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Application of Six Sigma in Construction Industry

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ABSTRACT
Construction plays an important role in the economic growth of a nation. This project deals with the quality standards and customer satisfaction. The aim is to evaluate the quality of a multi-storey building by using six sigma. Six sigma concepts are used to reduce the variation and eliminate the root cause of defects. The data collected from the defect assessment sheets are calculated by study done in a residential building and the quality of brickwork, concreting, plastering, flooring and painting are analyzed. Although Six Sigma has been implemented in the manufacturing and other services industries. This study described the Six Sigma concept as a quality initiative that may be applied in the building industry. The principles, methodology, and metrics of Six Sigma are first discussed. The application of Six Sigma for improving the quality of internal finishes during construction is also explained. For that a case of residential building is done to find out the defects in brickwork, concreting, plastering, painting & flooring. These defects are then evaluated by applying DMAIC methodology of six sigma. Before applying DMAIC, the sigma level is calculated by defects per million opportunities (DPMO). It also suggests various improvising methods for quality of building by minimizing the defects. In this paper, DMAIC (Define, Measure, Analyze, Improve and Control) phase of six sigma is used to improve the quality of the building. The cause and effect diagrams and pareto charts are done in E draw max software and MS Excel. This methodology is applied to enhance the quality of the existing process by analyzing the defects, percentage of occurrence, possible causes, effects of defects and recommendations to overcome them.

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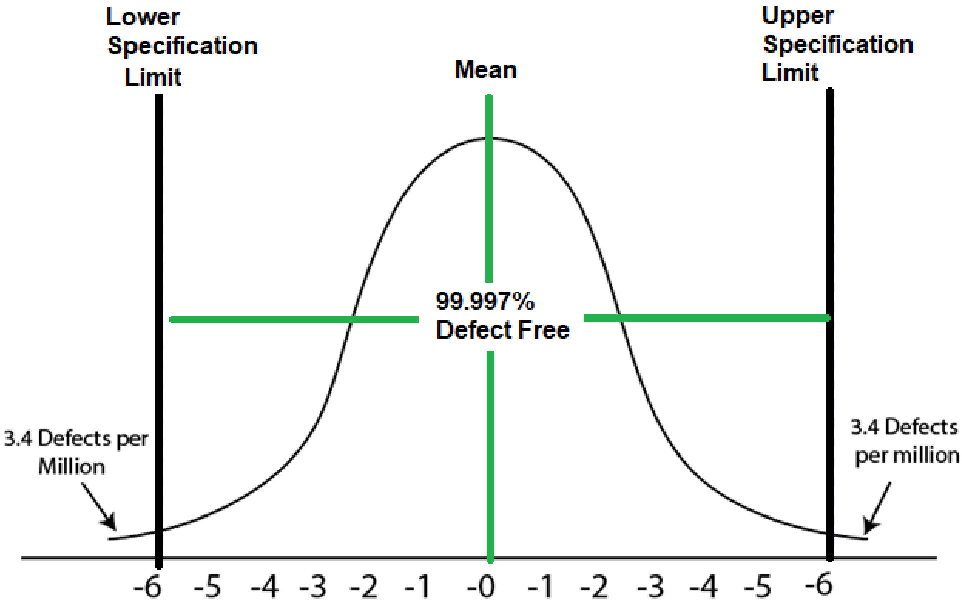
1. INTRODUCTION
1.1. General
Six Sigma is a quality-control methodology developed in 1986 by Motorola, Inc. The method uses a data-driven review to limit mistakes or defects in a corporate or business process. Six Sigma emphasizes cycle-time improvement while at the same time reducing manufacturing defects to a level of no more than 3.4 occurrences per million units or events. In other words, the system is a method to work faster with fewer mistakes. Six Sigma points to the fact that, mathematically, it would take a six-standard-deviation event from the mean for an error to happen. Because only 3.4 out of a million randomly (and normally) distributed, events along a bell curve would fall outside of six-standard-deviations (where sigma stands in for "standard deviation").

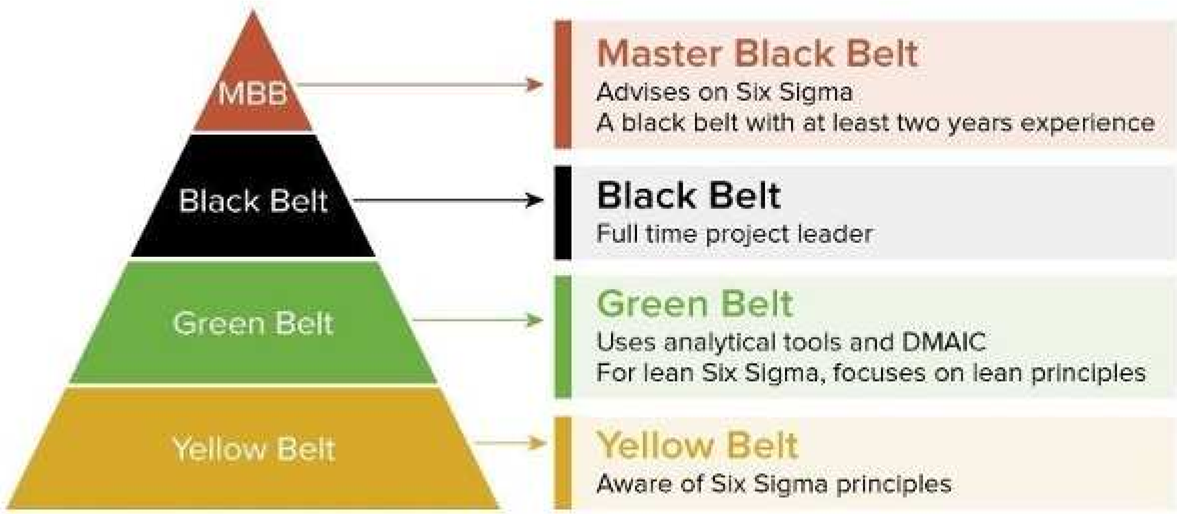


1.1. Six sigma- statistical curve

In recent years, Six Sigma has evolved into a more general business-management philosophy, focused on meeting customer requirements, improving customer retention, and improving and sustaining business products and services. Six Sigma applies to all industries. It advocates for qualitative measurements of success over qualitative markers. Therefore, practitioners of Six Sigma are those business people who use statistics, financial analysis, and project management to achieve improved business functionality. Six Sigma evolved to define numerous ideas within the business sphere and is sometimes confusing. First, it's a statistical benchmark. Any business process, which produces less than 3.4 defects per 1 million chances, is considered efficient.

A defect is anything produced outside of consumer satisfaction. Second, it is a training and certification program, which teaches the core principles of Six Sigma. It ranks among the foremost methodologies for making business processes more effective and efficient. In addition to establishing a culture dedicated to continuous process improvement, Six Sigma offers tools and techniques that reduce variance, eliminate defects and help identify the root causes of errors, allowing organizations to create better products and services for consumers.

The belt levels in Six Sigma are similar to the belt rankings awarded in the martial arts. Belts are titles awarded to practitioners based on their level of skill, experience, knowledge and training in Six Sigma principles. To understand how employees' strengths and skills can be applied in a Six Sigma project, it is helpful to understand what each belt signifies.



1.2. Sigma belts triangle

While most people associate Six Sigma with manufacturing, the methodology is applicable to every type of process in any industry. In all settings, organizations use Six Sigma to set up a management system that systematically identifies errors and provides methods for eliminating them. People develop expertise in Six Sigma by earning belts at each level of accomplishment. These include White Belts, Yellow Belts, Green Belts, Black Belts and Master Black Belts.

1.2. History Of Six Sigma

Experts credit Shewhart with first developing the idea that any part of process that deviates three sigma from the mean requires improvement. One sigma is one standard deviation. Six Sigma is a data-driven methodology that provides tools and techniques to define and evaluate each step of a process. It provides methods to improve efficiencies in a business structure, improve the quality of the process and increase the bottom-line profit.

In the 19th century, German mathematician and physicist Carl Fredrich Gauss developed the bell curve. By creating the concept of what a normal distribution looks like, the bell curve became an early tool for finding errors and defects in a process. In the 1920s, American physicist, engineer and statistician Walter Shewhart expanded on this idea

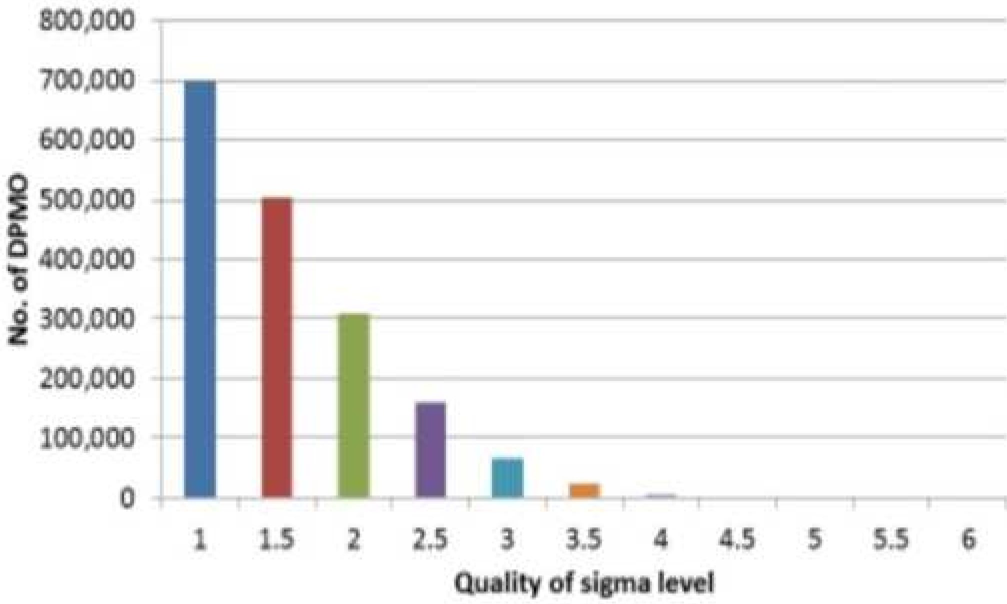
In the 1980s, Motorola brought Six Sigma into the mainstream by using the methodology to create more consistent quality in the company's products, according to "Six Sigma" by Mikel Harry and Richard Schroeder. Motorola engineer Bill Smith eventually became one of the pioneers of modern Six Sigma, creating many of the methodologies still associated with Six Sigma in the late 1980s. The system is influenced by, but different than, other management improvement strategies of the time, including Total Quality Management and Zero Defects.

1.3. Standards Of Six Sigma

The statistical representation of Six Sigma describes quantitatively how a process is performing. To achieve Six Sigma statistically — a process must not produce more than 3.4 defects per million opportunities. A Six Sigma defect is defined as anything outside of customer specifications. A Six Sigma opportunity is then the total quantity of chances for a defect. Process sigma can easily be calculated using a Six Sigma calculator. The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement projects. This is accomplished through the use of two Six Sigma sub-methodologies: DMAIC and DMADV.

The Six Sigma DMAIC process (define, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for incremental improvement. The Six Sigma DMADV process (define, measure, analyze, design, verify) is an improvement system used to develop new processes or products at Six Sigma quality levels. It can also be employed if a current process requires more than just incremental improvement.

Both Six Sigma processes are executed by Six Sigma Green Belts and Six Sigma Black Belts, and are overseen by Six Sigma Master Black Belts. Six Sigma at many organizations simply means a measure of quality that strives for near perfection. But the statistical implications of a` Six Sigma program go well beyond the qualitative eradication of customer-perceptible defects.



1.3. Graphical Overview of Sigma Level

It's a methodology that is well rooted in mathematics and statistics. The objective of Six Sigma quality is to reduce process output variation so that on a long term basis, which is the customer's aggregate experience with our process over time, this will result in no more than 3.4 defect parts per million (PPM) opportunities (or 3.4 defects per million opportunities – DPMO).

For a process with only one specification limit (upper or lower), this results in six process standard deviations between the mean of the process and the customer's specification limit (hence, Six Sigma).For a process with two specification limits (upper and lower), this translates to slightly more than six process standard deviations between the mean and each specification limit such that the total defect rate corresponds to equivalent of six process standard deviations.

Many processes are prone to being influenced by special and/or assignable causes that impact the overall performance of the process relative to the customer's specification. That is, the overall performance of our process as the customer views it might be 3.4 DPMO (corresponding to long term performance of 4.5 sigma)..Typically, when reference is given using DPMO, it denotes the long term capability of the process, which is the customer's experience. The role of the Six Sigma professional is to quantify the process performance (short term and long term capability) and based on the true process entitlement and process shift, establish the right strategy to reach the established performance objective. As the process sigma value increases from zero to six, the variation of the process around the mean value decreases. With a high enough value of process sigma, the process approaches zero variation and is known as 'zero defects. Decrease your process variation (remember variance is the square of your process standard deviation) in order to increase your process sigma. The end result is greater customer satisfaction and lower costs.

1.4. Scope And Objective

The objective of this paper is to study about quality management using six sigma and identify the key parameters that affect the quality in construction and to reduce the defects in construction. Quality is the key to success in case of any industry. For a vast industry like construction industry which relies on numerous departments as well as split up works, quality management usually becomes a hectic task. Since the implementation of quality seems inevitable as in any industry suitable quality assessment as well as implementation techniques has to be carried out suitably. The key objectives of this project include:

- Study principles of six sigma concept
- Analyze various tools and methodologies used
- Assess quality of the residence for following works:
  - Brickwork
  - Concreting
  - Plastering
  - Flooring
  - Painting
- Identify impact of defects and its root causes
- Suggesting ways for defect reduction

This project work focuses certain works of a completed residence and assess their defect occurrences. later this data can be analysed using six sigma method to effectively implement quality management. Hence this project serves as a guideline for implementing six sigma in construction and related fields. So the Six Sigma Concept can be used as an improvement process to address the individual problems that have occurred or can be used for preventive actions. The Scope of this paper includes:

- Ensure completed work meets specifications
- Reduce clients complaints
- Improve reliability of final work
- Reduce production costs
- Improve customer satisfaction
- Attain sustained quality of production process

2. LITERATURE REVIEW

2.1. General

A literature review is a detailed report of information obtained from the literature that are related to our topic of study. The review describe, summarize, evaluate and clarify this literature. It gives a base for the research and helps in determining the nature of the study. This section represents the review of literature collected from various journals and articles that are most relevant to the study

1. ***"Application of Six Sigma in construction",*** IJIRSET, vol.6, Issue-11;Shantanu Sathe, Dr. Satish B. Allampallewar, (2017)

Basic theory of six sigma & DMAIC studied in this paper. A case study on commercial building was conducted and Six sigma principles were applied for few internal finishing works such as Plastering &Painting. Later a defect assessment sheet has been prepared and common occurrences of defects listed.The improvement is presented in terms of process sigma and standard deviation. Implementation of quality tools for six sigma evaluation proves effective implementation of six sigma methodology throughout the process. Final results suggests possible remedies for the occurred defects, measures to prevent its occurrences in future projects as well as a control plan for maintaining defect free process progress throughout the project life.

2. '***Implementation of six sigma for quality Evaluation of RMC plant with DMAIC Methodology*',** IJERT;Vol.6, pp.153-157.Darpan Keshore (2017)

This paper analyzes the quality factors for an RMC plant. Feedback identified with customer satisfaction survey and suitable customer surveys. Final findings are ranked using relative important index scale. Proper analysis made using the implementation of defect sheet, pare to charts, control charts and histogram analyses. Later Sigma level calculated using DPMO .Statistical tools such as excel software and linear regression analysis were used to reach at the final conclusion that six sigma application helps to achieve and stabilize defect freee process management throughout the companies life time. This paper describes an idea to identify & analyze the major quality factors for RMC plant at Indore. The feedback of company identified with customer satisfaction survey which is ranked using relative important index (RII) Scale. The existing sigma 3 International Journal for Modern Trends in Science and Technology Sree Vidhya C: Quality Management in a Residential Building Using Six Sigma Construction Techniques level of the company has been found to be 2.03, it shows poor level of company. In order to validate manufacturing system's current status, improvement potential and solutions, statistical tools such as excel state software and linear regression analysis were used. This ensured that all decisions were based on actual data.

3. ***'Implementing and applying six sigma in construction',*** ASCE-.482-489- Low Sui Pheng and Mok Sze Hui (2018)

This study involves detailed review of the principles, methodology, and metrics of Six Sigma Implementation phases & training programs required are also explained. A case study of six sigma in the building industry is presented .Six sigma for improving the quality of internal finishes are also explained. In this paper a residential building is taken in which six sigma principles are applied for internal finishing work. The sigma level of the building is 3.36; set target sigma level of 4.5. The findings suggest that proper training and management support and minor changes in current work procedure can help improve the quality and ultimately customer satisfaction. Six-Sigma also provides scale to measure whether the quality has been improved or not

4. ***'Defects Reduction in High Rise Residential Building using Six Sigma: A Case Study', IJSERT***, Vol.4, Issue.3, pp.31-34. -Susmy Michael(2016):

Determined defects which lead to low quality in the construction projects. DMAIC phase of six sigma is used for improving the quality of building. Used questionnaire survey & then calculated six-sigma level. Process variations detected and correction applied.

5. ***'Quality Improvement in Building Construction Using Six Sigma',*** IOSR Journal of Mechanical and Civil Engineering, pp.1-5.Sandeep Bodke(2017):

This study analyses Six Sigma for quality improvement in construction. Using the DMAIC methodology defects are analyzed and suitable defect sheet formed. Furthur investigations aided suggestions for preparation of cause analysis graph, pareto charts and finally control plans. For changes that required in current work are spotted.Six sigma gives systematic approach to identify and improve the current construction process. This paper describes the factors contributing to wastes in construction which is identified by ranking. Ranking was done by SPSS software and it is validated by the value stream mapping. Variations in the Key performance indicators can be easily analyzed to compute lean performance with the fuzzy inference model.

6. '***Applying Six Sigma Principles in Construction Industry for Quality Improvement***', International Conference on Advances in Engineering and Technology, pp.407-411Sneha- P.Sawant (2014)

This paper studies a residential building by applying six sigma principles. Sigma level calculated and applied for internal finishing work. Findings suggest management support to improve the quality & customer satisfaction.Provides scale to measure quality improvement

7. ***'The use of six sigma as a performance improvement strategy in the construction industry: new trends and applications',*** IJEMR:Vol.6, Issue.1, pp.538-546- Jemima A.Ottou, Bernard K.Baiden and Joseph K.Ofori (2016)

This journal explains the basic concept of six sigma and DMAIC methodology.Also explains about the six sigma change agents. It concludes that although the approach is simple by no means easy. But the results justify the efforts expended. It explains the firms that successfully implement six sigma perform better in virtually every business. In this paper, Concrete samples in the form of cubes were collected from RMC plant. The strength values will be analysed for variances and defects and the sigma levels would be identified. The defects arising in concreting process due to various controllable and non-controllable factors are identified and the remedies are suggested.

8. ***"Applying Six Sigma to Quality Improvement in Construction":*** ASCE-VOLUME 29'Issue-4 Kio liang lee(2015)

This paper demonstrates how Six Sigma team determine key input variables affecting the cracks in wall. A case study methodology is used in this research to illustrate the tools of Six Sigma

There are number of factors which affect the quality of product, time of work, cost, waste of material, etc. the objective of construction industry is to complete a project within a stipulated time, cost as per required standard and specifications, minimum waste efficient use of resource. Also the paper describes the study on Six Sigma and quality improvement in building construction using Six Sigma principle. By using the DMAIC methodology of Six Sigma which help to identify the quality of existing structure by analyzing the defects that will suggest in DFSS for changes that required in current work.

9. ***"Reducing Defects in RCC Member by using Six Sigma Principle"***: IISJER –VOL 4,Issue 7/1.2;Neha Bagdiya (2016)

This paper describes the basic theory of six sigma principles, methodology and various tools used for reducing defects. A case study of a residential building is taken in which the DMAIC principle is applied for reducing defect in RCC members. Process improvement for present study, residential building at wagholi, Pune is selected to find out the causes of construction defects. For case study, checklist was prepared for all the RCC members and the percentage defects were found out. Six sigma also provides scale to measure whether the quality has been improved or not

3. SIX SIGMA IN CONSTRUCTION INDUSTRY

3.1. General

Construction industry faces a distinct challenge when it comes to customer service. Few other businesses have the customer standing right in front of them while the product in question is being assembled. Yet that's the case in construction, where many owners pay regular site visits to monitor and sometimes micromanage the building process.

For this reason, it can benefit contractors to pay close attention to customer service and, if necessary, think creatively for ways to avoid costly conflicts. One approach to consider is "Six Sigma" for construction management — a disciplined, data-driven methodology for improving any business process, but particularly useful in improving customer service.

3.2. Purpose of Six Sigma

Six Sigma is all about identifying and eliminating "defects." The word "defect" doesn't refer only to mistakes but also to any result that fails to meet customer specifications or could lead to a process likely to dissatisfy customers. Companies that implement Six Sigma should expect to undertake continuous efforts to achieve stable and predictable process results. For contractors, these efforts could apply to every stage of a construction project from sales to bidding to on-site operations and in-house financial management.

3.3. Six Sigma in construction management

Businesses that undertake a Six Sigma program generally must choose from two primary methodologies. For improving an existing business process, you'll navigate "DMAIC," an acronym for define, measure, analyze, implement and control. For creating a new product or process, you'll deal with "DMADV," an acronym for define, measure, analyze, design and verify. Because most contractors are likely looking to improve an established approach to customer service, let's focus on DMAIC. It will ask you to follow five stages:

1. Define the problem you're trying to solve. Don't just look at it from your own perspective. You'll need to "speak in the voice" of your customers and point to specific goals.

2. Measure key aspects of the process. Target metrics that will enable you to measure progress toward the stated goal, by collecting relevant data.
3. Analyze the data, looking for c ause-and-effect relationships. Here, you'll put on your investigator's hat and look for the root of the defect you're seeking to eliminate.
4. Improve the current process. Six Sigma will recommend data analysis techniques for using the information gathered and reconfiguring the process in question. You can then set up tests to establish whether the improvement is real.
5. Control the process going forward. You'll be guided through steps to set up systems for monitoring the improved process once you've implemented it.

3.1. Six sigma methododlogy

A carefully executed Six Sigma program should provide specific answers about what you can do to better serve customers. Eliminating defects means you'll spend less time putting out fires and more time completing quality work. In turn, you'll be able to stay within your cost estimates and thereby improve your odds of getting more referrals and repeat business. Plus, Six Sigma's "control" phase often allows contractors to tighten their financial management procedures. These could enable you to free up cash flow and better leverage the growth value of your existing customer relationship.

3.4. Implementing Six Sigma

Six Sigma implementation strategies can vary significantly between organizations, depending on their distinct culture and strategic business goals. After deciding to implement Six Sigma, an organization has two basic options:

- Implement a Six Sigma program or initiative
- Create a Six Sigma infrastructure

Option 1: Implement a Six Sigma Program or Initiative

With this approach, certain employees (practitioners) are taught the statistical tools from time to time and asked to apply a tool on the job when needed. The practitioners might then consult a statistician if they need help. Successes within an organization might occur; however, these successes do not build upon each other to encourage additional and better use of the tools and overall methodology. When organizations implement Six Sigma as a program or initiative, it often appears that they only have added, in an unstructured fashion, a few new tools to their toolbox through training classes. One extension of this approach is to apply the tools as needed to assigned projects. It's important to note, however, that the selection, management, and execution of projects are not typically an integral part of the organization.

Implementing a Six Sigma program or initiative can present unique challenges. Because these projects are often created at a low level within the organization, they may not have buy-in from upper management, which may lead to resistance from other groups affected by the initiative. In addition, there typically is no one assigned to champion projects across organizational boundaries and facilitate change.

Option 2: Create a Six Sigma Infrastructure

Instead of focusing on the individual tools, it is best when Six Sigma training provides a process-oriented approach that teaches practitioners a methodology to select the right tool, at the right time, for a predefined project. Six Sigma training for practitioners (Black Belts) using this approach typically consists of four weeks of instruction over four months, where students work on their projects during the three weeks between sessions. Deploying Six Sigma as a business strategy through projects instead of tools is the more effective way to benefit from the time and money invested in Six Sigma training.

Consider the following Six Sigma deployment benefits via projects that have executive management support.
- Offers bigger impact through projects tied to bottom-line results
- Utilizes the tools in a more focused and productive way
- Provides a process/strategy for project management that can be studied and improved
- Increases communications between management and practitioners via project presentations
- Facilitates the detailed understanding of critical business processes Gives employees and management views of how statistical tools can be of significant value to organizations
- Allows Black Belts to receive feedback on their project approach during training
- Deploys Six Sigma with a closed-loop approach, creating time for auditing and incorporating lessons learned into an overall business strategy

A project-based approach relies heavily on a sound project selection process. Projects should be selected that meet the goals of an organization's business strategy. Six Sigma can then be utilized as a road map to effectively meet those goals. Initially, companies might have projects that are too large or perhaps are not chosen because of their strategic impact to the bottom line. Frustration with the first set of projects can be vital experience that motivates improvement in the second phase.

Six Sigma is a long-term commitment. Treating deployment as a process allows objective analysis of all aspects of the process, including project selection and scoping. Utilizing lessons learned and incorporating them into subsequent waves of an implementation plan creates a closed feedback loop and real dramatic bottom-line benefits if the organization invests the time and executive energy necessary to implement Six Sigma as a business strategy

3.5. Applying Six Sigma in Building Construction

Construction performance issues have been attempted to solve using a project approach. A project approach is used when the analyzer thinks that the problem of non-performance is being caused by the differences with projects. The authors propose to use a process approach. Contractors in the price-based environment with minimum standards, are motivated to lower performance. In a best value environment, it is in the interest of the contractor as well as the client to raise performance. The preliminary tests have shown an increase of 30% in performance. This paper proposes that the Six Sigma and other continuous improvement processes can be implemented only in best value environments.

Six Sigma uses data and statistical analysis to measure and improve a company's performance. It increases profits by eliminating variability, defects and waste by using the: define, measure, analyze, improve, and control (DMAIC) approach. This methodology has been applied in various domains such as manufacturing, services, finance, and healthcare. If the Six Sigma process is used on the entire construction industry, the process would identify that the construction industry problem is a process issue, validating the hypothesis that the performance problem is a process issue.

The construction industry has taken a project approach in solving its problems. A project approach is used when the analyzer thinks that the problem of non-performance is being caused by the differences with projects. Because the industry has accepted that projects are unique i.e no two projects in construction industry are same, there are no useful relative performance numbers on contractors, project managers, and site superintendents. Using this approach, if all projects are unique, using any project performance numbers to compare the performance of different contractors would be flawed. Without related and relative performance data, the industry must depend on the expertise of experts, consultants, and knowledgeable construction and project managers. It makes it difficult for clients to know what they are getting, and for contractors to continuously improve. This type of industry structure is unstable because it cannot continually provide performing construction and improve the quality of the construction.

The checklist is prepared for various components. The one which meets standard requirement is marked as „0‟ else it is marked as „1‟ and NA shows that item not applicable. The total number of defects and total number of opportunities for defects in each checklist is calculated as follows

DPMO = No. of „1‟ in checklist * 1000000 No. of Opportunities of defects*No of units.

Formula: DPMO = No. of defects * 1000000 No. of opportunities

3.6. Quality Tools

Quality is a very important feature for successful businesses to uphold. Six Sigma training or by Six Sigma Black Belts focus on improving processes to ensure better quality. It is essential that customers are given products and services that are convenient for them and hence, worth the money they pay. In order to be successful in business, we need to remember that customer satisfaction is always the most important goal.

Customer satisfaction is part of the Six Sigma principles are also briefly taught in free Six Sigma training. To ensure the best possible products and services are sold to customers at a consistent level, businesses should use the Seven Quality Control tools (7 QC Tools). The efficient and effective use of these 7 QC tools can help maintain the consistency of the products and services being produced. The use of these tools is spread out throughout the different phases of the DMAIC process. The 7 QC tools is a title given to a fixed set of graphical techniques identified as being most helpful in troubleshooting issues related to quality. The 7 QC tools are fundamental instruments to improve the process and product quality. They are used to examine the production process, identify the key issues, control fluctuations of product quality, and give solutions to avoid future defects.

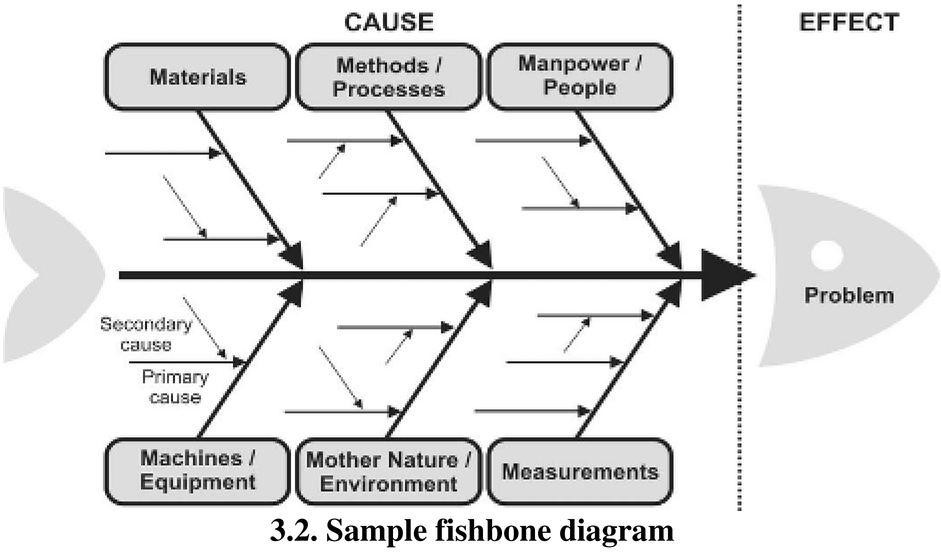
These are the tools which facilitate the organization to resolve the basic problems. When an organization starts the journey of quality improvements, the organization normally has many low hanging fruits; which should be tackled with these basic 7 QC tools. These 7 QC tools are easy to understand and implement and does not need complex analytical/ statistical competence.

The Seven Basic Tools of Quality (also known as 7 QC Tools) originated in Japan when the country was undergoing major quality revolution and had become a mandatory topic as part of Japanese's industrial training program. These tools which comprised of simple graphical and statistical techniques were helpful in solving critical quality related issues. These tools were often referred as Seven Basics Tools of Quality because these tools could be implemented by any person with very basic training in statistics and were simple to apply to solve quality-related complex issues.

7 QC tools can be applied across any industry starting from product development phase till delivery. 7QC tools even today owns the same popularity and is extensively used in various phases of Six Sigma (DMAIC or DMADV), in continuous improvement process (PDCA cycle) and Lean management (removing wastes from process).

1. Cause-and-effect diagrams

The first of the 7 QC tools is the Fishbone Diagram helps **organize ideas and understand the relationship between potential causes and an effect or a problem by formatting, arranging and organizing potential causes into themes and sub-themes in preparation for a cause identification effort**.

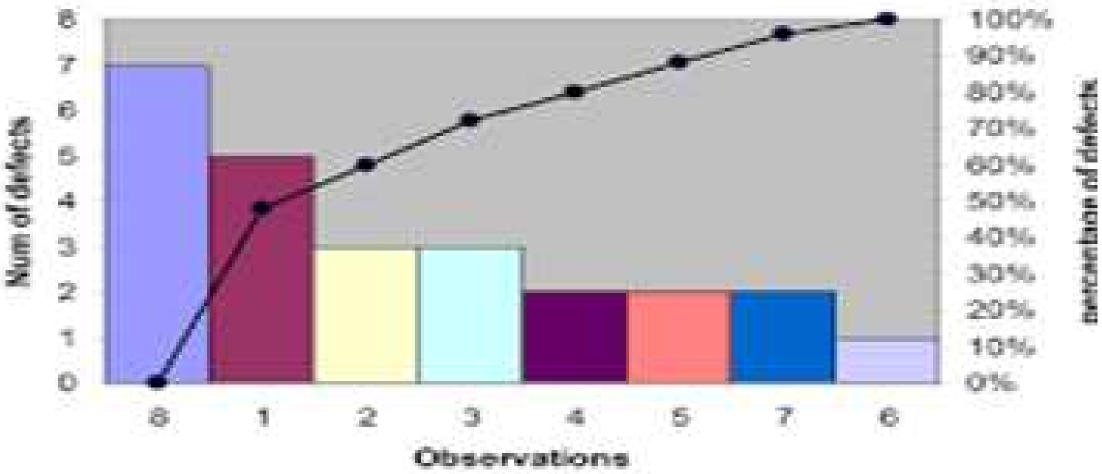


3.2. Sample fishbone diagram

It helps stimulate thinking when developing the list of the potential sources of a problem. It guides concrete action and tracks the potential causes during an investigation effort to determine whether the item significantly contributes to the problem or not.

2. Pareto chart

It is used **to prioritize the contributors which make the biggest impact on a problem, or which represents the largest areas of opportunity**. A Pareto chart is a tool to focus attention on priorities while trying to make decisions. It is a good communication tool that describes the data in a simple and easy-to- read bar diagram.

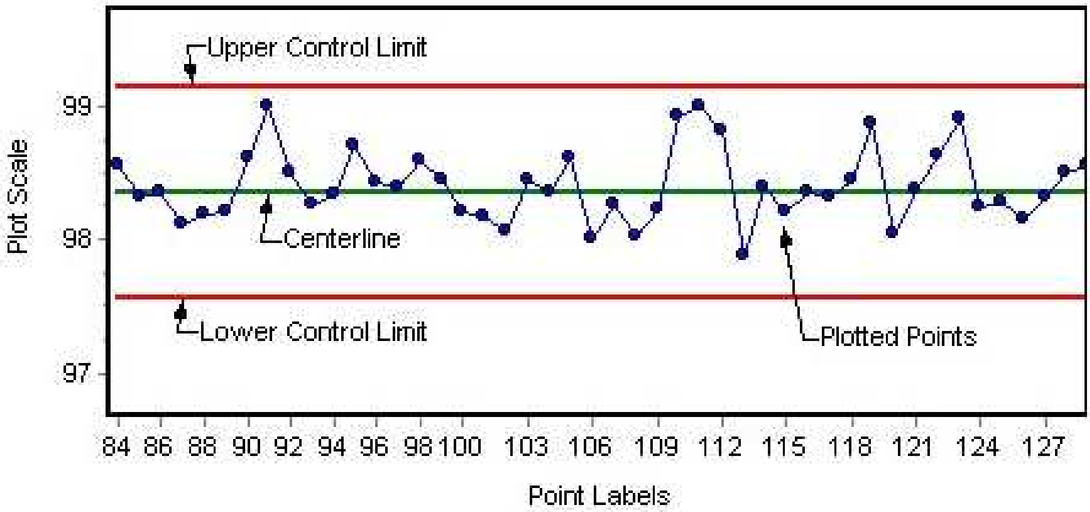


3.3. Sample pareto chart

The chart helps to study and analyze the frequency or occurrences of an event in a process and identify the biggest contributors. These diagrams communicate the principle of 80:20. It states that 80% of an effect comes from 20% of the causes.

3. Control Chart

The third of the 7 QC tools is the control chart. The best tool **to investigate variation in a process is a control chart**. A control chart is often called a time series plot that is used to monitor a process over time. It is a plot of a process characteristic, usually through time with statistically determined limits.

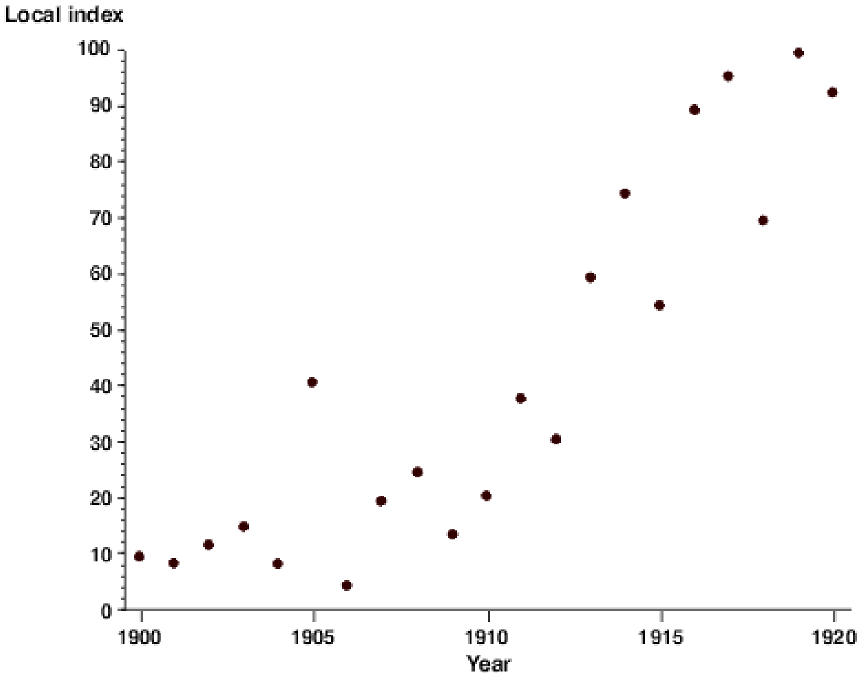


3.4. Sample control chart

When used for process monitoring, it helps the user to determine the appropriate type of action to take on the process depending on a degree of variation in the process.

4. Scatter diagrams

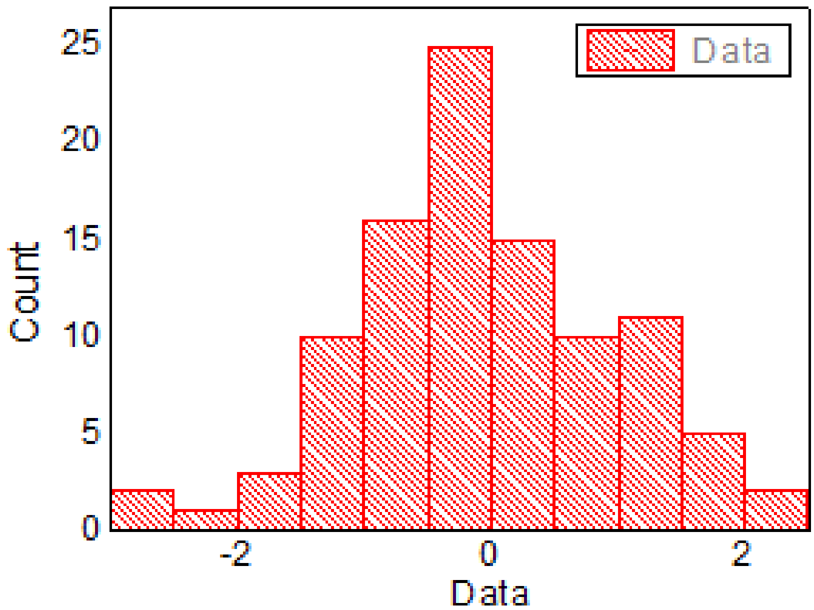
The fourth of the 7 QC tools is the scatter diagram. The scatter diagram is also known as a scatter plot or a correlation graph. It helps **visualize the relationship between two variables**. The graph helps check for outliers too.



3.5. Sample scatter diagram

5. Histograms

The fifth of the 7 QC tools is the histogram. A histogram is a **pictorial representation of a set of data.** The histogram is a bar graph that shows the frequency of values. It is created by grouping the measurements into ‘‘cells” or “bins.”



3.6. Sample histogram

Histograms are useful to understand the location, spread, and shape of the data. In addition, potential outliers or missing data can be seen.

6. Flow charts

The sixth of the 7 QC tools is the flow chart. A flow chart is a **visual representation of a process** that can illustrate:
- What activities are completed, by whom, in what sequence
- Hand-offs between departments or individuals
- Internal and external operational boundaries

7. Checklists

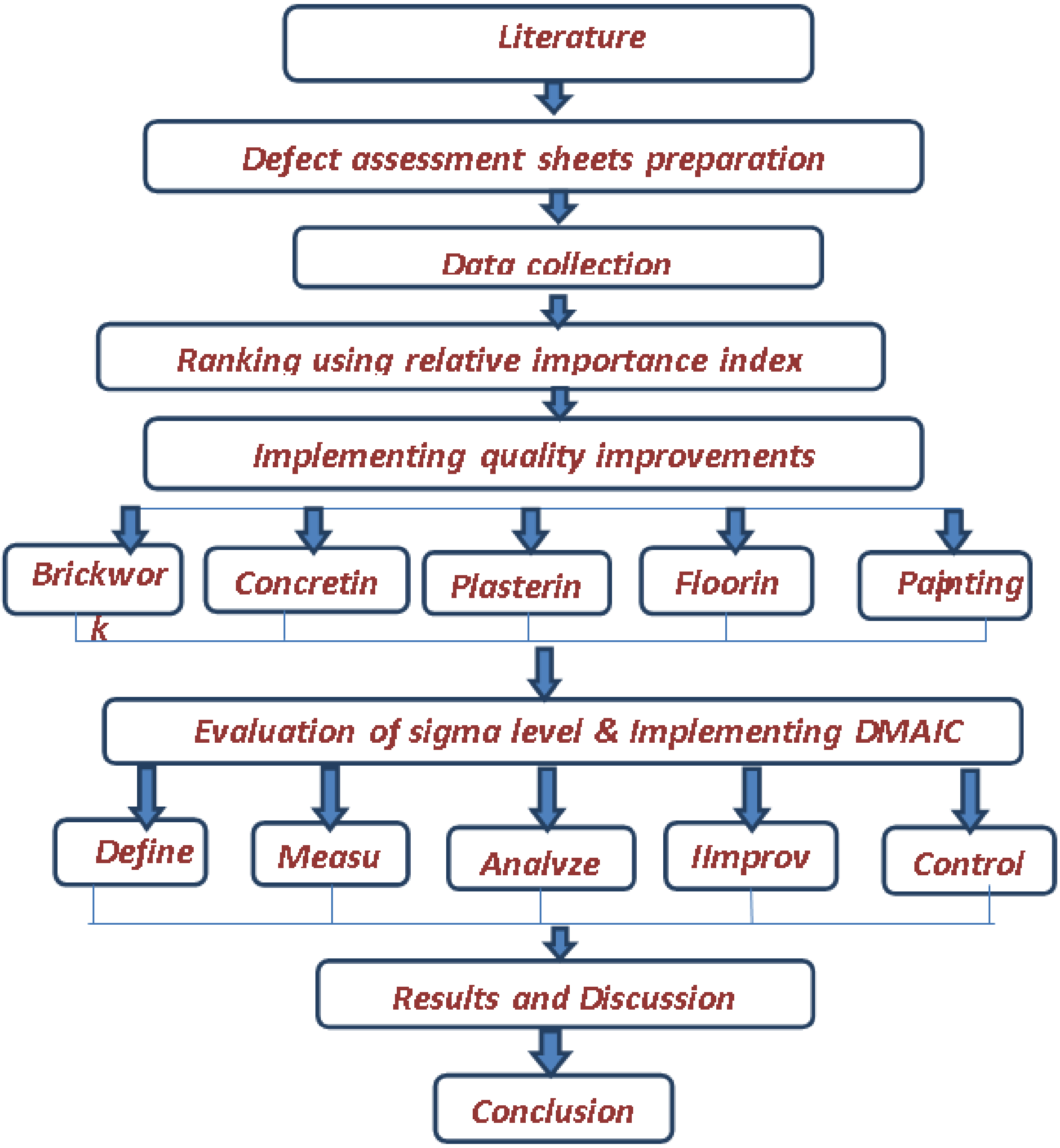
The last of the 7 QC tools is the checklist. The purpose of a checklist is **to summarize, and in some cases; graphically depict a tally count of event occurrences.** A checklist is used when users are interested in counting the number of occurrences of an event, such as defects or nonconformances.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Wrong orders	///	𝍸	𝍸 𝍸 𝍸 𝍸 //	/	//	////	𝍸 //
Reworked orders		/	//	///		/	//
Late deliveries	𝍸 ///	/	///	//		///	//
Shipping damage						𝍸 𝍸 𝍸 𝍸	𝍸 ///
Late payments		/					
Totals	11	8	27	6	2	28	19

3.7. Sample checklist

In many instances, a checklist will summarize countable data related to certain types of defects and will provide a rough graphical representation of where, in a part or process, defects occurred.

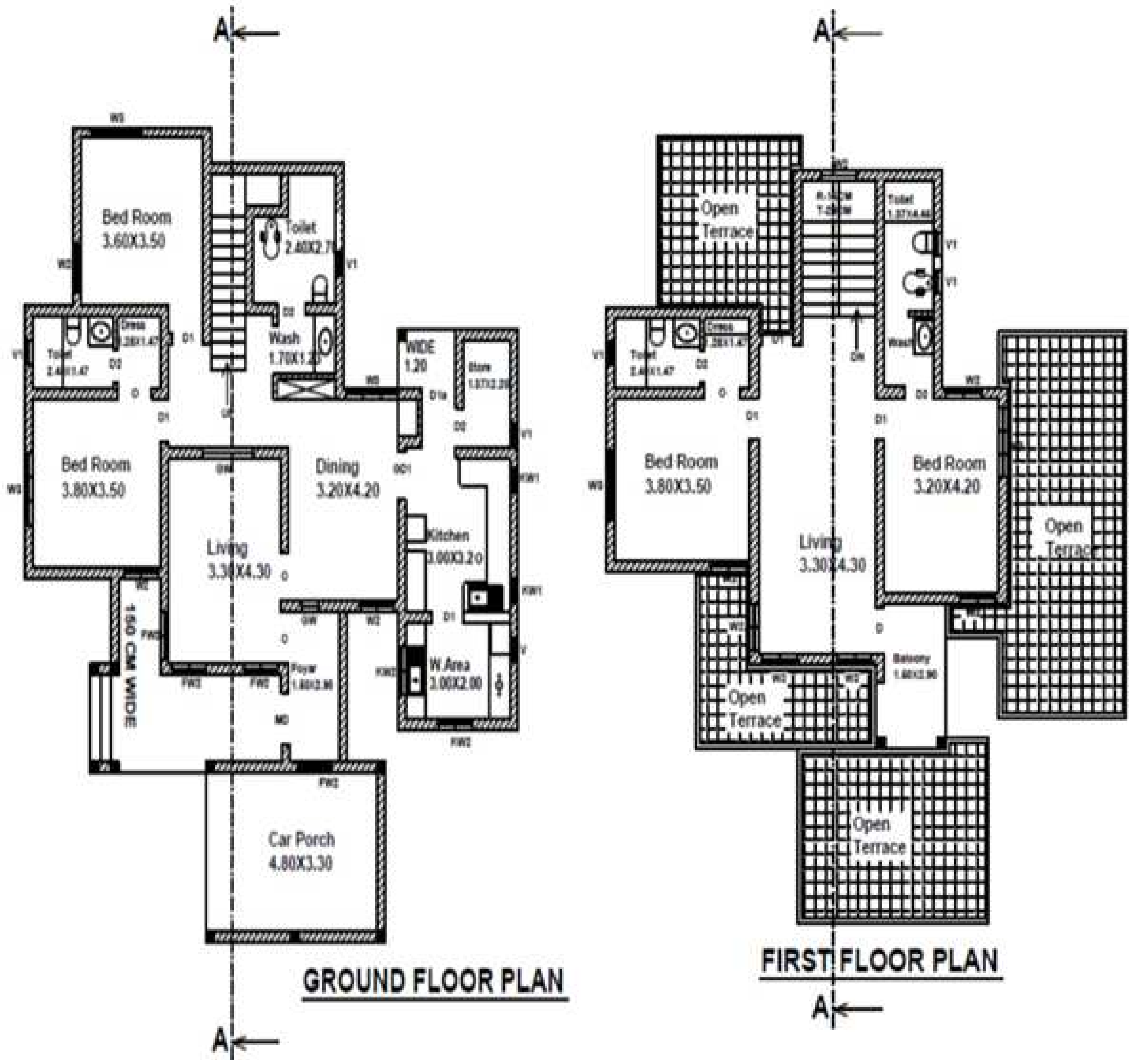
4. METHODOLOGY



4.1 Methodology Flowchart

4.1. Proposed residence

The proposed residence located at 13 km North nad 12 km South in Tirur Muncipality of Malappuram district, with an area of approx. 4350 sq ft has got its structural work and internal finishing works completed by June 2020.



4.2 Proposed residence

The defect assessment sheet preparation is the foremost task in applying six sigma. The project site was explored to find possible occurrences of defects. Existing defects and their occurrences are marked in the defect sheet. Defect assessment is done for the following works:

- Brickwork
- Concreting
- Plastering
- Flooring
- Painting

The assessment was done for each defect. If the building is affected, then mark as '1'. If the building is not affected mark as '0'.NA indicates that the item is not applicable.

After the preparation of the defect sheet, the DPMO(defects per million opportunities) and the corresponding sigma levels are calculated using six sigma statistical charts. Using these collected data we can head on to the process of data analysis.

4.2. Data Collection

Defect Assessment Sheet For Brickwork

DEFECTS	a	b	c	d	E	f	G	H	i	j	k	l	m	n
Frost Attack	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Efflorescence	0	0	0	0	0	0	0	1	1	0	0	1	0	1
Lime run off	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weathering	0	0	0	1	0	0	1	0	1	0	0	0	1	1
Unfilled bed joints	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thick bed joints	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corrosion of embedded iron	0	0	0	1	1	1	0	1	1	0	0	0	0	0
Shrinkage	0	0	0	0	1	0	1	0	0	0	0	0	0	0

4.1 Defect Assessment sheet for brick work

DPMO = (no of defected units / total opportunities) x 100
= ((22 /128) x 100000)= 1,71,875

From the sigma conversion table, sigma level is 2.56

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

4.3 Sigma chart

➢ Defect assessment sheet for concreting

Defects	a	b	c	d	E	f	g	h	i	j	k	l	m	n
Unexpected Overloading	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Abrasion of granular material	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Poor reinforcement placement	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Poor detailing of joints	0	0	1	0	0	0	1	0	0	1	0	0	0	0
Cracking	0	0	0	1	1	0	1	0	1	1	0	0	0	1
Crazing	0	0	1	1	0	0	1	1	1	0	1	1	1	0
Delamination	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Efflorescence	1	0	0	0	0	0	1	1	1	0	0	0	0	0
Honeycomb & rock pockets	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finishing errors	0	0	0	1	1	1	1	1	0	1	0	1	1	1
Shrinkage cracks	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bugholes	0	1	1	1	1	1	1	1	1	0	1	1	1	1

4.2 Defect Assessment Sheet For Concreting

DPMO = (56 / 192) x 10000 = 2,91,666.67

From the sigma conversion table, sigma level is 2.07

➢ Defect assessment sheet for Plastering

Defects	a	b	c	d	e	f	g	h	i	j	k	l	M	n
Blistering of plastered surface	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Cracks in plastering	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Falling of plaster	0	0	0	1	0	0	0	1	1	0	0	0	0	1
Efflorescence on plastered surface	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Peeling off top finish layer of internal plaster	0	0	0	0	0	0	0	1	1	0	0	0	0	1
Uneven surface of plaster	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Vertical & horizontal edges of beams	1	0	0	1	0	0	0	0	0	1	0	1	0	0
Flaking	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Popping	0	0	0	0	0	0	0	1	1	0	0	0	0	1
Softness of plaster	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rust stains	0	0	0	1	0	0	0	0	0	0	0	0	1	0
Grinning	0	0	0	0	0	0	0	1	1	0	0	0	0	0

4.3 Defect Assessment for Plastering

DPMO = (56 / 192) x 10000 = 2,91,666.67
From the sigma conversion table, sigma level is 2.07

➢ Defect Assessment Sheet for Flooring

Defects	a	b	c	d	E	f	g	h	i	j	k	l	m	N
Uneven surfaces	1	0	0	1	0	0	1	1	0	0	0	0	1	0
Right angles at corners	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Hollow sound	1	1	1	0	1	0	0	0	1	1	1	1	0	1
Cracks observed	1	0	0	1	0	0	0	1	1	0	1	1	0	0
Colour /shade variation	1	1	1	1	1	1	0	1	0	0	1	0	0	1
Damages due to	NA	NA	NA	1	NA	0	1	1	NA	NA	NA	0	1	NA
Proper slope Maintenance	0	0	0	0	0	0	0	1	0	0	0	1	1	0
Stainmarks	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Bad pointing (grouting	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Skirting are in line,	1	0	0	1	1	0	0	1	0	0	0	0	1	0

4.3. Defect sheet for flooring

DPMO = (51/ 132) x 1000000
= 3,86,363.63

From the sigma conversion table, sigma level is 1.7

➢ Defect Assessment Sheet for painting

Defects	Inner and outer walls													
	A	b	c	d	E	F	g	h	i	J	k	l	m	N
Blistering	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Blooming	0	0	0	1	1	0	0	1	0	1	0	0	0	1
Fading	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Flaking	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Flashing	0	0	0	0	0	0	0	1	0		0	0	0	0
Grinning	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Running of paint	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sagging	0	1	1	1	1	0	0	1	0	0	0	0	0	0
Saponification	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wrinkling	0	0	0	0	1	0	0	0	0	0	0	0	0	0

4.5 Defect Assesment sheet for flooring

DPMO = (27/ 170) x 1000000 = 1,58,823.53

From the sigma conversion table, sigma level is 2.52

5. DATA ANALYSIS

Data Analysis done using six sigma tools under DMAIC (Define-Measure-Analyse-Improve-Control) strategy

5.1. Define

Define stage is all about describing the problems. Its all about establishing the project therefore many individual activities to complete. There are multiple tools and concepts available in this phase of six sigma. In the define stage of the project possible occurances of defects are noted and sequentially the possible causes of defect has to be clearly studied. This is done using an SIPOC (Supplier Input Process Output Control) Chart

An SIPOC chart displays the clear prpose and scope of a process. With this tool an organized view of your work process is built which helps the process owner and those working on the process to clarify the primary elements of a process.

- SIPOC Chart for brickwork

Supplier	Input	Process	Output	Control
Builder	1.Bricktrowel 2.Old board 3.Tape measure 4.Spirit level 5.Brick/string line 6.Shovel 7.Club hammer 8.Bolster 9.Stiff brush	1.Calculate how many bricks needed 2.Order the bricks 3.Prepare the foundation 4.Mark the guideposts 5.Mix the mortar 6.Lay the first brick 7.Cut a brick in half for next row 8.Repeat the process to build the brick wall 9.Finishing of wall	Completed wall	Owner

5.1 SIPOC for Brickwork

- SIPOC Chart for concreting

Supplier	Input	Output	Process	Control
Builder	Cement Sand Aggregate Admixtures Concrete mixer	Purchase of the raw materials Batching of raw materials by volume or machine batching. Dry mixing and wet mixing in concrete mixer. Transport the concrete by manual or mechanical method. Compaction is done to remove the air bubbles. Curing process	Concrete laying	Owner

5.2 SIPOC for concreting

- SIPOC Chart for Plastering

Supplier	Input	Process	Output	Control
Builder	1. Cement 2. Sand 3. Water 4.Admixtures 5.Mortar pans 6. Spade 7. Chisel 8. Hammer 9. Trowel 10. PVC water level tube 11. Metal float 12. Right angle, small and big 13. Measuring tape 14. Nylon string 15. Plumb bob 16. Screens for sieving sand 17. Wire brush	1. Arrange the scaffolding and check it for stability and proper height. 2. Dump the required sand, cement, water, admixture as perthe proportions. 3. Mix only2-3 bags depots at a time and use mixed depots within half an hour. 4. Start plastering of ceiling first and then walls. 5. Leave and cut the plaster correctly 23cm from floor level for skirting. 6. Neatly finish all the corners of windows, doors and column. etc with pure cement. 7. Clean all window, fan, door frame. 8. See that no chicken mesh wires are seen outside the plaster. 9. Ensure maximum plaster thickness should not exceed 20mm.	Plastered surface	Owner

➢ SIPOC Chart for Painting

Supplier	Input	Process	Output	Control
Builder	1.Paint 2.Paint roller 3.Paint roller extension pole. 4.Paint brush 5.Sand paper 6.Drop clothes	1. Choose the colour 2. Clean the walls with sand paper. 3. Pour the primer into a tray and mix properly. 4. Roll the primer onto the wall. 5. Paint the trim 6. Roll on the paint in a 'W' shape. 7. Remove the painter's tape	Finished wall surface	Owner

5.4 SIPOC for painting

➢ SIPOC Chart for Flooring

Supplier	Input	Process	Output	Control
Builder	1.Vitrified tiles 2. 43 Grade OPC 3.Mortar pan 4.Laticrete grout 5.Measurement box 6.Spade for mortar Mixing 7.Trowel 8.Straight edge 9.Spirit level 10.Tile cutter 11.Wooden-Hammer 12.Adhesive	1. Select and stack tiles adjacent to the work. 2. Clean the surface, set mortar/concrete if any on base surface. 3. Proper check to be done on the level of plaster then tile marking should be done. 4. Mark the tile pattern on the plastered surface to predefine the positions of electric and plumbing points. 5. Handover the area to plumbing and electrical agency laying of plumbing lines. 6. Fix the tiles with tile adhesive (3mm thickness) on the plastered wall surface 7. Do gentle tapping with wooden hammer. 8. Grout the tile joints and remove spacers before grouting. 11. Thoroughly clean the surface.	Finished surface	Owner

5.5. SIPOC for flooring

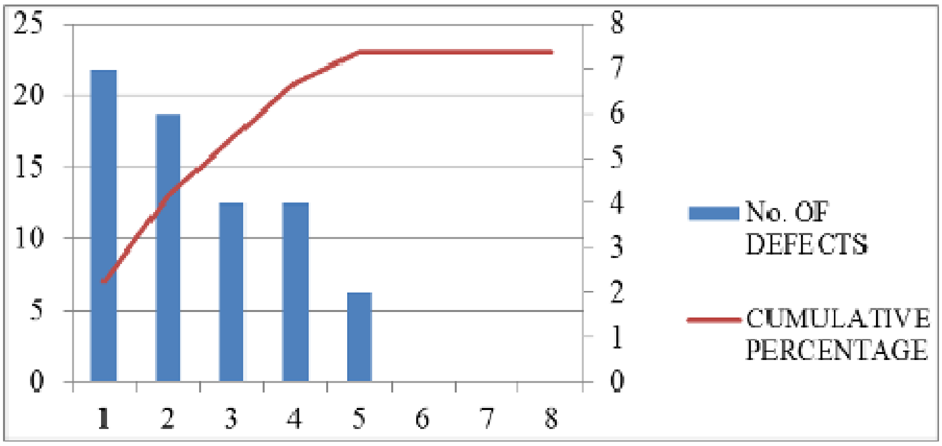
5.2. MEASURE

The Measure phase involves more numerical studies and data analysis than the define phase. This phase focuses on measurement system validation and gathering root causes. A Pareto chart is used in the measure phase of applying six sigma.

Pareto charts are commonly used in Six Sigma, particularly during DMAIC projects. Named after Wilfredo Pareto, this type of chart is similar to a bar chart but shows categorical (discrete) data arranged in order of highest frequency to lowest frequency. In addition to showing bars depicting each category's frequency, labeled with the category name and frequency, a Pareto chart also includes the cumulative percentage. This is the percentage of all the data accounted for by totaling the counts from the first category to the current category. If the Pareto principle applies, a very small number of categories contains 80 percent or more of all the data.

➢ Pareto Chart for Brickwork

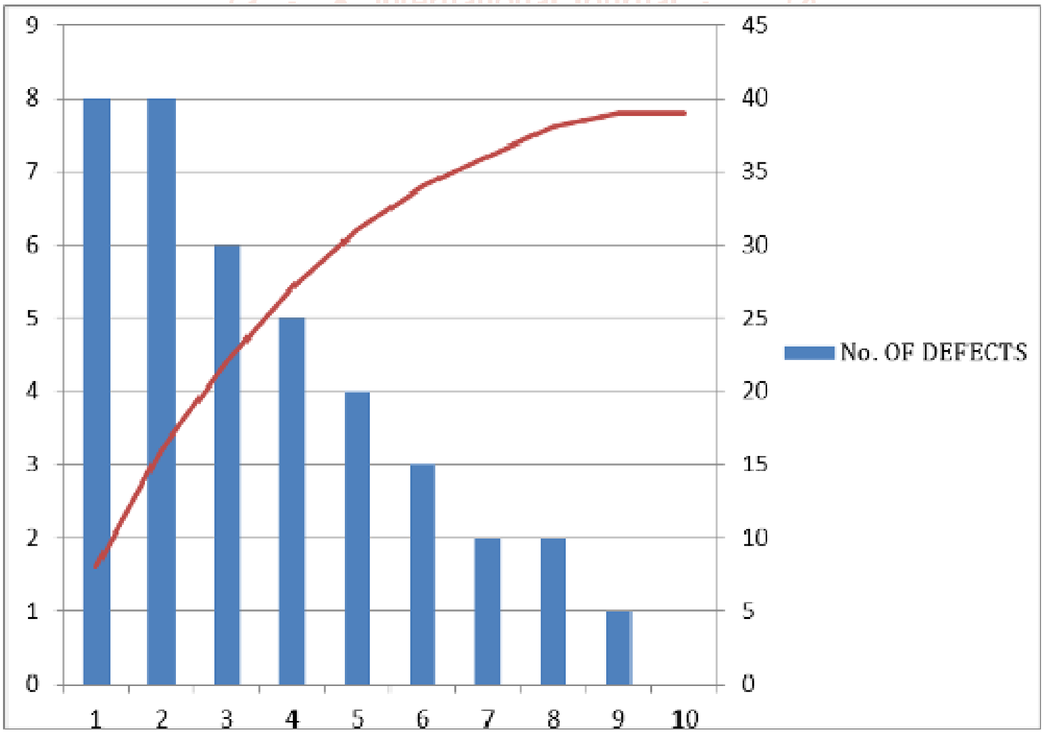
Defects	No. Of Defects	Cumulative Percentage
Weathering	7	7
Corrosion of embedded iron	6	13
Efflorecense	4	17
Shrinkage	4	21
Frost attack	2	23
Lime runoff	0	23
Unfilled bed joints	0	23
Thick bed joints	0	23



5.1 Pareto chart for brickwork

➢ Pareto Chart for Concreting

DEFECTS	No. OF DEFECTS	CUMULATIVE PERCENTAGE
Bugholes	8	8
Finishing error	8	16
Crazing	6	22
cracking	5	27
Abrasion of granular material	4	31
Lime runoff	3	34
Unfilled bed joints	2	36
Thick bed joints	2	38
delamination	1	39
honeycomb	0	39

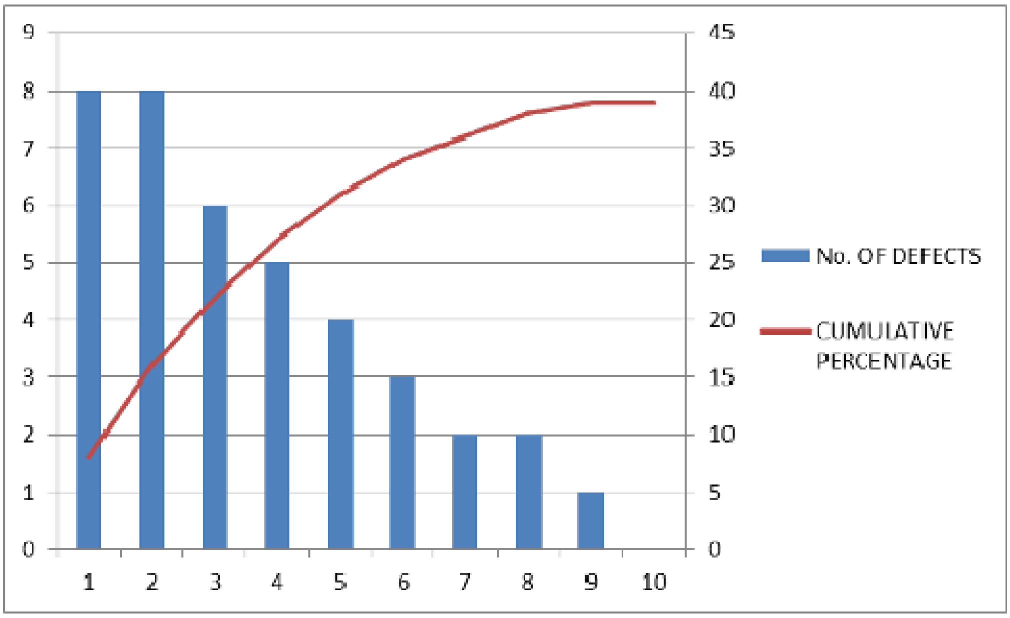


5.2 Pareto chart for concreting

➢ Pareto Chart for Painting

DEFECTS	NO OF DEFECTS	CUMULATIVE PERCENTAGE
Weathering	8	2
Corrossion of embedded iron	8	6
Efflorecense	6	14
Shrinkage	5	20
Frost attack	4	25
Lime runoff	3	31

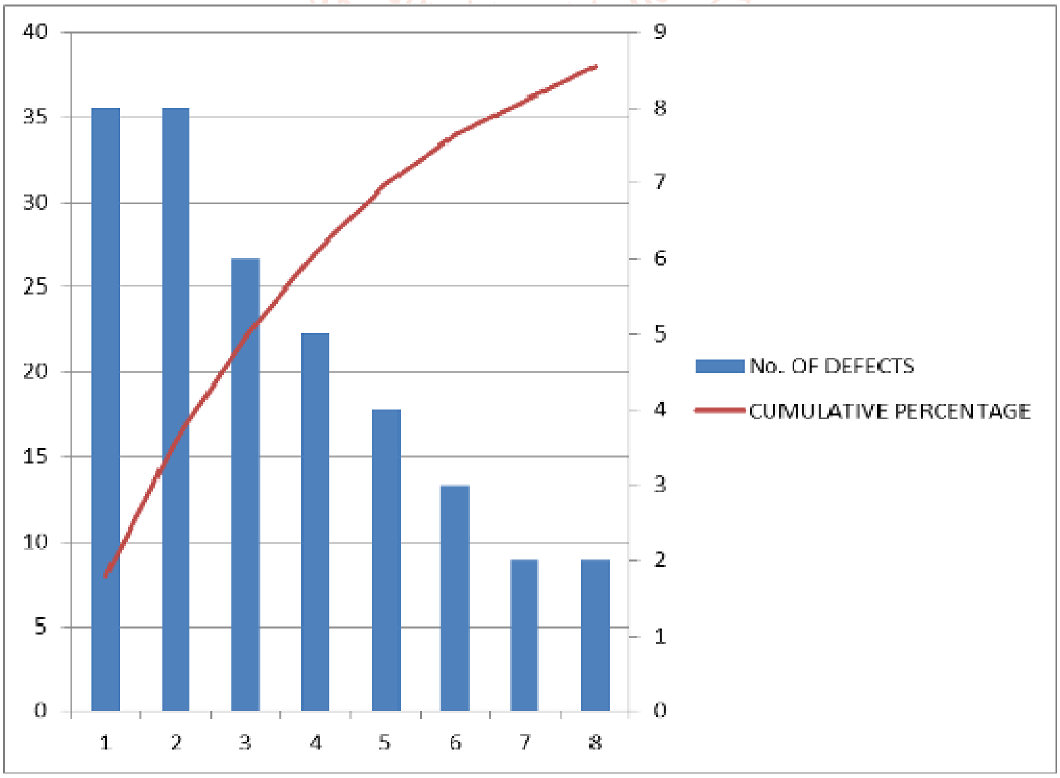
Unfilled bed joints	2	36
Thick bed joints	2	38
delamination	1	41
cracks	0	42



5.3. Pareto chart for plastering

- Pareto Chart for Flooring

Defects	No. Of Defects	Cumulative Percentage
Weathering	7	7
Corrosion of embedded iron	6	14
Efflorecense	4	20
Shrinkage	4	24
Frost attack	2	228
Lime runoff	0	30
Unfilled bed joints	0	30
Thick bed joints	0	31



5.4 Pareto chart for painting

5.4. ANALYSE

The analyze phase is the beginning of the statistical analysis of the problem. The practical problem was created earlier. This phase statistically reviews the families of variation to determine which are significant contributors to the output. Analyze phase is the third phase of DMAIC. The main activity in the analyze phase is to identify the potential root cause of the problem and arrive at the actual root cause. In other words, let's use the data obtained in the measure Phase to identify the root causes that we want to fix. Analysis phase in six sigma method is done using cause and effect diagram

A Cause and Effect Diagram (aka Ishikawa, Fishbone) is a pictorial diagram showing possible causes (process inputs) for a given effect (process outputs). In other words, it is a visual representation used to find out the causes of a specific problem.

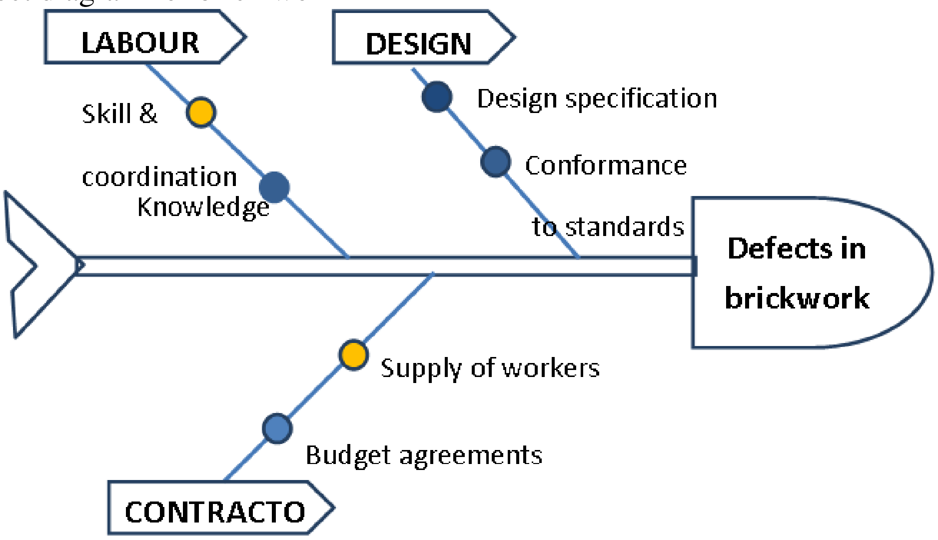
The Cause and Effect diagram is also referred to as the "Ishikawa diagram" or "fishbone diagram. The design of a diagram looks much like a skeleton of a fish.

Fishbone diagram typically draw right to left, with each large bone of fish branching out to include smaller bones containing more detail.

The Cause and Effect Diagram (aka Ishikawa, Fishbone) introduced by Kaoru Ishikawa (1968) that show the causes of a specific event. He also introduced the company-wide quality control (CWQC) and also Quality circles concept in Japan.

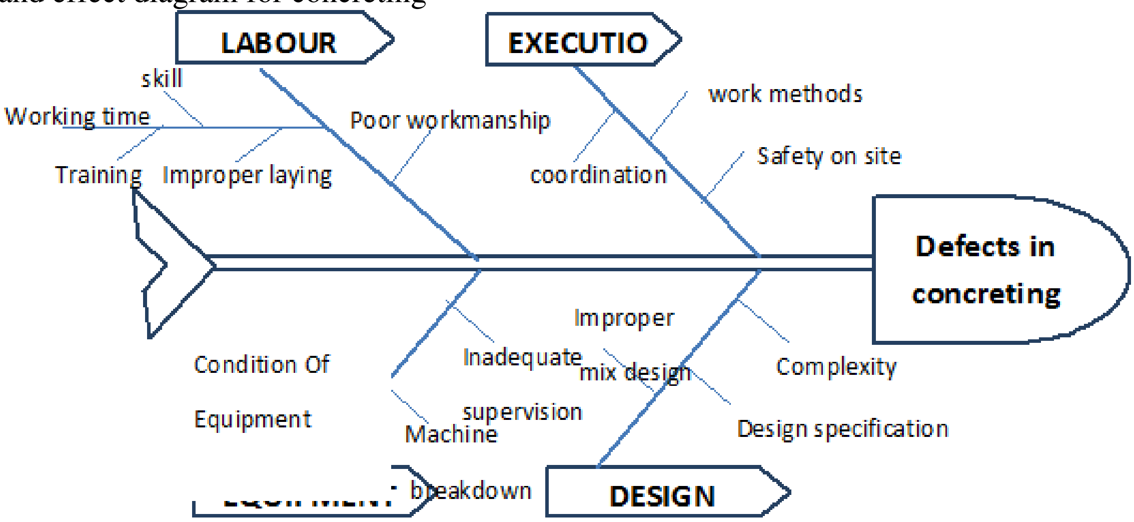
Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. It is one of the seven basic tools of quality control. Its commonly used in brainstorming and in the "open" phase of root cause analysis.

- Cause and effect diagram for brick work



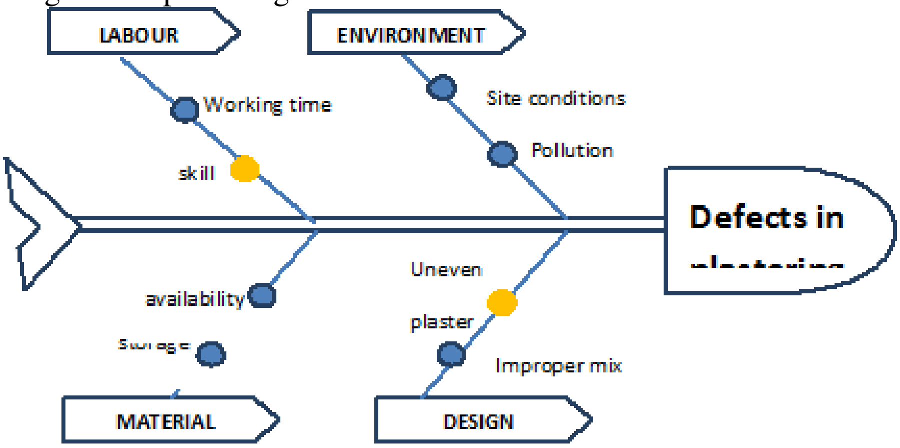
5. 5 Cause and effect diagram for brickwork

- Cause and effect diagram for concreting



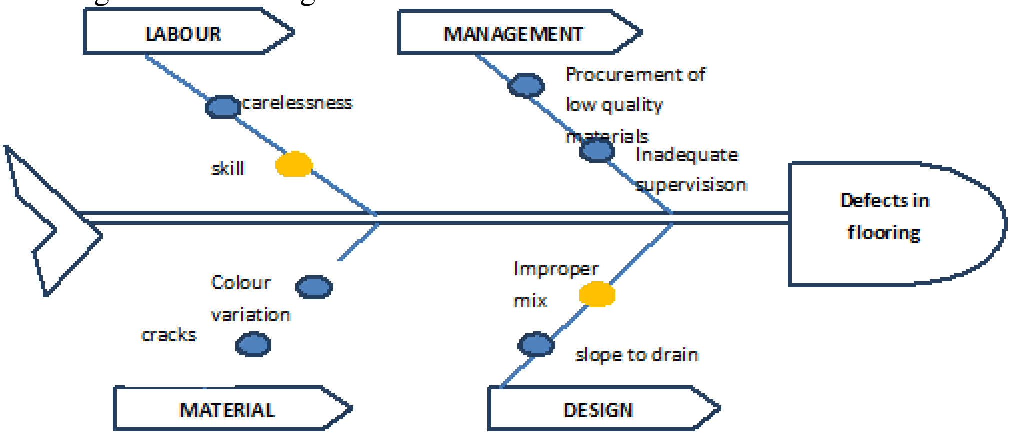
5.6 cause and effect diagram for cooncreting

- Cause and effect diagram for plastering



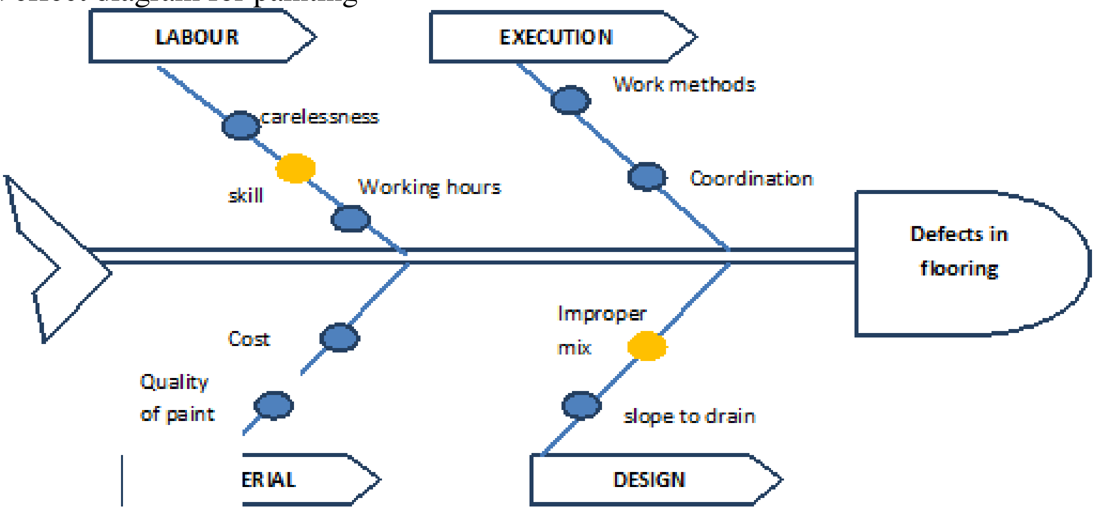
5.7 cause and effect diagram for plastering

- Cause and effect diagram for flooring



5.8 cause and effect diagram for flooring

- Cause and effect diagram for painting



5.9 Cause and effect diagram for flooring

5.5. IMPROVE

Improve is the fourth phase in the Six Sigma DMAIC cycle. The Improve phase focuses on developing ideas on how to remove sources of variation in the process. This phase deals with testing and standardizing potential solutions. The idea at this point is to understand what is really occurring in the process and not what is perceived to be the root cause(s) of any variation. Once you have identified specific inputs that affect the outputs, you can start to develop a strategy on how to control the process. The Improve phase focuses on developing ideas on how to remove sources of variation in the process. This phase begins testing and standardizing potential solutions. Once how specific inputs affect the outputs are understood, a strategy on how to control the process can be developed.

➢ Corrective actions for brick work

From the pareto chart, weathering, corrosion and efflorescence mainly affect the quality of the brickwork

Following corrective actions are provided to overcome the defect

Defects	Corrective actions
Weathering	1. Sealants can be applied on external face of the wall 2. Application of water repellents
Corrosion of embedded iron	1. Provide thick cover 2. Apply epoxy coating on the reinforcement bars
Efflorescence	1. Rinsing with water 2. Sand blasting

5.6. Corrective actions for brickwork

➢ Corrective actions for concreting

- Project work execution as per schedule.
- Selection of experienced contractors for the project in the same field.
- Frequent quality and waste control audit with specialized personals.
- Proper co-ordination among the clients and contractors and contractors and workers.
- Establishment of material inventory plans and stores.
- Proper maintenance of stocks in inventory.
- Timely project evaluation.
- Optimizing the utilization of workers and equipment.
- Establishment safety awareness programs.
- Availability of desired tools and equipment

➢ Corrective actions for plastering

Defects	Corrective measures
Popping	1. Fill the cracks with good filler. 2. Reattach the loose plaster. 3. Stripping the plastered surface.
Falling of plaster	1. Watering of base coat at least one day before plastering. 2. Fresh surface should be kept wet for at least 15 days.

5.7 Corrective actions for plastering

➢ Corrective actions for flooring

Defects	Corrective actions
Hollow sound	1. Ensure proper and uniform spread of tile adhesive and mortar. 2. Tap with wooden mallet after installation of tiles as a check for hollow sound.
Bad pointing	1. Select suitable grouting material. 2. Joints should be properly filled. 3. Tiles surface to be properly cleaned after installation.

➢ Corrective actions for painting

- Remove the layer of skin and stir the paint thoroughly.
- Provide buffer coat for drying of primary coat.
- Avoid the accumulation of paint.
- Clean the surface without any dust.
- Avoid painting in humidity temperatures.

5.7. CONTROL

The Control phase involves: implementing the actual changes, whether they be physical, behavioural or both; rewriting procedures and work instructions; retraining staff on new procedures; putting systems in place to measure and monitor the new process, such as control charts; and writing an action plan.

The Control phase is the fifth and last phase of a DMAIC process. The main activity in the Control phase is to control the improved process. In other words, the control phase is about ensuring the new process is implementing and don't revert back to old ways. The focus of the control phase is to implementing whatever changes we have decided on in the improve phase of DMAIC for the new process.

We've positioned the new process for success that was well implemented and maintained. In addition, we successfully transitioned all responsibilities to the new owner. At the end of Control phase process, owners are responsible for ensuring the new process is enforced.

The Control phase is approximately a 2 to 3 weeks process. The activities in Control phase are to create and update standard works or work instructions. Quantify the cash savings and get the financial controller concurrence. Create and implement process monitoring mechanism using control charts. Then prepare control plan and reaction to remain an effective mechanism to monitor and control the process.

Finally, gain the management approval, update lessons learned, formally close the project, and hand over the process to the process owner. There are multiple tools and concepts available in the Control phase of six sigma.

6. CONCLUSION

In this the study, it is seen how various factors have high impact on the quality of the construction. These factors must be identified as early as possible so that quality can be improved. Detailed methodology has been implemented based on Six Sigma principles which give us systematic approach to identify and improvise the current process. Six Sigma also provides scale to measure whether the quality has been improved or not. There are various factors that have high impact on the quality of the construction. These factors are identified by the literature review as early as possible so that the quality can be improved. In this paper brickwork, concrete work, plastering, flooring and painting work of a residential building has been studied and sigma level is evaluated. The calculated sigma level is low so that the work process required improvement. In this, DMAIC methodology is implemented based on Six Sigma principles which give a systematic framework to identify the impact of defects, their root causes and ways to reduce them.

Briefly, Six Sigma, as a quality initiative, aims to reduce defects and variations in processes using statistical measurements, process design and quality control analysis in order to increase customer satisfaction In this the study, it is seen how various factors have high impact on the quality of the construction. These factors must be identified as early as possible so that quality can be improved. Detailed methodology has been implemented based on Six Sigma principles which give us systematic approach to identify and improvise the current process. Six Sigma also provides scale to measure whether the quality has been improved or not.

Six sigma is likely to remain as one of the key initiatives to improve the management process. The focus should be on improving overall management performance, not just pinpointing and counting defects. Researchers and practitioners are trying to integrate six sigma with other existing innovative management practices that have been around to make six sigma even more attractive to different organizations that might have not started or fully implemented.

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