Bashar et al. (2019)

1.2. Discovery Phase (1970-1990)

Drucker (1971) was the first to bring Japanese work management culture into limelight although methods were not elaborated. With his paper, a need and scope to understand the Japanese work culture emerged. The effectiveness was still a question as methods were not known and the underlying philosophy was yet to be understood. The Japanese management tend to make decisions by consensus, with capabilities to adapt to multidirectional situational demands. It reflects on the diversified balance in decision-making and flexibility of the strategy. Developing young people, job enrichment and informal approach being the key highlights of implementation process, its results were overwhelming. Sugimori et al. (1977) threw light on the Toyota production System and Kanban systems. They highlighted the concepts of ‘Just in Time’ and ‘respect for human’. Only necessary products, at necessary time, in necessary quantity need to be produced. The practice was challenging as it has been mastered by the creators themselves with diligent work for over twenty years. Cultural adaptability was a time consuming and hectic process for the workforce. The myth that productivity and quality levels are determined by plants location was busted by Krafcik (1988). He came up with a fresh conclusion that lean can be implemented in any plant location without bargain in quality, productivity and performance. The major hindrance was the complexity of lean and the workers psychology to resist to the more dynamic work culture of discipline and skill. He identified the primary indicators of plant performance as productivity, quality and flexibility. The plants that most effectively balance productivity, quality and flexibility to suit their particular market niches have a decided advantage. Corporate parentage and culture do appear to be correlated with plant performance; the level of technology does not.

1.3. Dissemination Phase (1991-1996)

Berkley (1992) discussed the impact of material handling by studying various models for Kanban buffer capacities and periodic material handling. It provided the finer idea of operations, one can alleviate the limiting trade-offs in cost and effectiveness. As stated by Warneckea and Huser (1995), lean is an intellectual approach consisting of a system of measures and methods to bring a competitive state in a company These set of standards need to be modified as every organisation has different goals to achieve with existing set-ups. In the light of the changing circumstances, the paper provides a food for thought to restructure the outdated production industries. The feasibility is the only obstruction because of high costs or inherent limitations. Another challenge is worker psychology as flexibility, quality and team work is misunderstood as control, exploitation and surveillance respectively.

1.4. Implementation Phase (1997-2000)

Kippenberger (1997) reflects lean thinking as an antidote to ‘muda’ or waste but its implementation is too difficult in its complete shape. A global scope to lean thinking is embodied in his work. The only dilemma is its acceptance levels and fear of failure in new scenario of activities. Cappeli and Rogovsky (1998) emphasizes that employee involvement drives the industry to a new curve of cultural freedom. In the hustle and bustle of decision making, success rate of good decisions may be poor but immaterial as long as it improves for the better. Further, individuals will be enthusiastic about decision-making powers which cultivate as agents of change and continuous improvement. In certain instances, decisions of same scope might broil a conflict in interest which might deteriorate relationships for which professional decorum will command respect within the organization. Yingling et al. (2000) developed mathematical models to improve the systems and used simulation to assess the better potentials against existing ones. Although models are based on certain assumptions whose reflections are an ideal state, still the chances to predict for the enhanced productivity, quality and performance increases. During this phase, difficulty was found in mastering the shop-floor principles to success.

1.5. Enterprise Phase (2001-2006)

Fairris and Tohyama (2002) integrated industrial relations to lean production. They suggested lean production responsible for labour management co-operation and productive efficiency of industrial relations. Amidst lack of institutional mechanisms and reduced safety and health issues as resistive forces, workers job enrichment, satisfaction, innovative life style propelled them to contribute to the wheel of progress in the industry. Hines (2004) emphasized on the development and localisation of lean concept. Lack of human integration and limited applicability outside high volume repetitive manufacturing environments was evident. To encourage value and cost, tactical to strategic decisions were integrated to supply chain and new product development endeavours. Liker (2004) highlighted the partnerships to be the life blood of supply chains of the scale driven, technology intensive global economy. The emphasis was to build trust, transparency and loyalty to achieve the relationship goal. Lean economic goal was to set the target price based on a reason, not by mere wants and needs. Doolen and Hacker (2005) developed a survey instrument to assess the implementation of lean practices within an organisation. It was well inferred that challenging conditions limit the applicability of lean, so the need of a system of evaluation which would act as a base for conducting surveys was critical.

1.6. Performance Phase (2007-2009)

Takeuchi et al. (1986) dealt with the speed and flexibility in product development which required high effort from the project team. Lean Process and Product Development (LPPD) is a propelling design to enhance the speed and flexibility aspects of product development. Sometimes, contradictory goals within the same product or process may be a hindrance to the development process along with its adaptability. Graff (2007) concentrated on lean organisations and the use of “less of all resources” than that used by their traditional counterparts. It was never easy to achieve and sustain integrated coherence. Workers also lost focus and the vision of integrated format. But it was confirmed that integrating and harmonising the total implements of an organisation creates the competitive advantage. Baines et al. (2006) suggested that new product development is "the state of the art" of lean to product design, engineering and development. The responsibilities of design can be segregated into chunks by competent individuals for better innovation. Human tendencies to wear out and lack of pace in work can nullify the impact of lean. As a remedial, a Chief Engineer should be an able and dynamic personality of influence who can take bold decisions.

1.7. Quantification Phase (2010-2013)

Vinodh et al. (2012) emphasized the use of structural equation modelling to determine the critical factors in lean practices towards success. The models are based on assumptions (ideal conditions), so interpretations have to be adjusted in practice. Lean has got enormous number of principles and practices which can be converted into equations. Equation modelling mostly is industry specific or process specific and may not be suitable universally. Achanga et al. (2012) developed a decision support tool: The Fuzzy-Logic advisory system. Although the validation is difficult, the costs, readiness status, level of value-add to be achieved (impact/benefits) studied yields better control. In this preliminary quantification phase, heuristic rules is implemented which may create ambiguity in further research. Ramachandran et al. (2013) solved complex problems by the use of multicriteria decision making. Every aspect of human behaviour and processes can be put into this method of decision making. It is subject to the trade-off that a mathematical output may contradict a human conscience in making a particular decision.

1.8. Sustainability Phase (2014-2019)

Hartini et al. (2015) studied and analysed various frameworks to bring about a clear connection between lean and sustainability with improved performance. They felt a strong and complete articulated picture of lean is yet to be proposed. Directional investigation can be carried out on the topic based on this analysis. A strong issue may be the validity and reliability issues in actual operating environments of such theoretical frameworks. Cherrafi et al. (2016) overviewed the integration of lean, sustainability and six sigma management systems. This analysis identifies time gaps which would propel research in new and proper directions. The uncertain large scale domain of lean and sustainability is yet to be revealed. Vanichchinchai (2019) explored the lean and supply chain relationships as a novel attempt. The supply chain dynamics may change with demand patterns. Vast areas exist to be exploited into fresh dimensions of research in this field.

The eight best/ frequently used techniques are chosen to predict their rank in three different industries implementing lean practices (Table 2). Lean was developed by Toyota automotive company and hence its techniques. In this paper, we have selected the eight most frequently used techniques as depicted by its creators like Taiichi Ohno and lean experts like J.K.Liker (2004) in his book "The Toyota Way" and Pascal Dennis (2016) in his book "Lean production Simplified" followed by research articles used for survey of literature regarding techniques.

These techniques are as shown in Table 2.

1.8.1. Framework

The framework depicts a structured view of evolution of lean practices from the sphere of scientific method. Lean strategies comprises of two components: tools and techniques. Tools are developed from the scientific approach that propel the system to effective and efficient processes. When tools are validated and become reliable, two or more tools may combine to give a structured work module called a technique specified to perform a certain task. Proven in long-term these tools and techniques are referred to as Principles. The application and execution of the principles is not always possible due

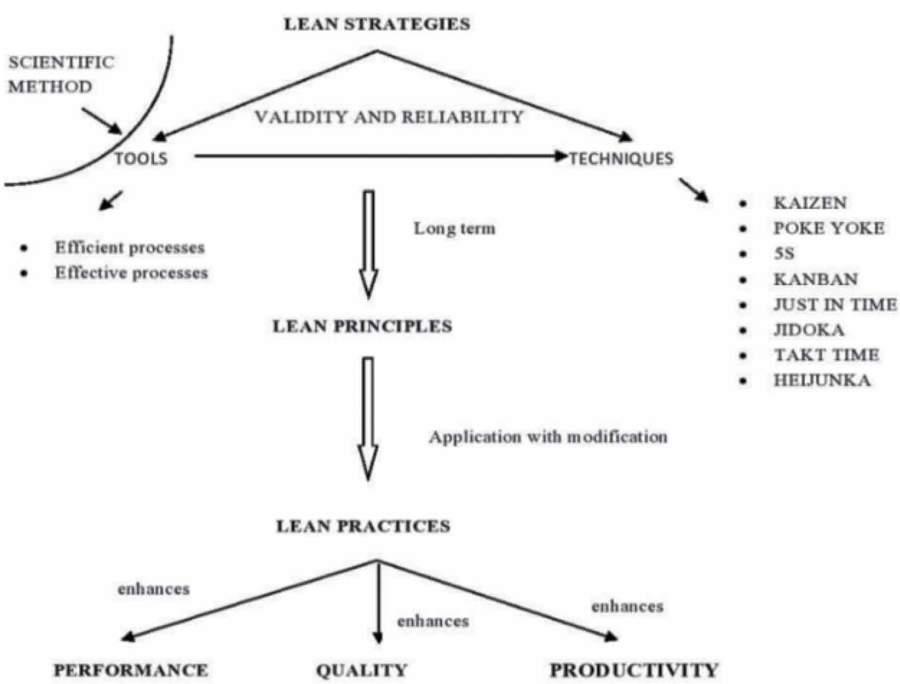
Table 2. Techniques and their meanings

SL	Technique	Meaning
1.	Kaizen	Continuous improvement of work practices and personal efficiency.
2.	Poke-yoke	Mistake-proofing or ability of machines to detect mistakes
3.	5S (sort, set-in-order, shine, standardize, sustain)	A stabilizing standard
4.	Kanban	A visual tool/ card used to achieve just-in-time production
5.	Just-in-time	To produce right item at right time in right quantity.
6.	Jidoka	Intelligent workers and machines identifying errors and taking quick countermeasures.
7.	Takt-time	The actual time to perform a process or how frequently we must produce a product.
8.	Heijunka (Production levelling)	Distributing the product volume and mix evenly over time.

to variety of changing circumstances. So, principles are modified to have a practical orientation to be termed as practices. These practices enhance the performance, quality and productivity of the system.

The best eight techniques identified for first six phases were Kaizen, poke-yoke, 5S, Kanban, Just-in-time, Takt time and Heijunka (Figure 1). This paper is an attempt to rank these techniques with respect to the seventh phase of Lean i.e. Lean and Sustainability using the analysis technique called Grey Relational Analysis.

Figure 1. Position of techniques in the paradigm of scientific method



2. RESEARCH METHODOLOGY

2.1 Mathematical Method Used: Grey Relational Analysis

Grey Relational Analysis technique (Deng, 1982) is an effective method used to solve uncertainty problems with discrete information. It is superior to other Multi Criteria Decision Making (MCDM) techniques while analysing qualitative attributes converted into quantitative scale values (Likert scale) which are to be normalized to determine the relative performance of attributes. The opinions in the problem of this research problem are discrete values numbered in Likert scale (1 to 7) which are to be transformed into meaningful insights under uncertainty. Moreover, the techniques selected for opinions are qualitative constructs which are transformed into quantitative equivalents using scale values with a certain degree of unpredictability. These features of Grey analysis justify its suitability to be selected as the method for analysing the concerned problem. The procedure of Grey Relational Analysis is as follows:

STEP 1: Tabulate the 7-point Likert scale values/opinions of the experts(columns) and the techniques (rows) obtained through a structured questionnaire about the implementation of lean techniques in industries A,B and C.
STEP 2: Add each technique's Likert opinions individually for all the eight techniques.($\sum X_i$ (i=1 to 12)).
STEP 3: Find the Grey Number.

Grey Number = ($\sum X_i$ /n)

where 'n' is the number of experts.

STEP 4: Divide the Grey Number by maximum scale value (7) to obtain the maximum value in scale (from seven) { Gij_{max} }.
STEP 5: Find the normalized value {Gij* = Grey number/Gij max). for all the techniques in a particular industry.
STEP 6: Predict the Rank by observation of the normalized value. (Highest value= Rank 1; then descending down to the eighth with lowest value).
STEP 7: Repeat the procedure for data of each industry under consideration.

The Grey Method is summarized as:

$\sum Xi$ represents the sum of all the opinions based on Likert scale out of 84(max; 7*12)
Gij is grey number (= $\sum Xi/12$)
Gij_{max} is the maximum value in scale= 7
Gij*= Normalized value (= Grey number/Gij max)

A Grey number is defined as the value of the summation of all the opinions for a particular technique divided by the number of observers. Grey number divided by maximum value of scale gives normalized value. The normalized value multiplied by weightage of each expert gives the value of the "technique" used to predict the rank. Here, as all experts have ten years and above experience the weightage of each is 1. Thus, the normalized values can directly be used to predict the rank.

2.2 Scale Used: LIKERT "7-Point" Scale

The Likert scale (Flynn et al.1990, Dawes 2008) is selected to address the problem as the data requirements are of interval type. Further, there is a need to summate it to predict the rank of the attributes for which the scale values are assigned. The Likert scale involves opinions and the value assigned to them. Very Poor was valued '1' followed by Poor'2', Medium poor'3', Fair '4', Medium Good '5', Good '6' and Very Good '7'. This scale was used to extract qualitative opinions from experts.

2.3 Survey and Analysis

Twelve experts with more than ten years experience of lean adaptation and practices in Indian manufacturing industry gave their valuable opinion which forms the database for the grey analysis. Three industries viz.a) Textile, b) Automotive spare parts and c) Electrical and Electronics industries were considered in the eastern India representing the first, second and third industrial revolution eras and its adaptability towards the lean techniques and hence degree of embracing lean strategy in the seventh generation of lean. The industries have been named as A, B and C respectively. A, B and C reflect the IR 1.0, IR 2.0 and IR 3.0 when we delve into the origin of these industries in the world. Moreover, the feasibility of finding these industries in the vicinity was another plausible reason for their selection. Further, the lean practices that were implemented in these companies has a special charm pertaining to the present state of these industries of such rich history. The experts are not related to the chosen industries and hence the opinions are genuine (Tables 3-8).

Table 3. INDUSTRY A: The textile industry

Techniques	Experts											
	1	2	3	4	5	6	7	8	9	10	11	12
Kaizen	5	6	4	5	6	6	6	7	7	6	6	5
Poke-yoke	7	7	6	6	7	6	6	5	6	6	6	7
5S	7	7	7	7	7	6	6	6	6	6	5	4
Kanban	3	4	4	5	6	6	4	4	6	5	4	5
Just in time	3	4	5	5	3	4	6	6	7	7	6	6
Jidoka	6	6	6	6	5	4	3	2	6	6	6	6
Takt time	2	3	3	3	3	4	3	2	2	3	4	4
Heijunka	5	6	6	6	6	6	7	7	6	6	6	6

Table 4. Rank prediction

Technique	ΣX_i (i=1 to 12)	$G_{ij}=\{\Sigma X_i/12\}$	G_{ij} (max)	$G_{ij}^*\{=G_{ij}/G_{ij}(\max)\}$	Rank
Kaizen	69	5.75	7	0.82	4
Poke-yoke	75	6.25	7	0.89	1
5S	74	6.16	7	0.88	2
Kanban	56	4.66	7	0.66	7
Just in time	62	5.16	7	0.73	6
Jidoka	62	5.16	7	0.73	5
Takt time	36	3.00	7	0.42	8
Heijunka	73	6.08	7	0.86	3

Table 5. INDUSTRY B: The automotive spare parts industry

Techniques	Experts											
	1	2	3	4	5	6	7	8	9	10	11	12
Kaizen	5	6	7	6	5	6	7	6	6	5	5	6
Poke-yoke	5	6	6	5	6	5	6	6	5	4	5	6
5S	7	6	7	7	6	6	7	6	7	6	7	6
Kanban	5	5	6	5	6	7	6	5	4	5	6	6
Just in time	3	4	3	5	4	4	5	5	4	4	5	6
Jidoka	4	3	4	4	5	4	5	4	6	5	6	5
Takt time	5	6	5	6	6	5	4	5	6	7	6	4
Heijunka	4	5	6	6	5	6	7	7	6	5	5	4

Table 6. Rank prediction

Technique	ΣX_i (i=1 to 12)	$G_{ij}=\{\Sigma X_i/12\}$	G_{ij} (max)	$G_{ij}*\{=G_{ij}/G_{ij}(max)\}$	Rank
Kaizen	70	5.83	7	0.833	2
Poke-yoke	65	5.41	7	0.773	6
5S	78	6.50	7	0.928	1
Kanban	66	5.50	7	0.785	3
Just in time	52	4.30	7	0.619	8
Jidoka	55	4.50	7	0.642	7
Takt time	65	5.41	7	0.773	5
Heijunka	66	5.50	7	0.785	4

Table 7. INDUSTRY C: The electrical and electronics industry

Techniques	Experts											
	1	2	3	4	5	6	7	8	9	10	11	12
Kaizen	6	6	5	6	5	5	6	5	7	6	7	6
Poke-yoke	7	6	6	7	5	6	5	5	6	5	6	7
5S	4	5	5	4	4	5	6	6	5	5	6	5
Kanban	5	6	5	5	6	6	6	5	6	7	6	7
Just in time	4	5	4	5	3	4	5	6	5	5	6	5
Jidoka	5	5	4	5	6	6	5	4	5	4	4	5
Takt time	2	3	4	4	4	5	4	5	5	4	4	5
Heijunka	4	5	4	5	5	5	4	6	6	4	5	4

Table 8. Rank prediction

Technique	ΣX_i (i=1 to 12)	$G_{ij}=\{\Sigma X_i/12\}$	G_{ij} (max)	$G_{ij}^*\{=G_{ij}/G_{ij}(max)\}$	Rank
Kaizen	70	5.83	7	0.833	2
Poke-yoke	72	6.00	7	0.857	1
5S	60	5.00	7	0.714	4
Kanban	70	5.83	7	0.833	3
Just in time	57	4.75	7	0.678	6
Jidoka	58	4.83	7	0.690	5
Takt time	49	4.08	7	0.583	8
Heijunka	57	4.75	7	0.678	7

3. RESULTS AND DISCUSSION

From Table 9, the "importance of the best techniques" of lean in Sustainability phase is:

Poke-yoke (0.89)> 5S (0.88)> Heijunka (0.86)> Kaizen (0.82)> Jidoka (0.73) = Just in time (0.73)>Kanban (0.66)>Takt time(0.42)

Poke-yoke or mistake proofing has emerged as the most important technique in the sustainable phase of lean implementation. As clearly visible, mistakes lead to waste which deteriorates the sustainable aspects or pillars- social, economic and environmental. The 5S technique emphasizes the culture of work and then standardisation of procedures which aptly follows mistake-proofing. The third technique of importance is Heijunka or production levelling. The complexity of industrial processes has made this technique of enormous importance. The fourth technique called kaizen is 'incremental continuous improvement' whose integrated approach is a fundamental aspect of lean philosophy. Jidoka or autonomation (= automation with human touch) is the fifth ranked technique among the eight best considered. Work culture is finely ingrained with this technique along with the country's technological frontiers. The sixth rank is actually a tie with fifth and is called Just-in-time. It has close correlation with jidoka and work culture of the nation. Kanban, which was one of the pioneers of early lean management era has dropped down to seventh position. The last best

Table 9. INDUSTRY A: The textile industry

Techniques	Rank
Poke-yoke	1
5S	2
Heijunka	3
Kaizen	4
Jidoka	5
Just in time	6
Kanban	7
Takt time	8

technique in the list is Takt-time or cycle time which has become a second nature in the growing era of advanced technology (Tables 9-10).

Thus, the “importance of the best techniques” of lean in Sustainability phase is:

5S (0.928)> Kaizen (0.833) > Kanban (0.785) = Heijunka (0.785)> Takt time (0.773) = Poke-Yoke (0.773) > Jidoka (0.642) > Just in Time(0.619).

Table 10. INDUSTRY B: The automotive spare parts industry

Techniques	Rank
5S	1
Kaizen	2
Kanban	3
Heijunka	4
Takt time	5
Poke-yoke	6
Jidoka	7
Just in time	8

5S swipes the first spot in automotive spare part industry.5S represents sort, set in order, shine, standardize and sustain. It is followed by kaizen and Kanban in second and third spot respectively. Heijunka equals Kanban and has the fourth spot followed by Takt time and poke-yoke having same degree of importance at fifth and sixth spot respectively. The seventh spot is acquired by Jidoka, while just in time ends up in the eighth spot (Table 11).

Thus, the “importance of the best techniques” of lean in Sustainability phase is:

Poke-yoke (0.857)> Kaizen (0.833) = Kanban (0.833)> 5S (0.714)> Jidoka (0.690) > Just in time (0.678) > Heijunka(0.678) > Takt Time(0.583)

Table 11. INDUSTRY C: The electrical and electronics industry

Techniques	Rank
Poke yoke	1
Kaizen	2
Kanban	3
5S	4
Jidoka	5
Just in time	6
Heijunka	7
Takt Time	8

Mistake proofing again tops the chart of most popular techniques of lean in electrical/electronics industry. Kaizen or continuous improvement ranks second with equal priority to Kanban. It is followed by 5S, Jidoka, Just in time, Heijunka and Takt time.

4. CONCLUSION

The present analysis marks a clear shift in trend of lean techniques in sustainability with respect to previous phases and identifies the best set of techniques to realign the mode of operations in the present context of three industries each representing the three phases of industrial revolution i.e. IR 1.0, IR 2.0 and IR 3.0 respectively. The industry A (Textile industry) with origin from IR 1.0 has implemented lean techniques where mistake-proofing, 5S and production levelling (Heijunka) tops the list. It signifies that the ability of machines to detect mistakes is the advancement in technology in this industry. The standardisation process, 5S marks that making systems sustainable is the key goal of the industry as well. As evident, production levelling is always a cornerstone to balance capacity and demand which justifies the third spot effectively. The industry B (Automotive spare parts) has standardisation technique 5S in rank 1 which signifies how part making is done through using lean techniques for batch production. It is followed by Kaizen which demystifies the concept of continuous improvement in operations. The third most important technique is Kanban which prioritizes which work to be processed in what order through coloured cards. It also shows the industry's' transit to JIT production. The industry C (Electrical/Electronics) represents IR 3.0 in origin where poke-yoke or mistake proofing emerges as the most important technique. It reflects that the industry produces error-free components like chips etc. on a large scale. It is followed by Kaizen (JIT transit in production) and Kanban (visual aid to prioritize work flow) respectively.

These results justify the qualitative techniques that are quantified through the use of Grey Relational Analysis technique. This analysis has a very fragrant perspective to the manager/ decision maker. The shift in trends can be observed and 4M's (Men, Machine, Material, and Methods) can be channelized in the right direction at the right time. It would help in streamlining operations, reducing resistance to market complexity (fluctuating demands), reduce costs and improve competitive advantage of industries. The scope of the analysis can be extended to various regions over more number of techniques to find the present trends of sustainable lean to acquire the modern shift in trends of lean philosophy.

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