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Measure and Analyze the Problems of Concrete Mixture Production via Six Sigma DMAIC Tools: Central Concrete Mix Plant as a Case Study

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Abstract. The aims of this study are to measure the defect rate and analyze the problems of production of ready concrete mixture plant by using Six Sigma methodology which is a business strategy for operations improvement depending basically on the application of its sub-methodology DMAIC improvement cycle and the basic statistical tools where the process sigma level of concrete production in the case study was 2.41 σ.

Introduction

Six Sigma has been transformed over the last twenty years. It is now a flexible and adaptive business strategy, applicable to many aspects of business and organizations. It has been applied over this time with great success, and subsequently ascribed four separate and varying definitions with respect to its literal, conceptual, and practical uses [1]. Six Sigma means a business management process that provides tangible business results to the bottom line by continuous process improvement and variation reduction. As a data-driven, statistically-based approach, Six Sigma aims to deliver near-zero defects as defined by customers for every product and process within an organization. In other words, it is a practical approach to running a business with the involvement of each resource at all levels [2].

Six Sigma

In 1980s, Motorola's top leaders conceded that the quality of its products was awful. As a result, the managers started to think of a new approach to improve quality [3].

In 1987, Robert Galvin, at that time CEO at Motorola, together with Bill Smith, Mikel Harry and Richard Schroeder created a new improvement program that was named Six Sigma. The program was inspired by Japanese work and strongly influenced by Juran's thoughts [2].

Due to Six Sigma, Motorola managed to reduce their costs and variation in many process and won the Malcolm Baldrige National Quality Award in 1988. Six Sigma is a quantitative approach for improvement with the goal of eliminating defects from any process, specifically a numerical goal of 3.4 (DPMO) defects per million opportunities [4]. While Chowdhury (2001) defined Six Sigma as a statistical measure and a management philosophy that teaches employees how to improve the way they do business, scientifically and fundamentally, and how to maintain their new performance level. It gives discipline, structure, and a foundation for solid decision-making based on simple statistics [5].

Six Sigma DMAIC Methodology

Six Sigma is divided into sub-methodologies, DMADV, DFSS and DMAIC. DMAIC acronym refers to the terms: Define, Measure, Analyze, Improve, and Control. It is an improvement methodology focusing on improving existing processes and performance [1].

Define Phase. In this step, defining problems that can be fixed is an important key. It is important to pick problems that are costing the company most or are giving you the most problems [2]. This research focuses on the problem of poor quality of concrete mixtures and the consequent deviation in the quality of building

Measure Phase. In this step, the Black Belt calculates how many errors are made. In other words, measures the current performance of the process (yield, DPMO, sigma level, etc) [2]. Six Sigma offers the following formulas to calculate percentage of yield and number of defects per million opportunities [6]. Table 1 shows the relationship between sigma level and these metrics values while Eq. 1 and Eq. 2 are the formulas of calculating the yield and DPMO [2].

$$\text{Yield} = \text{correct items} / \text{opportunities} \quad (1)$$

$$\text{DPMO} = (\text{defects} / \text{opportunities}) * 10^6 \quad (2)$$

Table (1) Relationship among sigma level, defect rate and yield [2]

Sigma Level	DPMO	Yield (%)
2σ	308 770	69.1230
3σ	66 811	93.3189
4σ	6 210	99.3790
5σ	233	99.9767
6σ	3.4	99.99966

Analyze Phase. In this step, understand and analyze the data collected by using simple statistical tools as well as the process to determine the root causes of the problem that need improvement [5]. In construction, the main task is to identify when, where and why the defects occur in the project, which includes actual and potential problems by using Six Sigma tools [6].

Improve Phase. In this step, Six Sigma project aims to eliminate the identified defects through the knowledge derived from analyze phase. Motivating the team and effective coordination of the different processes and activities and their interface are required to improve the entire construction project [6].

Control Phase. In this step, after finding root causes, alternatives for improvement are considered and improvements made. Then, further data is collected to ensure that improvements have occurred and control plan is put in place to ensure the changes are permanent. In a nutshell, this step ensures that the process improvement is not lost over time [7].

Measure and Analyze Problems

This research includes the application of Six Sigma DMAIC improvement cycle on ready concrete mixture plant (the case study) through the uses of statistical quality tools, and both process capability and stability analyses. In this stage, after gathering data, the Six Sigma team has to decide what to measure and how do they measure it.

The defect is defined, according to the technical specifications of C30 mixture for foundations in the case study, as *all concrete cubes have not passed the compressive strength test based on the American Specification (ACI-318)*.

Accordingly, it is noticed that from 243 products, only 199 have passed, which means there are 44 defects.

After having both the number of correct items and defects, '*DPMO Calculator*' tool which is a part of '*QI Macros Lean Six Sigma SPC Software 2011*' has been used to calculate the current performance level as shown in Fig. 1.

Opportunities	243
Defects	44
Units	1
DPMO	181,070
% Defects	18.11
% Yield	81.89
Sigma	2.41

Figure (1) DPMO Calculator tool of QI Macros software

Quality tools will be used to study and analyze the data statistically, also identifying key process variables that cause failures and understanding root cause's behavior of why failures occurs as follows:

Histogram. It is a graphical representation, showing a visual impression of the distribution of data. It consists of tabular frequencies that represent a frequency distribution and rectangles whose areas are proportional to the corresponding frequencies [7].

Histograms are used in Six Sigma to establish variability or deviation from the center line of the target value in a bell shape; also, they are a way of doing a 'capability' studies. Fig. 2 shows '*histogram with Cp and Cpk*' which drawn by using the QI Macros.

There is a couple of index called Cp and Cpk which help to determine whether a process is capable or not. A Cp ≥ 1 means the process fits between the upper and lower specification limits; whereas Cpk ≥ 1 means the process is centered between these limits. Also, there are many other calculations shown in histogram [2].

According to the values presented, the process is not capable (based on Cp and Cpk) and the histogram is moderately skewed to the left while many point are located outside the lower specification limit (LSL).

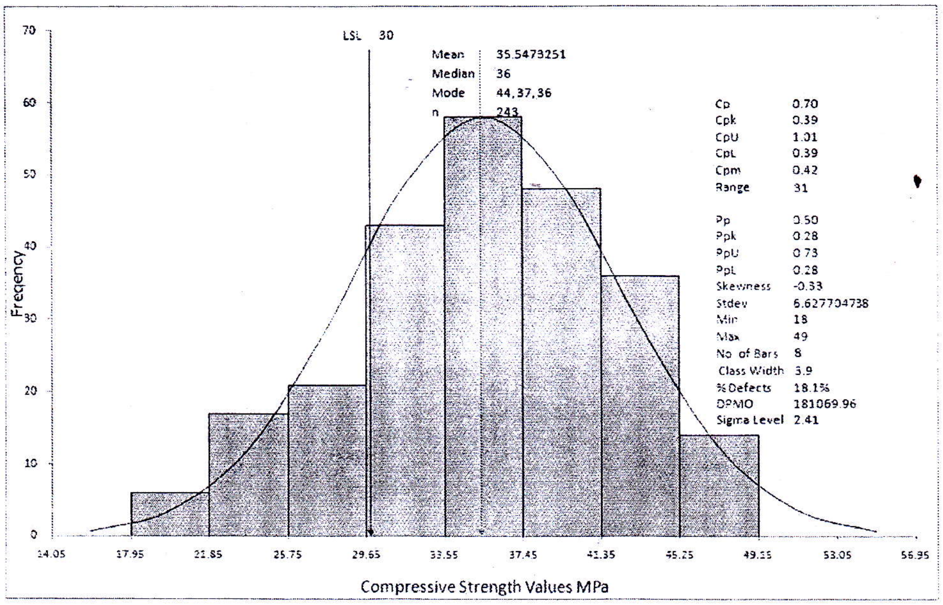

Figure (2) Histogram and capability analysis

Control Chart. Control charts are the appropriate tool to monitor processes. They are useful to find unusual sources for variation. Samples falling outside the control limits are a signal for unusual sources and an investigation should be made to find the causes behind. The appropriate response to the signal is to stop the process at once and preventing defects [8].

There are so many different control charts that estimate μ and σ using the average and range of samples. The formulas to do this vary depending on the type of data (variable data such as time, cost, length, weight, etc. or attribute data such as number of percent defective) and the sample size. Each control chart's formulas are designed for these varying conditions. In variable charts, the XmR uses a sample size of 1, XbarR (2-10) and XbarS (11-25) [9]. Accordingly, the right control chart for this study is the XbarR charts which can effectively help evaluating the stability of processes.

Fig. 3 shows X bar - control chart of the values of compressive strength testing. QI Macros has been used to draw this chart. From this figure, values seem scattered and out of statistical control. Therefore the process is *not stable* (unpredictable).

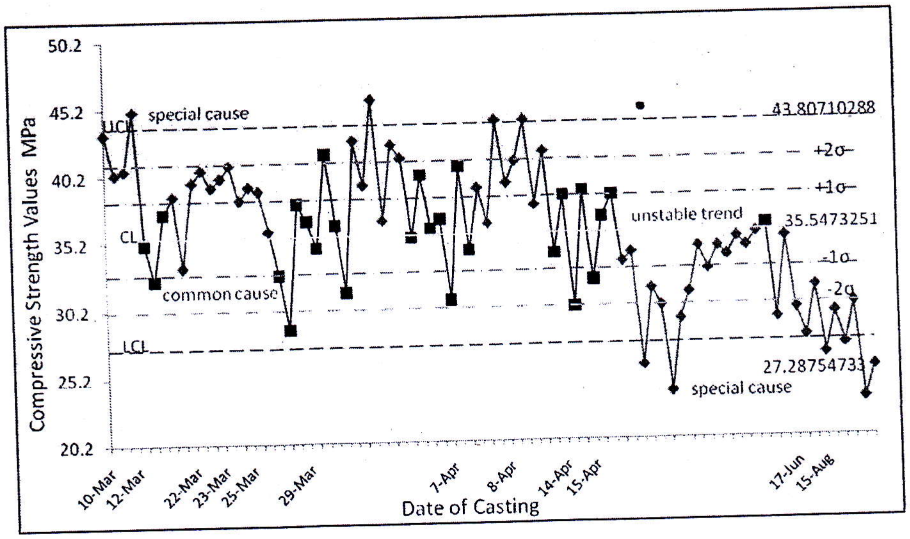

Figure (3) X bar-control chart for the compressive strength testing

Also, it can be noticed that the values start to drop down with the passage of time especially in the second half of the year. Therefore, the control chart, as shown in Fig. 4, is divided into two parts: '*before Summer*' and '*in Summer*' where it is noticed that before Summer the process is almost stable while in Summer the values slope down and become unstable. Thereby, it can be said that the reason for this deviation may return to the *high temperatures* in that period of year in Iraq.

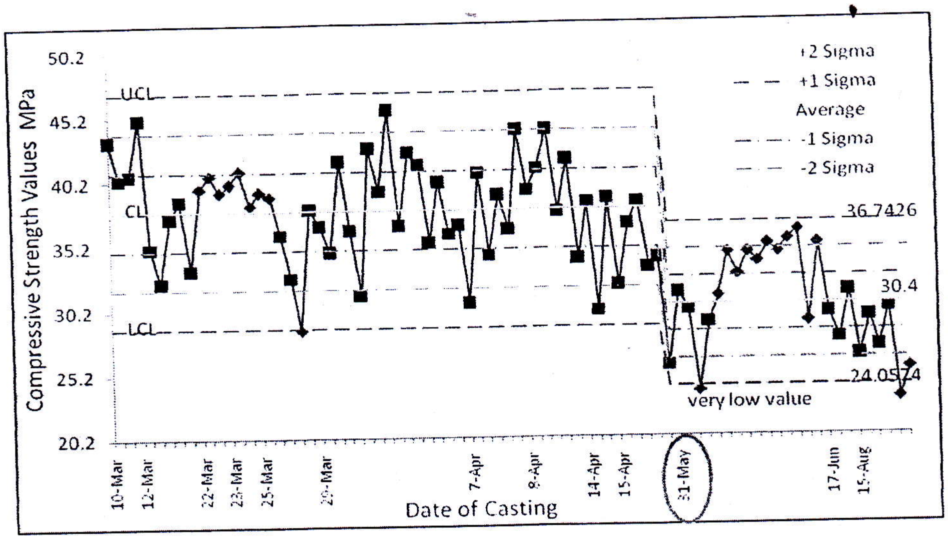

Figure (4) Process change of the X bar-control chart for compressive strength testing

Pareto Diagram. Pareto analysis is a technique for focusing attention on the most important problem areas. The Pareto concept, named after the nineteenth-century by Italian economist Vilfredo Pareto, is that a relatively few factors generally account for a large percentage of the total cases (e.g., complaints, defects, and problems). The idea is to classify the cases according to degree of importance, and focus on resolving the most important, leaving the less important [7].

Pareto chart presents ranking of the main causes of deviation in the quality of concrete mixtures have been found depending on the responses of respondents for the close questionnaire form as shown in Fig. 5 which is drawn by using QI Macros software.

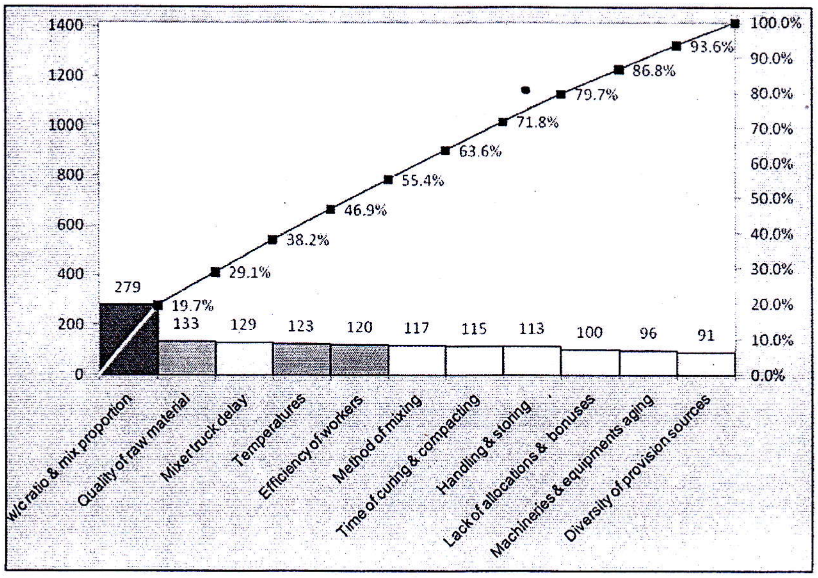

Figure (5) Pareto Diagram of causes of deviation in concrete works

Cause and Effect Diagram. It is known as Ishikawa diagram after its originator or as a fishbone diagram because it looks like that. This tool is a facility that helps organizing ideas or a way of capturing root causes in Six Sigma [2].

According to the results of close questionnaire, field visits to the concrete plant, and interviews with both: key project participants and engineers as well as Pareto chart, the major causes of deviation in the quality of concrete mixtures have been found and pictured in Fig. 6.

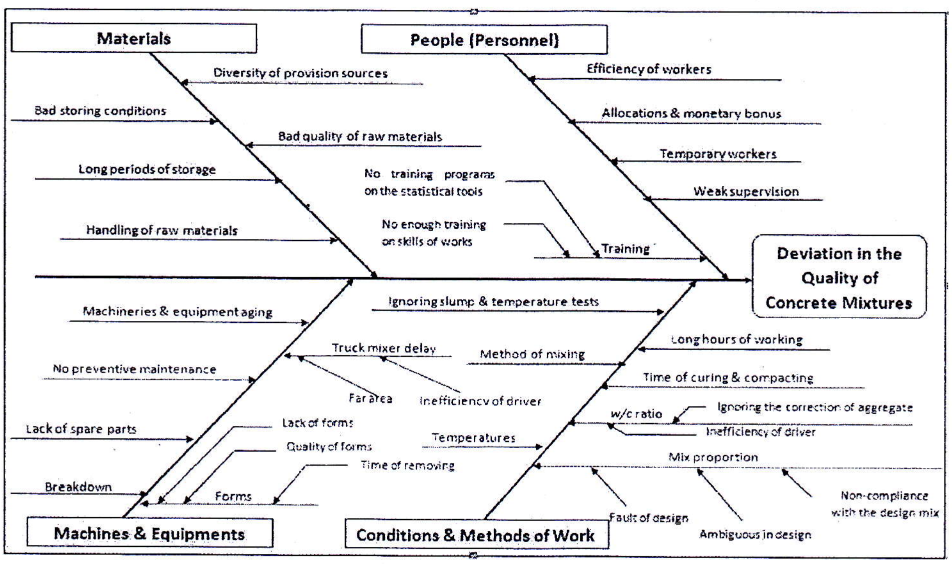

Figure (6) Fishbone dia. for causes of deviation in the quality of concrete mixtures

The statistical analysis and quality tools have shown the problems that cause weak quality of concrete works where it is noticed that the major difficulty for the ready mixed concrete industry lies in achieving the specified consistence (workability), maximum water/cement ratio and minimum cement content for each delivery. Therefore, corrective and preventive actions must be taken place to improve performance. Also, offering employee skills training courses and incentive programs are recommended to insure continual process improvement.

Conclusions

1. The current process performance for the quality of concrete works in the case study are: 2.41 level of sigma, 81.89% quality yield, 18.11% non-conformance production and 181,070 DPMO which are considered too bad as compared with the current global competition and need to be improved.
2. Histograms are a way of determining capability (does the process meet customer specification?), while control charts are a way of measuring stability (is the output of process predictable and consistent?). Therefore, the values of compressive strength testing in the case study were neither capable nor stable.
3. From Pareto chart, the major causes of deviations in the quality of concrete mixture are: *w/c* ratio and mix proportion; then, bad quality of materials, truck mixer delay; after that, temperatures; next, efficiency of workers and other reasons.
4. Suffering from lack of interest in the quality returns to the wrong belief in organizations which thinks that controlling quality costs too much.

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