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In Pursuit of Lean Six Sigma: A Systematic Review

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Abstract
The purpose of this paper is to develop a systematic framework of lean six sigma according to its systematic process improvement methodology; Recognize, Define, Measure, Analysis, Improvement and Control (RDMAIC). Using this framework, methodology the decision makers will have a systematic approach for continued improvement. The methodology involves in the review study of 56 papers related to LSS from well known database searches. Today's service design of current improvement processes in many industries suffering from deficiency such as quality level, lack of knowledge and aspiration with too much difficulty in India. Success of Six Sigma established the mixture of power of team and processes. The entire quality business will not only endow with the high quality and service, but will also function at a lower cost with higher efficiency for all the business process optimization. The success of six sigma development has generated giant interest in this business world.

Keywords: Lean Six Sigma (LSS), RDMAIC, Key tools of RDMAIC.

Introduction

Lean six-sigma (LSS) is a methodology that relies on a collaborative team effort to improve performance by systematically removing waste [1] [2]. It is the single most effective problem-solving methodology for improving business and organizational performance [3] [4] [5].

Motorola first introduced the Six Sigma program in the late 1980s [6] [7] [8] with the aim of increasing profitability by reducing defects [9]. General Electric (GE) followed the approach of their manufacturing sites and later at their financial service divisions. After that, Six Sigma was thought to be applicable to all processes and transactions within GE [10]. Lean Six-Sigma has now evolved from a quality improvement program [11] [12] [13] [14] to an overall business strategy executive system and business-results-oriented program which seems more total than total quality management [16].

LSS is a highly disciplined process [17] that helps us focus on developing and delivering near-perfect products and services [18]. The central idea behind Six Sigma is that if you can measure how many "defects" [19] you have in a process, you can systematically figure out how to eliminate them and get as close to "zero defects" as possible [20]. The integration of the two approaches improves efficiency and accuracy and helps to achieve CI faster than the implementation of each approach in isolation [21] [22]. There are noticeable limitations in the fields of research into areas of LSS [23] [24] [25] [26], but the benefits of applying Lean and Six Sigma in parallel are noted in many case study papers in both the manufacturing and service sectors [27] [28] [29].

LSS is both a business improvement strategy and a methodology to measure process performance [8] [16] [30]. It is used to increase profits by eliminating defects, waste, and variability and to find the causes of mistakes in products, processes and services to increase yields. It focuses on the customer is the top priority [31] and performance standards are based on actual customer input so that process effectiveness can be measured and customer satisfaction can be predicted [32].

The word sigma or the symbol "σ" is used in statistical notation to represent the standard deviation of a population [33] [34]. The standard deviation is also used as a general measure of variation in any kind of product or process [18]. With six standard deviations between the process mean and the customer's specification limit [35] [36] [37] [38], we arrive at 3.4 defects per million opportunities (DPMO) [39]; i.e. a 99.9997 percent yield [40] [41]. Before the Six Sigma technique was introduced, a three-sigma level of variation was regarded as being fairly good quality performance [3]. These are done through powerful analytical and statistical tools and techniques such as Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Statistical Process Control (SPC) [42], Design of Experiments (DOE) [2], Analysis of Variance (ANOVA), etc. [43]. It may be acceptable for a product or process having only a single or a few stages. It is not good enough for many products that are the result of hundreds of thousands of stages, such as automobiles and computers.

Literature Review

Motorola's Bill Smith initiated a Six Sigma almost two and a half decades ago building on the philosophy, principles, and methods of Deming's Total Quality Management [44] [45]. Since then, thousands of organizations have become Six Sigma companies by adopting specific training and project management practices [45] [46]. The use of Six Sigma has been relatively high among many western organizations till now, see, for example, Inozu et al. (2006) [47], Raisinghani et al. (2005) [32], and Antony (2004b) [48], but there exists a diversity of opinion among researchers regarding the actual benefits of Six Sigma. Literature explaining about the positive effects on financial performance can be found in e.g. Jones Jr. (2004) [49], Goh (2002) [39], Caulcutt (2001) [50], and Rucker (2000) [51]. However, McAdam and Lafferty (2004) [52], Senapati (2004) [17], and Paul (1999) [53], for instance, express a more pessimistic view regarding the benefit of Six Sigma investments. With Six Sigma's industries based origins, it becomes important to assess the

state of the related academic contributions now that the associated field of study is maturing [44].
Snee R. D., Hoerl, R. W., suggested that Six Sigma, a process-focused strategy and methodology for business improvement, is a strategic approach that we have seen work across all processes, all products, and all industries [54] [55-59]. Sokovic et al. [60] and Hahn [61] proposed that Six Sigma is an effective way to find out where are the greatest process needs and which are the softest points of the process [60] [61].
It is emphasized that LSS makes a dramatic reduction in the customer defined defect rate [Lindeman et al. 3 (p. 195)] [62] [63], effective business strategies [64] [46], solution for empirical problems ranging from semi structured to well structured [65] and future trend for combining tools & methodologies [61]. Six- sigma DEMAIC was found to be approaching 3-sigma since 1.8, while the process yield increased 93% from a very low figure 61.8% [64].

Describing Lean Six-Sigma Concept

LSS is a system of management that results in a steady pulping of projects that are ready for improvements. The successful implementation of LSS can result in benefits in the areas of cost reduction, increased profit, increased market share and enhanced business competitiveness, mainly by the reduction of the cost of poor quality (COPQ) [66].
COPQ usually includes appraisal costs, internal failure costs, and external failure costs. Appraisal and inspection costs are often incurred, for example, in checking finished goods before they leave the factory, inspecting purchased equipment/supplies, proof reading financial and legal documents, reviewing charges prior to billing, etc. Internal failure costs are those for repairing, replacing, or discarding work in progress or completed work before the delivery of the product to the customer [9].
The table below gives long-term DPMO values corresponding to various short-term sigma levels [4] [67].

Table 1: DPMO Values Corresponding to Various Short Term Sigma Levels

Sigma level	Sigma (with 1.5σ shift)	DPMO	Percent defective	Percentage yield	Short-term C_{pk}	Long-term C_{pk}
1	-0.5	691,462	69%	31%	0.33	–0.17
2	0.5	308,538	31%	69	0.67	0.17
3	1.5	66,807	6.7%	93.3%	1.00	0.5
4	2.5	6,210	0.62%	99.38%	1.33	0.83
5	3.5	233	0.023%	99.977%	1.67	1.17
6	4.5	3.4	0.00034%	99.99966%	2.00	1.5
7	5.5	0.019	0.0000019%	99.9999981%	2.33	1.83

It must be understood that these figures assume that the process mean will shift by 1.5-sigma toward the side with the critical specification limit [68] [69]. In other words, they assume that after the initial study determining the short-term sigma level, the long-term C_{pk} value will turn out to be 0.5 less than the short-term C_{pk} value. So, for example, the DPMO figure given for 1 sigma assumes that the long-term process mean will be 0.5 sigma beyond the specification limit $(C_{pk} = -0.17)$, rather than 1 sigma within it, as it was in the short-term study $(C_{pk} = 0.33)$ [70]. Note that the defect percentages indicate only defects exceeding the specified limit to which the process mean is nearest. Defects beyond the far specification limit are not included in the percentages.

Normal Curves and Sigma

Six Sigma concepts can be better understood and explained using mathematical term Sigma and Normal Distribution [71]. The bell shape curve shown in Figure 1 is called "normal distribution" in statistical terms. In real life, a lot of frequency distributions follow a normal distribution, as in the case of delivery times in Pizza and other businesses. One of the characteristics of this distribution is that 68% of the area (i.e. data points) falls within the area of -2σ and +2σ on either side of the mean. Similarly, 4σ on either side will cover approximately 95.5% area. 6σ on either side from mean covers almost 99.7% area. A more peaked curve (e.g. more and more deliveries were made on target) indicates lower variation or more mature and capable process. Whereas a flatter bell curve indicates higher variation or less mature or capable process. To summarize, the Sigma performance levels One to Six Sigma are arrived at in the following way.

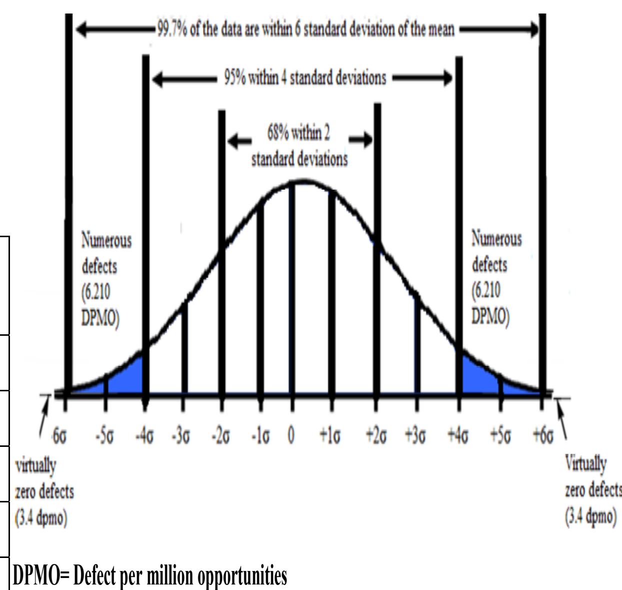

Figure 1: Standard Distribution Curve with Mean, Sigma Values and 4-Sigma Tolerance

For any process with a standard distribution (something that looks like a bell-shaped curve), the probability is 68.26% that the next value will be within one standard deviation from the mean. The probability is 95.44% that the same next value will fall within two standard deviations. The probability is 99.73% that it will be within three sigma and 99.994% that it will be within four sigma.

Table 2: Sigma Quality Level with Respect to Number of Parts or Steps

Overall Yiels Vs. Six Sigma Quality Level (Distribution Shifted +/- 1.5σ)				
Number of parts or steps	**+/-3σ**	**+/-4σ**	**+/-5σ**	**+/-6σ**
1	93.32	99.379%	99.9767%	99.99966%
7	61.63	95.733%	99.839%	99.9976%
10	50.08	93.96%	99.768%	99.9966%
20	25.08	88.29%	99.536%	99.9932%
50	3.15	73.24%	98.24%	99.98%
80	0.40	60.75%	98.156%	99.9728%
100	0.10	53.64%	97.700%	99.966%
150	----	39.38%	96.570%	99.949%
200	----	28.77%	95.45%	99.932%
300	----	15.43%	93.26%	99.898%
400	----	8.28%	91.11%	99.864%
500	----	4.44%	89.02%	99.830%
600	----	2.38%	86.97%	99.796%
700	----	1.28%	84.97%	99.762%
800	----	0.69%	83.02%	99.729%
900	----	0.37%	81.11%	99.625%
1000	----	0.20%	79.24%	99.661%
1200	----	0.06%	75.88%	99.593%
3000	----	----	50.15%	98.985%
17000	----	----	1.91%	94.384%
38000	----	----	0.01%	87.880%
70000	----	----	----	78.820%
150000	----	----	----	60.00%

The reviewed studies universally concluded the implementations of these transformations of strategic tools were successful in improving of regarding processes and outcomes. Since defects are cumulative, as more parts or more operations are added, the chance of producing a defective product goes up. With process drift as a factor, if the number of parts or process steps exceeds 1200, four-sigma processes are virtually incapable of making one good product. On the other hand, a Six Sigma process with 1200 parts or steps would still be producing a yield of 99.593% good products.

Methodologies

Six Sigma projects follow two project methodologies inspired by Deming's Plan-Do-Check-Act Cycle. These methodologies, composed of five phases each, bear the acronyms DMAIC and DMADV. DMAIC is used for projects aimed at improving an existing business process [13-15] [72]. DMADV is used for projects aimed at creating a new product or process designs. De Feo, Joseph A.; Barnard, William (2005) [73]. The DMADV project methodology, known as DFSS ("**D**esign **F**or **S**ix **S**igma"), features five phases: Define, Measure, Analysis, Design and Verify.

RDMAIC method

The DMAIC methodology follows the phase define, measure, analyze, improve and control, although PDCA could be used for process improvement to give a new thrust. Some organizations add a Recognize step at the beginning, which is to recognize the right problem to work on, thus yielding an RDMAIC methodology [79]. Webber et al. [74], Rosing et al. [75] LSS is introduced with model RDMAIC.
The RDMAIC project methodology has six phases:

- ***R**ecognize* the right problems and identify the projects.
- ***D**efine* the problems, the voice of the customer and their requirements, and the project goals, specifically.
- ***M**easure* key aspects of the current process and collect relevant data.
- ***A**nalyze* the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out the root cause of the defect under investigation.
- ***I**mprove* or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- ***C**ontrol* the future state process to ensure that any deviations from target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process.

Table 3: RDMAIC Implementing the Framework

Strategic steps	**Deliverables**	**Tools used**
Recognize	Recognization of right problems	Strategic view of business and identifying the projects
Define	Project charter or statement of Works (SOW)	Gantt chart/ Time Line Flow chart/ Process Map Quality function deployment (QFD)
Measure	Baseline figures	SIPOC (Suppliers, Inputs, Process, Outputs and Customers) or IPQ (Input Process Output) diagram
Analyze	Identified Root Causes	Cause and effect diagram 5-why Scatter diagram Regression ANOVA
Improve	Selected root causes and countermeasures Improvement Implementation Plan	Affinity diagram Hypothesis testing DOE Failure Mode Effect Analysis (FMEA)
Control	Control Plan Chart & Monitor Standard Operating Procedures (SOP) Corrective Actions	Control chart Poka-Yokes Standardization Documentation

Key Tools to Support the RDMAIC Process

The RDMAIC steps work because they are understandable and make sense. Before they can be applied, however the project leader should his or her team to scope the problems with the using of these key tools.

Business Process Mapping (SIPOC Diagrams):
SIPOC stands for suppliers, inputs, process, outputs and customer. SIPOC diagrams are graphical tools to identify all relevant elements of a business process and map the process flow before the project begins. They are usually used in the definition phase.

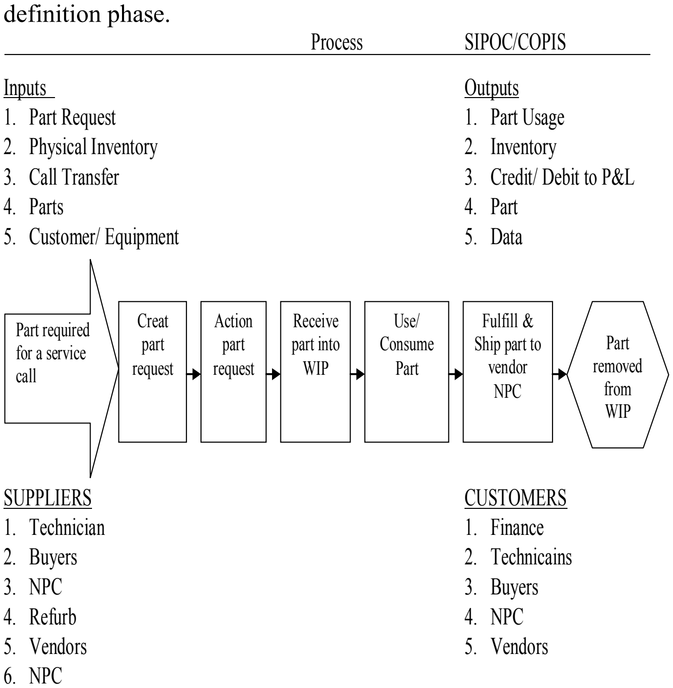

Figure 2: SIPOC Diagram of RDMAIC Process

How to do it

Step 1: **Supplier:** Whoever produces, provides, or furnishes the products or services for the input of the process, either an internal or an external supplier.

Step 2: **Inputs:** Material, resources and data required to execute the process.

Step 3: **Process:** A collection of activities that take one or more kinds of input and creates output that is of value to the customer.

Step 4: **Outputs:** The tangible products or services that result from the process.

Quality Function Deployment (QFD):
QFD is a systematic approach to prioritize and translate customer requirements (i.e., external CTQ) into appropriate company requirements (i.e., internal CTQ) at each stage of product development to operations to sales and marketing to distribution. This method is usually used in the measure phase. It is also useful in design for Six Sigma (DFSS) and will be introduced in more detail in the DFSS section.

How to do it

Step 1: Determine the customer demands

Step 2: Customer competitive evaluation.

Step 3: Determine the technical requirement

Step 4: Interrelationship matrix between technical requirements.

Step 5: Relationship matrix between how and what

Step 6: Column weights

Step 7: Quality plan

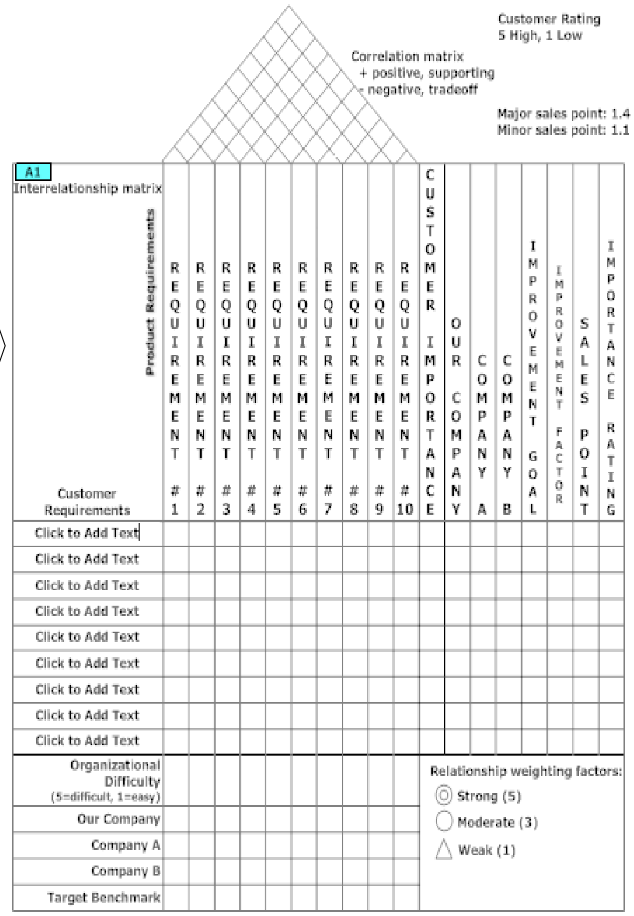

Figure 3: Quality Function Deployment of RDMAIC Process

Failure Modes and Effects Analysis (FMEA):
FMEA is a tool to reduce the risk of failures. It is also a tool to identify and prioritize CTQ at the measurement phase.

How to do it

Step 1: Identify the products, services, or processes.

Step 2: Identify the potential failure that would arise in the target process.

Step 3: Identify the causes of the effects and their likelihood of occurrence.

Step 4: Identify the current controls for detecting each failure mode and the ability of the organization to detect each failure mode.

Step 5: Calculate the RPN by multiplying the values of severity, potential causes, and detection.

Step 6: Identify the action for reducing or eliminating the RPN for each failure mode.

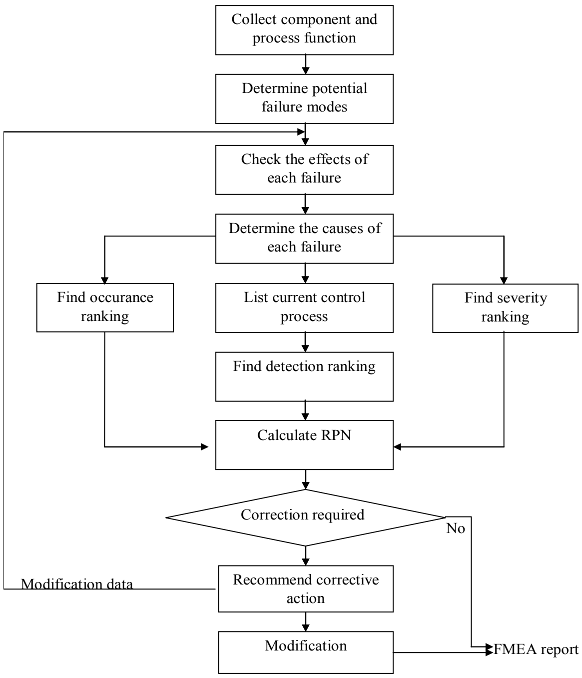

Figure 4: FMEA Procedure [78]

Measurement System Analysis (MSA):
A statistical evaluation of the measurement system must be undertaken to ensure effective analysis of any subsequent data generated for a given process/product characteristic. MSA is usually used in the measurement and control phases to validate the measurement system for the *y* and *x's*.

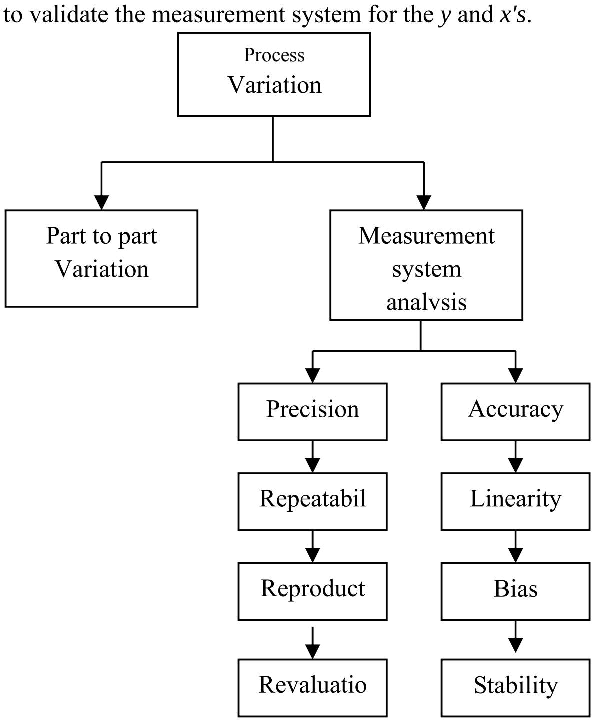

Figure 5: Measurement System Analysis

How to do it:

Step 1: Collect the data. Generally two to three operators, 10 units to measure, and each unit is measured 2–3 times by each operator.

Step 2: Perform the calculations to obtain% R&R.

Step 3: Analyze the results. A rule of thumb is that:

- %R&R<10%: measurement system is acceptable.
- %R&R between 10–30%: measurement system may be acceptable. We will make decisions based on the classification of the characteristics, hard applications, customer inputs, and the sigma level of the process.
- %R&R >30%: measurement system is not acceptable. We should improve the measurement system by finding problems and removing root causes.

5.1.1.5 Process Capability Analysis

Process capability study is a scientific and a systematic method that uses control charts to detect and eliminate the abnormal causes of variation until a state of statistical control is reached [76]. When the study is completed, you will identify the natural variability of the process.

5.1.1.5.1 Measures of Process Capability- Process Capability Indices:

We are often required to compare the output of a stable process with the process specifications and make a statement about how well the process meets specification. To do this we compare the natural variability of a stable process with the process specification limits. The C_p, C_{pk} and C_{pm} statistics assume that the population of data values is normally distributed. Assuming a two-sided specification, if μ and σ are the mean and standard deviation, respectively, of the normal data and $USL, LSL \& T$ are the upper and lower specification limits and the target value, respectively, then the population capability indices are defined as follows.

$$C_p = \frac{USL - LSL}{6\sigma}$$

$$C_{pk} = \min\left[\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right]$$

$$C_{pm} = \frac{USL - LSL}{6\sqrt{\sigma^2 + (\mu - T)^2}}$$

- Process capability indices measure the degree to which your process produces output that meets the customer's specification.
- Process capability indices can be used effectively to summarize process capability information in a convenient unit less system.

C_p and C_{pk} are quantitative expressions that personify the variability of your process (its natural limits) relative to its specification limits (customer requirements).

How to do it:

Step 1: Select the process to be analyzed and collection of data.

Step 2: Identify specific limits according to which capability analysis will be evaluated.

Step 3: Verify the process is under statical control.

Step 4: Analyze data distribution.
Step 5: Estimate capability indices.

Cause–Effect Diagram (Fishbone Diagram):
This is also known as Cause & Effect Diagram, Fishbone Diagram, Ishikawa Diagram, Herringbone Diagram and Ishikawa Diagram.

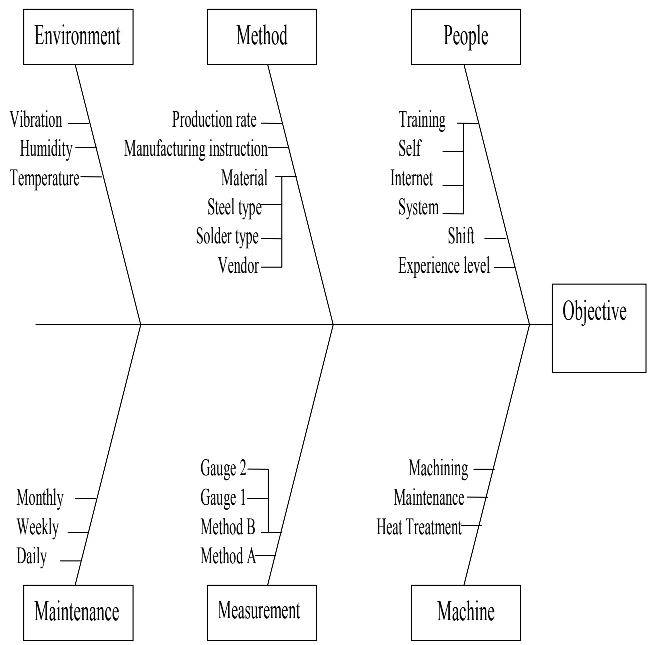

Figure 6: Cause and Effect Diagram

How to do it:
Step 1: Firstly, identify the problem and write it in a box, and draw an arrow pointing towards it. Think about the exact problem in detail. Where appropriate, identify who is involved, what the problem is and when and where it occurs.
Step 2: Identify the major factors and draw four or more branches of the large arrow to represent the main categories of potential causes.
Step 3: Brainstorm all the possible causes of the problem in each of the main categories and brainstorm possible causes of the problem. Explore each one to identify more specific causes of causes. Continue branching off until every possible cause has been identified. Where a cause is complex, you might break it down into sub-causes. Show these as lines coming off each cause line.
Step 4: Analyze the diagram. By this stage there should be a diagram showing all the possible causes of your problem.

Design of Experiments (DOE):
Design of experiments is a multi-purpose technique [27]. Its usage is not limited to physical experiments, but can be applied to simulate experiments [28], to the investigation of calculating the results of complex analytical expressions whose parameters are methodically varied or to other decision problems, where the effects of several factors are examined.

How to do it:
Step 1: Design the experiment
Step 2: Define factor constraints
Step 3: Add interaction terms
Step 4: Determine the numbers of run
Step 5: Check the design
Step 6: Gather and enter the data
Step 7: Interpret and analyze the data results

Response surface methodology (RSM):
The RSM is the most popular optimization method used in recent years [77]. This method is a collection of statistical techniques in which a response of interest is influenced by several variables and the objective is to optimize this response through determining the relationship between the response and the independent variables.
Some examples of the RSM applications per- formed for optimization of biochemical process are hydrolysis of pectic substrates, enzymatic synthesis of fatty esters, lipase-catalyzed incorporation of docosahexanenoic acid (DHA) into borage oil, alkaline protease production from Bacillus mojavensis in a bioreactor, butylgalactoside synthesis by-galactosidase from Aspergillus oryzae, biotransformation of 2-phenylethanol to phenylacetalde- hyde in a two-phase fed-batch system, lipase catalyzed esterification reactions, pectinase usage in pretreatment of mosambi juice for clarification, cholesterol oxidase production by Rhodococcusequi no. 23, phytase production by Pichia anomala and determination of reaction parameters for damaged starch assay [11], [68], [70], [79-85].

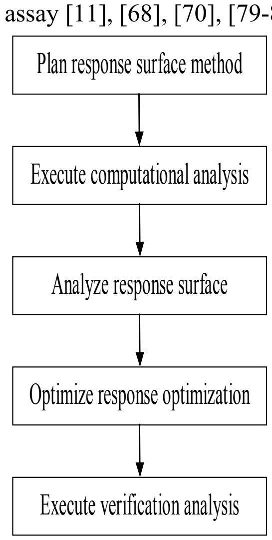

Figure 7: Response Surface Methodology (RSM) Flow Chart

How to do it:
Step 1: State the problem.
Step 2: Choose the response variable (y).
Step 3: Choose the factors (x's) and their levels and ranges.
Step 4: Determine the experimental plan (i.e. the design matrix).
i. To screen the x's to obtain the few, vital x's, we often use factorial experiments. In such cases, if the

number of runs is moderate and we have enough time and resources, we may conduct a full factorial experiment; if the number of runs is large or time and resources are limited, we may consider a fractional factorial experiment.

ii. To obtain the optimal response, we may conduct RSM, which is usually conducted after variable screening.

Step 5: Run the experiments under the prescribed conditions and collect the response data.

Step 6: Analyze the data collected using main effect plots, interaction plots, ANOVA, etc.

Step 7: Conclude the experiment and make recommendations. A confirmation run or a follow-up DOE is usually needed.

Advantages and Limitations of LSS

The analysis of LSS benefits in the business sector being identified in various case studies. Including all the research paper using these study top ten advantages cited in this paper.

i. Increase the productivity
ii. Reduce cost
iii. Increase profit and financial saving
iv. Reduce cycle time
v. Reduce number of defective items
vi. Reduce inventory
vii. Improvement in quality
viii. Increase competitive edge
ix. Improvement in all types of performance matrices
x. Improve market share

Many authors have argued that there are significant numbers of limitation of LSS. Some limitations are addressed as follows:

1. The limited number of practical applications of LSS integrated framework.
2. This framework (RDMAIC) is suitable for rather extensive of problem definition, diagnosis and the design of remedies. It is less suited for problem tasks of a smaller scope.
3. The limitation of generic versions of RDMAIC is not generally recognized in the practitioner's literature.

Conclusion

Based on these literature surveys it is found that Lean six sigma is a set of statical tool that act as a lens through which hidden problems can be identified and root cause uncovered, better equipping leadership to through tough issues. It provides execution so as to enable ongoing improvement in competitiveness and manufacturing and business operation. There are important themes cited in this paper which are key tools RDMAIC and benefits. Adoption of this strategy completely revolutionizes a business, organization and culture, allowing the chance for optimal success for business. These systems based processes with greater impact on big business performance. Six-Sigma has also provided the opportunities to make forward significant consumer focused initiatives across the worldwide organization. Product management and process through a statistical method for delighting the customers is a modern approach. According to this study it is concluded that Lean six sigma not only can benefit to business, but can transform it to becoming more agile and respond faster to change.

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