# On the Use of the Basic Quality Tools for the Improvement of the Construction Industry: A Case Study of a Ready Mixed Concrete Production Process

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***Abstract*— The paper is dedicated to make a review of the basic concepts on process improvement and to show the benefits of applying these concepts in improvement projects of construction firms. A special focus is made on the use of the basic quality tools to improve the production process of ready mixed concrete (RMC). A local ready mix concrete producer at the region of Hail in Saudi Arabia has been taken as a case study, where the 28 days compressive strength of the plant has been monitored and analyzed using the histogram and Xbar-R control charts techniques. The analysis shows clearly that concrete producers can effectively improve their production processes, save money, materials and make their processes sustainable.**

***Index Terms*— Process Improvement, Quality Tools, Construction Industry, Ready Mixed Concrete, Saudi Arabia**

## I. Introduction

In the era of competitive markets and globalization, quality concepts and philosophies have emerged as strategic issues at all organizational levels and in all industries and services including the construction industry which is the major asset of national economies. International quality standards and excellence models such the ISO 9000 standards, the EFQM model, Deming Prize and the King Abdul-Aziz Quality Award model require organizations' quality systems to be built on processes, rather than requirements, departments or functions. Consequently, proper process identification and management are becoming more relevant and critical challenges for quality professionals, process engineers and business leaders. World/class organizations use total quality management (TQM) tools to identify, analyze and assess qualitative and quantitative data that are relevant to their processes with the main objective towards the continuous improvement of the process and the delivery of high quality products and services. One of the simplest and most effective tools used by engineers in manufacturing and service processes for problem solving and quality improvement, are the basic quality tools known as the magnificent seven [23]. Japanese quality guru, engineering professor, Kaoru Ishikawa who is the inventor of the seven basic quality tools stated clearly that 95% of quality related problems in any organization can be resolved using these tools and hence many opportunities for improving processes can be generated; This important statement has been proven in the field by different organizations and researchers including the construction industry worldwide ([6] and [14]).

The Kingdom of Saudi Arabia has been rated as the 13th most economically competitive country in the world, according to the International Finance Corporation (IFC)-World Bank annual "Doing Business" report issued for 2010. The report highlighted the rapid rate of economic growth among Middle Eastern countries, especially in the construction industry. According to a recent study conducted by the national research institution KACST [17], the Saudi construction industry counts for 8% of the national GDP. Economic data indicated that spending on construction of residential units were SR 82 billion (USD 22 billion) in 2007, and may further increase to SR 112 (USD29) billion by 2016. Spending on non/residential construction increased by 8% from SR 42 billion in 2006 to SR 46 billion in 2007, is expected to grow further to SR 73 billion in 2016. Infrastructure spending, which increased from SR 82.5 billion in 2006 to SR 90 billion in 2007, is expected to grow to SR 171 billion in 2016 backed by the government’s privatization initiatives and the huge projects of the newly established economics cities such as King Abdullah economic city. Despite the evolution of the national economic structure, the unprecedented construction boom of recent years has led to the reemergence of some problems and challenges related to the quality of construction projects deliverables and products. According to the same study, the Saudi construction sector suffers from the lack of advanced know-how, use of energy-intense manufacturing processes, high construction costs, lack of commitment to quality, and disregard to improvement of

This work was undertaken within the BinLaden Research Chair on Quality and Productivity Improvement in the Construction Industry sponsored by Saudi BinLaden Group. The RMC data analyzed here were provided by Tammami Mix Co.
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material properties to meet Saudi Arabian Standards Organization (SASO) standards. Hence, in such an important industry, there is a room for improvement in terms of product quality, productivity improvement and more importantly in customer satisfaction. This can be achieved through the implementation of quality philosophies such as TQM, six-sigma or the excellence models and the application of the associated tools and techniques.

The seven basic quality tools have been used by quality professionals to identify procedures, ideas, statistics, cause and effect concerns and other issues relevant to their organizations. They can be used to enhance the effectiveness, efficiency, standardization and overall quality of procedures, products, services and work environment, in accordance with ISO 9000 standards. These tools and techniques have been used in manufacturing and services organizations to aid in the analysis, documentation and organization of quality systems. They have been also used as problem solving and process improvement tools [8]. Recent studies showed the effectiveness of these tools as simple and effective methods for construction processes improvement, problem solving and the achievement of customer satisfaction in many construction organizations ([14], [24] and [26]). Special focus has been shown in the literature on the use of the control chart tools for the improvement of many different construction processes such as concrete production ([19], [28], [10]) and asphalt production ([12], [3]).

The aim of the present paper is to review basic concepts on process improvement and to show how the basic quality tools can be used to solve problems and improve quality in construction organizations. A field case study on the use of the SPC tools for the improvement of a local Saudi Ready-Mixed concrete production plant will be presented and discussed.

## II. Literature Review

In this section, a review of the basic concepts of process improvement is made followed by a brief description of the seven basic quality tools. A discussion of the published technical literature on the use of these tools for the improvement of the construction processes is then presented.

### A. *Basic Concepts of Continuous Process Improvement*

A fundamental question is always raised in front of business leaders "Do we really need to improve our processes? Edwards Deming, in his book "out of the crisis" published in 1986; answered this question in his famous chain Reaction shown in figure 1. The benefits from quality and process improvements to all types of organizations including the construction business are:

- Improve Quality;
- Costs decrease because of less rework, fewer mistakes, fewer delays, better use of machine-time and materials;
- Productivity Improves;
- Capture the market with better quality and lower price;
- Stay in Business;
- Provide jobs and more jobs.

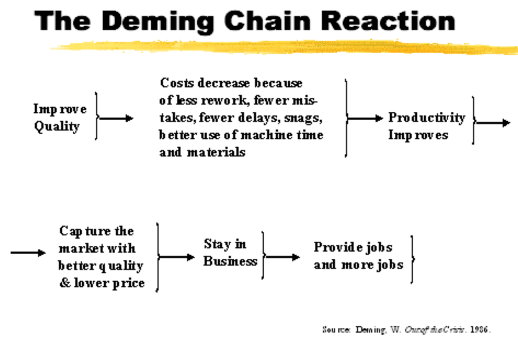



Fig. 1. Deming's Chain Reaction

### B. *How to ensure Continuous process improvement?*

The most common process of continuous improvement is the PDCA Cycle, which was first developed by Walter Shewhart in the 1920s, and promoted effectively from the 1950s by quality guru Dr Edwards Deming, as a strategy to achieve breakthrough improvements in processes. The four steps in the cycle which is also known as the Deming Wheel are as shown on figure 2.

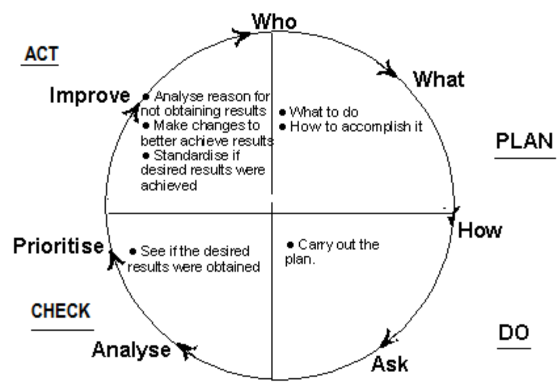



Fig. 2. The Deming Wheel (PDCA Cycle) for Continuous Process Improvement

Seven phases have been identified by quality scholars to implement the PDCA cycle in the improvement process of an organization:

Phase 1 - Identify the Opportunity for improvement
Phase 2 - Analyze the Current Process
Phase 3 - Develop Optimal Solutions
Phase 4 - Implement Changes
Phase 5 - Study the Results
Phase 6 - Standardize the Solution
Phase 7- Plan for the Future

### *C. The Seven Basic Quality Tools*

Once the quality improvement process is understood, the addition of quality tools can make the process proceed in a systematic manner. Many quality tools are available for quality professionals for this purpose. Many organizations use total quality management (TQM) tools to identify, analyze and assess qualitative and quantitative data that are relevant to their processes. These tools can be generally classified to three major categories namely the basic seven quality tools, the seven new tools for management and Planning and other tools. The seven basic quality tools are simple tools that can be used by any professional to ease the quality improvement process. These are: flowcharts, check sheets, Pareto diagram, cause and effect diagram, histogram, scatter diagram, and control charts. These tools were originally developed by Kaoru Ishikawa, one of the pioneers of the Japanese quality movement. Ishikawa's original list did not include flowcharts; instead, it had graphs as one of the tools. These seven basic tools have been considered a part of Statistical Process Control (SPC), a quality management system that uses a set of tools to analyze, control, manage, and improve process quality. But not all seven tools are quantitative, let alone statistical. The flowchart is simply a visual description of a process. A cause-and-effect diagram is a brainstorming/based problem/solving procedure. Check sheets and Pareto diagrams are simply commonsense tools. Histogram, scatter diagram, and control charts are the only statistical tools in the list. Table 1 shows the seven tools and their applications within the PDCA cycle for process improvement which can be used as a guide to select the right quality tool for the improvement process.

Quality Pioneer Ishikawa believed that 95% of quality-related problems in any organization can be solved with these basic tools. This statement has been proven by many organizations and researchers as it will be shown later. The key to their success in problem-solving and process improvement initiatives are their simplicity, ease of use and their graphical nature. The tools were originally meant to make process analysis less complicated for the average factory worker in Japan, but now they constitute standard analytical tools to analyze quality problems and develop and identify optimum solutions and standardise them. They can easily be taught to any member of the organization. These tools have been widely used in manufacturing and services and more recently by constructions organizations embracing process/improvement initiatives within the Total Quality Management (TQM) and Six Sigma approaches or the excellence models.

These tools have been extensively described in textbooks ([4], [16],[18],[23],[26]) and more recently by [1],[2],[26], [27]. Professor Nankana named these tools as the "Magnificent Seven" due to their efficacy in solving problems and improving virtually any process. Research papers on the use of these tools in the construction industry are discussed in section 3. A brief description of these tools is shown in this section:

***Flowchart***: a graphical display of the process steps in proper sequence. A flowchart shows all process steps under analysis by the quality improvement team, identify critical process points for control, suggest areas for further improvement, and help explain and solve problems.

***Check sheet***: A structured, prepared form for collecting and analyzing data; a generic tool that can be adapted for a wide variety of purposes.

***Pareto chart***: Shows on a bar graph which factors are more significant.

***Histogram***: The most commonly used graph for showing frequency distributions, or how often each different value in a set of data occurs.

***Cause/and/effect diagram*** (also called Ishikawa or fishbone chart): Identifies many possible causes for an effect or problem and sorts ideas into useful categories.

***Scatter diagram***: Graphs pairs of numerical data, one variable on each axis, to look for a relationship between process variables.

***Control charts***: Graphs used to study how the process changes over time.

TABLE I
THE SEVEN BASIC QUALITY TOOLS AND THEIR ROLE IN THE PDCA IMPROVEMENT CYCLE

| Methodology / Phase → <br> Tools ↓ | Identify Opportunity | Analyze Process | Develop Solutions | Implement Solutions | Evaluate Results | Standardize Solutions | Plan for the Future |
|---|---|---|---|---|---|---|---|
| Flow Charts | √ | √ | √ | | | √ | |
| Check Sheets | √ | | √ | √ | √ | | |
| Pareto Chart | √ | | | √ | √ | | √ |
| Histogram | √ | | | | | | |
| Cause and Effect Diagram | √ | √ | √ | √ | | | |
| Scatter Diagram | | √ | √ | | √ | | |
| Control Chart | √ | | √ | | √ | | √ |

### *D. Applications of the Basic Quality Tools in the Construction Industry*

As it was mentioned earlier, according to Professor Ishikawa 95% of quality related problems in any organization can be resolved using the seven basic quality tools. Professor Nankana [23] named these tools as "The Magnificent Seven". These important statements can be proven from the amount and the quality of research papers and articles published by quality professionals and researchers in manufacturing ([22], [11] and [5]) and services ([13], [8], [21] and [30]). Construction organizations are no exception to this flaw, they can greatly improve their processes and solve real problems in the field which hamper their efficiency and lead to customer and client dissatisfaction as shown from recent studies ([29], [14], and [6]). Recent interest has been shown on the use of control charts to monitor and improve production processes of

Ready Mix Concrete ([19], [28], [10]) and asphalt ([12], [9], [24], and [3]).

It is to be stressed here that these studies conducted in leading universities show clearly that within nowadays competitive environment, construction organizations worldwide and of course in the Saudi context can continuously improve their processes to meet ISO 9000 requirements and achieve breakthrough improvements and business excellence by a systematic use of the basic quality tools together with the deployment of quality awards standards. The benefits gained by these business organizations fit well with the Deming quality chain reaction discussed in the previous section; just to recall these are: product quality improvement, costs decrease, productivity improvement, defect rate reduction, customer satisfaction and increased profits; all these benefits are obvious targets and even more, reasons for the existence of constructions business owners and organizations.

## III. Research Methodology

The present paper describes initial results of a research project undertaken within the BinLaden Research Chair on Quality and Productivity Improvement funded by the Saudi BinLaden Group; One of the major construction organizations in the Middle East. The scope of the project was to set an implementation procedure of Statistical Process Control tools for the improvement of construction organizations within the Saudi context and conditions. Initially, particular focus was set on the use of control charts to monitor and control Ready Mix Concrete delivered to Hail university constructions projects. Primary data have been collected from a local RMC producer located in the region of Hail which acted as a supplier for the university projects, and analyzed using the Minitab 15 statistical software.

## IV. Results and Discussion

Sufficient have been gathered from the supplier's records of tests certificates for two types of ready mixed concrete (M21 and M35) during a period of six months. It is to be noted here that for M21, the character "M" stands for the design mix having a characteristic compressive strength of 21 MPa at 28 days. The compressive strength tests at 28 days for the concrete were performed by a third party accredited testing laboratory. Typical data are shown in table 2, for 20 samples of three cylinders each for a specified ready mixed concrete of 35 MPa of compressive strength. The data represent approximately 20,000 cubic meters of concrete delivered in two strength categories (M21 and M35) for one single project.

A preliminary analysis of the data is displayed in figure 3. In this figure the minimum specified compressive strength $f`_c$ is plotted against the actual strength of concrete delivered to the university jobsite. For the majority of materials delivered, the actual strength far exceeded that required by the client for the particular job. This can be seen from figure 3 by comparing the plotted points to the solid line that represents the ideal and perfect correlation between delivered and specified strengths. Since almost all of the data happen to be situated above the ideal line, it is clear the actual strength of concrete delivered is much higher than the specified strength. In fact, the actual strength is on average 170 percent higher than the specified values. From the customer point of view, this can be seen as a warrantee for him since he is receiving a concrete with a compressive strength that far exceeds the specifications of the design. However, from a quality perspective, this can be seen as an overdose of the concrete and more importantly as an opportunity to make savings in materials and costs while maintaining the required quality levels. Examinations of the concrete mix design records provided by quality control department shows that the quantity of cement used in the mix varies between 300 and 450 Kg/m3. Therefore, the amount of cement that could be saved by reducing the total cement content in the mixture can be significant. In order to reduce the cement consumption and develop sustainable concrete mixtures, compressive strength needs to be better incorporated in the design of mixtures and quality control during concrete production. In a recent study, Laungrungrong et al. [19] analyzed concrete data provided by Arizona Department of Transportation's (ADOT) and noticed the same observations obtained with the present data. They argued that due to the scarcity of raw materials for making concrete and penalties that can be incurred by companies, it is important to apply quality control methods to identify ways to reduce unnecessary use of materials while maintaining a high level of quality and meeting required specifications.

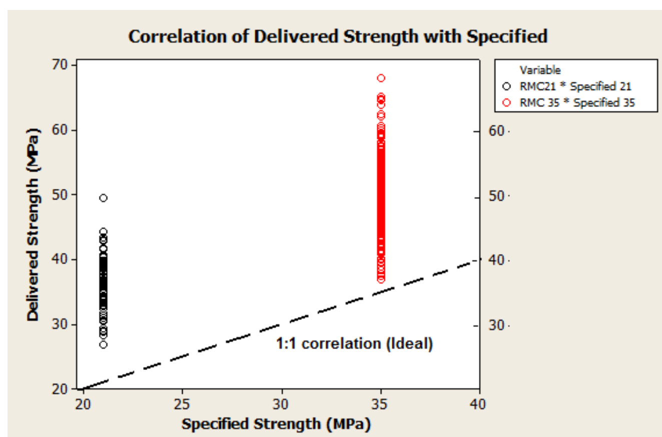
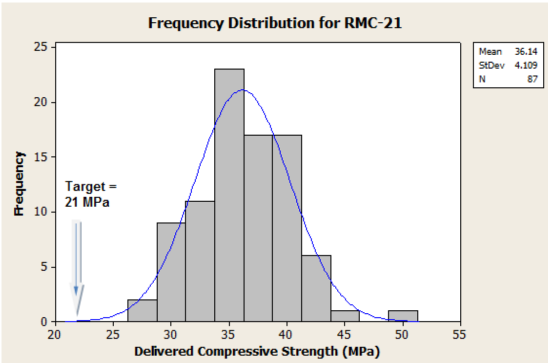
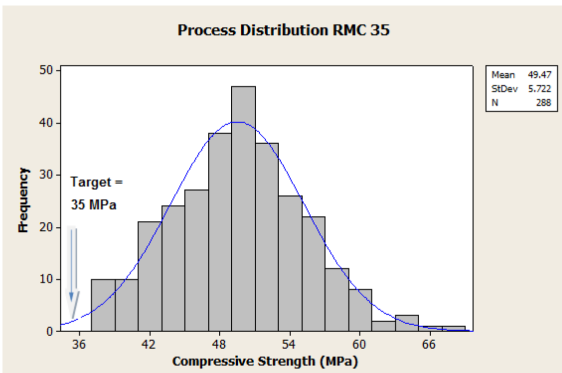



Fig. 3. Correlation of Delivered Compressive Strength with the Specified Value for the Ready-Mixed Concrete Production Plant

Analysis of the process data using the histogram tool shows that the production process distributions for the two types of concrete delivered were characterized by a big variability (Figure 4-a,b). While process targets were set respectively at 21 and 35 MPa, the actual process statistics were: (average of 36.14 MPa with a standard deviation of 4.11 MPa) for the M21 and (average of 49.47 MPa with a standard deviation of 5.72 MPa) for the M35. The shift in process means associated with such variability is a strong indication of over-designed concrete mixtures, which constitute an area for improvement for the management of the plant.




(a) Concrete Type M21




(b) Concrete Type M35

Fig. 4. Histograms of Ready-Mixed Concrete Production Plant

The basic assumption prior to the use of control charts to monitor processes is that the process data should be normally distributed, this can be seen from figure 4 (a, b) where a good comparison is shown between the actual process distribution (histogram bars) and the ideal normal bell curve distribution. To re-enforce this observation, probability plots are constructed for each concrete data set. Figure 5 and Table 3 display the results of the probability plots and the statistics summary of the two types of concrete analyzed. The normality assumption was tested using the Anderson-Darling (AD) test. The Anderson-Darling test can be used to determine if a sample of data could have come from a normally distributed population ([19]). A small value of the AD statistic indicates that the data follows a normal distribution. Results of the AD test reported in table 3 suggest that the process data follow a normal distribution. The p-values are usually used to determine the appropriateness of the normality assumption. If the p-value is less than or equal to the commonly chosen level of 0.05, then there is evidence that the data are not normally distributed. The p-values shown in table 2, (p=0.854 for concrete M21 and p=0.786 for the concrete M35) are greater that 0.05; Then it can concluded safely that the present data come from a normally distributed production process. Another support that the process data for both types of concrete are normally distributed can be seen from figure 5 which represents the probability plots for the two types of concrete together with descriptive statistics (Mean, standards deviation, AD coefficient and the p values).

TABLE II
TYPICAL DATA FOR 28 DAYS READY MIX CONCRETE COLLECTED FROM A COMMERCIAL RMC SUPPLIER

| Sample number | Compressive Strength at 28 days Required Strength = 35 MPa | | | Mean Strength for 3 Cylinders (MPa) |
|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | |
| 1 | 50.20 | 54.90 | 53.70 | 52.93 |
| 2 | 55.80 | 56.20 | 55.50 | 55.83 |
| 3 | 46.40 | 49.50 | 48.60 | 48.17 |
| 4 | 53.60 | 51.20 | 57.50 | 54.10 |
| 5 | 64.80 | 60.40 | 64.60 | 63.27 |
| 6 | 55.50 | 54.90 | 46.90 | 52.43 |
| 7 | 65.30 | 53.70 | 54.30 | 57.77 |
| 8 | 51.00 | 53.10 | 48.80 | 50.97 |
| 9 | 44.90 | 49.70 | 51.80 | 48.80 |
| 10 | 47.10 | 50.80 | 53.50 | 50.47 |
| 11 | 51.40 | 55.00 | 56.00 | 54.13 |
| 12 | 54.60 | 50.20 | 53.90 | 52.90 |
| 13 | 59.40 | 47.00 | 50.90 | 52.43 |
| 14 | 47.10 | 44.70 | 45.70 | 45.83 |
| 15 | 40.00 | 39.90 | 40.00 | 39.97 |
| 16 | 46.20 | 46.00 | 42.40 | 44.87 |
| 17 | 45.30 | 46.80 | 42.60 | 44.90 |
| 18 | 56.30 | 46.00 | 50.00 | 50.77 |
| 19 | 51.00 | 56.70 | 54.20 | 53.97 |
| 20 | 51.40 | 42.40 | 45.00 | 46.27 |

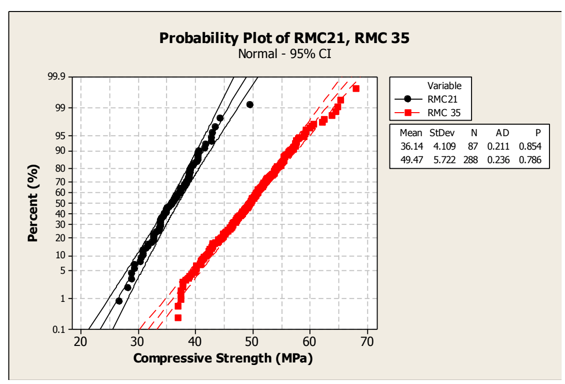



Fig. 5. Probability Plot of the Concrete Production Plant

TABLE III
STATISTICS FOR NORMALITY TEST RESULTS FOR THE DATA

| RMC Type | Mean | Standard Deviation | N | AD | P |
|---|---|---|---|---|---|
| M21 | 36.14 | 4.109 | 87 | 0.211 | 0.854 |
| *M35* | 49.47 | 5.722 | 288 | 0.236 | 0.786 |

Once the normality of the data is tested and proved, further analysis can be carried out to investigate the stability of the production process over time and its behavior. For that purpose, Shewhart $X_{bar}$-R charts were used. As shown in figures 6 and 7, the concrete production process was out of statistical control for both concrete types which means that there were some assignable causes that affected the production process and the quality of the concrete. Careful examination of the charts, especially for the M35 type of concrete (figure 6), shows that the process stability fails four tests out of the eight conventional Western Electric tests. This is clear indication of the existence of multiple sources of special causes in the concrete production process of the plant. These assignable variations can be attributed to change in mix constituent materials (cement characteristics, fine aggregates, coarse aggregates, ad-mixtures, water quality etc.), uncalibrated weigh-scales, workmanship, or a problem in the mix design itself. In order to improve the production process, management should conduct investigations and root causes analysis of the problem using available quality tools such as the cause-and-effect diagram (figure 8) and the Pareto analysis. Corrective actions should be taken to remove the special causes of variation from the process and to reduce the variability. It must be stressed here that this is a management's responsibility as always preached by quality gurus Dr Edwards Deming [7], Ishikawa [15], and Kume [18]. The roadmap for process improvement shown in figure 8 can be used by the plant management to solve concrete variability problems and achieve breakthrough improvement in the process.

Recent studies ([19], [28], [10]) confirmed that for noticeable process variability, Shewhart control charts such as $X_{bar}$-R and $X_{bar}$-s charts can be used to analyze the process, whereas for small variations and process shifts that could not be detected by the common charts, time weighted CUSUM and EWMA control charts should be used. For the present case study, the results show clearly that the variability is so big that it can easily be detected by standards control charts. At this stage, the author suggests only the use of the Shewhart control charts. In order to improve the process plant, management should conduct investigations and root causes analysis of the problem using available quality tools such as the cause-and-effect diagram and the Pareto analysis. Corrective action should be taken to remove the special causes of variation from the process and to reduce the variability. It must be stressed here that this is a management's responsibility as always preached by quality gurus Dr Edwards Deming [7], Ishikawa [15], and Kume [18].

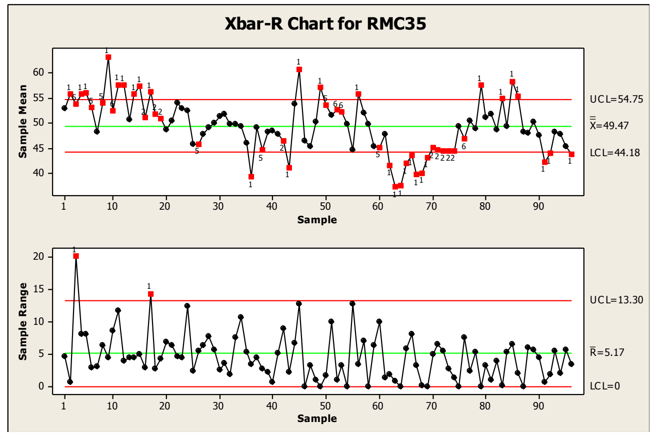



Fig. 6. $X_{bar}$-R Control Charts for Ready-Mixed Concrete (M35)

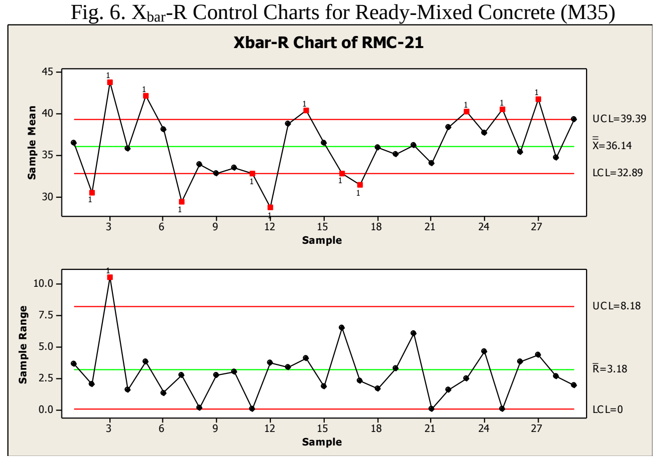



Fig. 7. $X_{bar}$-R Control Charts for Ready-Mixed Concrete (M21)

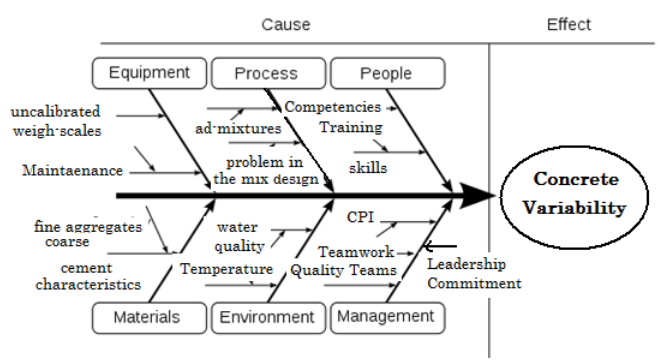



Fig. 8. Ishikawa Diagram for Root Causes Analysis of Concrete Variability

It is clearly shown from this analysis that Statistical Process Control (SPC) tools which constitute a major part of the basic quality tools can be used efficiently by the construction industry to continuously improve their processes by reducing the variability and eliminating errors and rework in their projects. As discussed in [8] and [14], and according to the quote of professor Ishikawa [15] "*Quality control starts with education and ends with education*", it is recommended that construction organizations possess planned and documented procedures for training of employees (management and technical) and for the implementation of SPC and quality tools in their processes to ensure a continuous improvement of the processes that would lead to customer satisfaction and achieving business excellence. Such a recommendation is fully supported by the findings of recent studies presented in [19], [28], [10] on Ready-Mixed concrete and in ([12], [9], [24], [3]) on asphalt. There will be no need to show how these two materials are important in our world in general and to emerging economies such as Saudi Arabia, where the undergoing construction projects cost billions of dollars.

## V. Summary and Conclusions

The present paper shows how construction organizations can use the basic quality tools for the improvement of their processes and save materials and money. A case study on a local Saudi construction company in Hail region was presented and discussed. It was shown that with the use of the basic quality tools in general, and the Statistical Process Control (SPC) tools, namely the control charts, construction organizations can monitor, control and improve their processes in order to achieve breakthrough improvements and business results. Ready Mix Concrete producers can monitor the strength of the concrete produced on a daily, weekly, or monthly basis. This would ensure that the quality of concrete delivered to the customer is as per the specifications of the mix design. As a result, producers need not opt for an over-design their mix to reduce the risk of failing the required strength, but they can avoid unnecessary wastage of material and cement.

It is to be stressed here that the control charts in particular and the seven basic quality tools in general have demonstrated a great capacity in the improvement of manufacturing and services industries across the globe and the construction industry can benefit from these tools. There are basically five reasons behind this:

1. The seven basic quality tools are proven techniques for improving productivity;
2. They are effective in defects and errors prevention;
3. They prevent unnecessary process adjustments;
4. They provide diagnostic information; and
5. They provide information about process capability to meet customer requirements.

The study concludes that planned and documented procedures for training of employees from top management to technical staff, and systematic implementation of the quality tools in production processes, together with a strong commitment of leadership to continuous improvement, are key success factors for construction industry organizations to stay in business and the achievement of customer satisfaction and business excellence. It is the author's conviction that ISO 9001 certification procedure associated with the systematic implementation of the quality tools would be an excellent approach for quality improvement in the RMC industry, especially in the context of the Saudi construction industry where there is continuous growth in the use of ready-mixed concrete (RMC) in the construction mega-projects of the economic cities launched by the government recently.

## VI. Future Research

The present paper stresses on the need for quality improvement in the RMC industry by analyzing the product variability. It is known that this variability in product characteristics would lead to short term consequences such as bad quality, increased costs, and unsatisfied customers and loss of business and market shares. The question that would be raised here is concerned about the long term consequences, i.e. the safety of the building and its structures in few years time. The ultimate goal of the owner of the structure, the engineer and even the quality professional is the safety of the structure that the concrete batch is intended to be used for constructing. Therefore, more informed decisions can be taken if the structural safety is used as supplement indicator on the quality of the produced concrete. Future research should focus on this aspect and should develop an approach for controlling and assessing the quality of ready mixed concrete using structural safety as a metric.

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