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QUALITY ASSESSMENT OF CONCRETE PRODUCTION USING STATISTICAL PROCESS CONTROL (SPC) TECHNIQUES

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Keywords:

Statistical Process Control (SPC); Quality; Quality Tools; Control Charts; Process Capability; Concrete.

ABSTRACT

This article aimed to review the ability of the Palestinian construction companies to apply the basic tools of statistical process control (SPC) in their concrete production systems for process improvement. A special focus is made on improving the production process of B30 concrete since it is the most widely used type in the Palestinian market. A local company was taken as a case study to monitor the compressive strength of their B30 concrete using different quality tools such as histogram, control charts and cause-and-effect diagram. The tools implementation and data analysis show clearly that these tools can be applied in such sector effectively and used to improve production processes to save materials and money.

1. INTRODUCTION

Nowadays, quality is considered as one of the most important competitive advantages each organization in all sectors (services and manufacturing) should possess and invest in to reach defect-free products. A quality led organization should recognize the needed level of quality to satisfy customers' expectations. The identification of customer requirements will help the organization to decide what to do to meet these expectations through stable processes with acceptable level of variability (Gejdoš, 2015). The competitive markets and globalizations all over the world have emerged quality concepts as strategic issues in all organizations and levels (Adinyira et al., 2014). Achieving high level of quality will directly improve the organizational performance such as financial and marketing performances to enhance organizational competitive advantages (Alghamdi & Bach, 2013). One of the most challenges all organizations face is the dynamic nature of quality since customers are increasingly demanding; this forces the organizations to be innovative to maintain productivity and competitiveness though producing high quality products with lowest possible cost to ensure survival (Godina et al., 2016). For organizations to be more competitive, the clue is in exceeding customer's expectations through providing the right products at the right time every time with minimum possible cost (Madanhire & Mbohwa, 2016)

To improve quality, recent research focuses on reducing the variability in the production processes and subsequently risking raising costs under continuous improvement approach (Lim et al., 2019). This improvement can be achieved through reducing defectives and overall quality costs by the implementation of quality tools and methodologies. This implementation should be linked with measures to quantify process improvement and defectives

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percentage (Sousa et al., 2017). Statistical Process Control (SPC) methodology is efficient in analyzing, managing, controlling and improving processes to enhance the quality of products that has been broadly used in a huge number of sectors including industrial and non-industrial fields (Subbulakshmi et al., 2017). SPC uses statistical methods to detect and monitor special cause events. It is considered as a powerful set of tools and techniques useful in achieving process stability and capability to reduce process variability by identifying and eliminating special causes (Montgomery, 2009). These tools are called magnificent seven or seven basic tools. This set of tools includes check sheet, histogram, Pareto chart, cause and effect diagram, graphical tools, scatter plot and control charts (Shahin et al., 2010). Management commitment and team work approaches are the most vital components for SPC to be potentially successful since it is impossible for one person to achieve improvement alone without a managerial involvement (Parmar & Deshpande, 2014).

In any country, construction sector is always considered as one of the most important sectors that significantly impact economies since it has an intense relationship with other sectors to stimulate the economic development. This is also applicable to the Palestinian context(El-namrouty, 2012). The Palestinian construction sector suffers from the lack of using quality control techniques in their production systems (such as concrete manufacturing systems). This industry mainly based on experience to meet the Palestinian Standards Institute (PSI) standards. Hence, in such an important industry, there are many opportunities for improvement using SPC tools to meet or exceed customer requirements and reduce the manufacturing costs. The aim of this article is to show how the basic SPC tools can be used to analyze and solve quality problems in a local construction company in Palestine that produces concrete, especially B30 concrete since it is the most widely used material in construction industry that has a nominal compressive strength of 300 Kg/cm^2.

2. LITERATURE REVIEW

SPC is a quality control approach based on statistical methods to monitor processes to make sure they are working in a stable efficient manner to produce a higher percentage of conforming products/services with less waste. It works like a preventive method rather than corrective to detect problems early instead of correcting them after they have occurred. Many research studies implemented different SPC tools and techniques to improve production systems in different industries and sectors such as construction, food, healthcare, manufacturing, and so on. SPC is an online quality control system that can be defined as a philosophy, strategy and methods to improve systems and their outcomes based of theory of variation due to common and special cause events (Suman & Prajapati, 2018). These special cause events should be detected and monitored to bring the process back to its in-control state (Lee et al., 2015). SPC oriented companies have achieved higher levels of process performance metrics as an integral component of quality management system (Antony et al., 2015). The level of success in SPC implementation relies on appropriate planning and immediate actions taken by workers to solve problems (Mengesha, Yonatan; Singh, Ajit Pal; Amedie, 2013). Implementing SPC requires a high level of motivation and not just forcing organization to meet customer requirements; so that it should be implemented voluntarily (Mohd Yunus et al., 2016).

The fact that appropriate utilization of SPC seven basic quality tools have a major capacity to improve industries globally has been stressed by different studies. With these tools, the organization can analyze, control and improve their processes to achieve outstanding business results (Adinyira et al., 2014). The continuous implementation of these tools has a major effect on workers as they become more able to think, generate ideas, plan and solve problems. This development helps in improving the internal environment in the organization as a requirement of Total Quality Management (TQM) adoption (Magar & Shinde, 2014).

SPC can be applied in any industry or system or discipline where the outputs' specifications and requirements can be identified and measures. For example, SPC was implemented in Nigeria to monitor the production, packaging and distributing processes of sachet water. Control charts and capability analysis were used to check the process state of stability and to verify the marketing process capability. The results showed that the manufacturing process should be re-adjusted to bring it back to in statistical control state before improvement. Whereas, the marketing process were in-control but incapable with respect to specifications that generated low profit. These results stimulate the company to propose solutions to improve the marketing process (Ieren et al., 2020). In Malaysia, due to the limited use of SPC in food industry; a study was accomplished showed that SPC is applicable and relevant for quality improvement of food safety opportunity for the security of food industry in Malaysia in the future by open global market (Mohd Yunus et al., 2016). Another study were implemented in the United Kingdome (UK) to assess the status of SPC in food manufacturing industry. Through surveying food manufacturing companies, 45% of them uses variable control charts as a common SPC tool. The study highlighted the management commitment as the most critical factor for a successful implementation of SPC programs. The main reason of not adopting SPC completely is the lack of awareness and training of SPC concepts and techniques. Finally the study provides information on most common practiced and useful quality tools for food industries since SPC companies achieved better results than non-SPC ones (Lim et al., 2019).

In healthcare sector, a review of literature article on SPC and control charts applications were constructed. This article showed that most of control charts application work is carried out in Surgery, Emergency and Epidemiology departments. This study found that United States (US), UK and Australia are the leaders where maximum of work was done on regular interval (Suman & Prajapati, 2018)

The SPC seven tools have significant roles in monitoring and controlling processes through detecting and solving problems for any production system to achieve organizational performance excellence (Neyestani, 2018). The quality tools can be implemented with the seven management tools in an integrative frame work (Shahin et al., 2010) The seven quality tools were implemented to reduce paint shop defects in an automotive factory. This implementation reduced the overall defects by 70%. One of the most important used tools is the cause-effect diagram since it helped to find the defects' root causes and eliminate them as much as possible (Memon et al., 2019). Some of quality tools can be used and implemented under different six sigma DMAIC (design, measure, analyze, improve and control) approach phases to optimize processes to gain the best quality level (Hakimi et al., 2018)(Lim et al., 2019)(Morales et al., 2016)(Karakhan & Alsaffar, 2013). Control charts as one of the quality tools is considered also as a tools for six sigma framework that used for quality monitoring in all organizational units in an extensive manner (Gohel & Sarkar, 2017).

In construction industry, quality inspection has an important role in concrete manufacturing processes that encourages producers to obtain a higher quality products (Caspeele et al., 2014). Some studies were conducted to identify and evaluate the improvement opportunities in the methods of production and pouring of concrete in Saudi Arabia using different quality tools in addition to show the benefits of applying process development concepts on improvement projects of construction firms (et al. Aichouni, 2017)(M. Aichouni, 2012). In Ghana, a survey of precast concrete products producers was conducted to explore their level of knowledge and usage of quality tools. Because of the level of knowledge and usage were limited, the study proposed some practical measures to improve the level of quality (Adinyira et al., 2014). A relationship between the Project Management Body of Knowledge (PMBOK) Guide and the quality management by combining them together was introduced to improve the level of quality management of a ready mixed concrete system on the basis of continuous improvement by finding the company's problems and achieving it through guidelines and instructions of PMBOK and the quality tools (Al-Saedi et al., 2019). Also, the concrete panel production rate can be stabilized and improved through lean six sigma approach implementation by variation elimination (Oguz et al., 2012)(Lade et al., 2015). Another study investigated the current practices in quality control of concrete production in Dhaka City through visiting 45 construction sites in the city and gathering relevant data. The survey results showed that most of the companies are not aware of quality control practices and the implementation key factors and proposed appropriate solutions and recommendations (Alam et al., 2016). A combination between SPC and Design of Experiments (DOE) is powerful in order to determine, improve and monitor the concrete production processes capability through a designed user interface based on several modules such as capability analysis, multi-attribute decision making (MADM)-based Taguchi optimization through TOPSIS and SPC (Şimşek et al., 2019)

3. METHODOLOGY

The used methodology in this article can be summarized and shown in figure 1 as follows:

i. Determination of the intended type of concrete to be studied.
ii. Determination of the most important product's Critical-to-Quality (CTQ) characteristic/s.
iii. Collection of related data.
iv. Construction of appropriate SPC tools and techniques.
v. Evaluation of process current behavior and stability based on tools' results.
vi. Evaluation of process capability.
vii. Development of improvement proposals to improve the process and reduce variability.

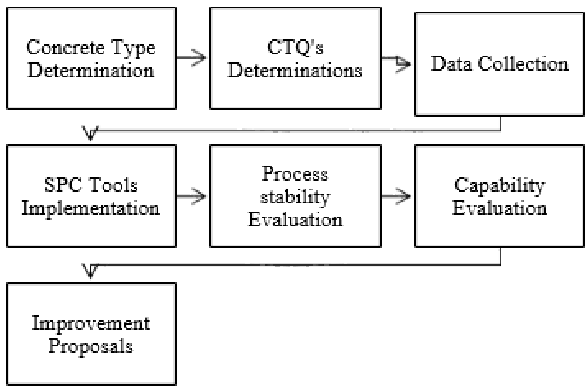

Figure 1. Research Methodology Steps

4. CONCRETE PRODUCTION PROCESS DESCRIPTION

This article considers ready mixed concrete of 300 Kg/cm^2 compressive strength coded as B30 according to the local Palestinian standard. This type has been chosen in this study because it is the most common concrete required by the Palestinian market. It is especially used in construction of residential buildings and other facilities. The production process as shown in figure 2 starts with preparing all required ingredients in correct quantities. These ingredients are cement, aggregates and water. Then, these ingredients are batched and mixed in a concrete mixer to produce fresh concrete. The mixer blinds all ingredient into a uniform mass for the required time. After placing concrete, curing process takes place to maintain moisture content. This process is very important in the development of concrete strength. After 28 days, three samples of cubic shapes are taken from each batch to perform compressive strength test.

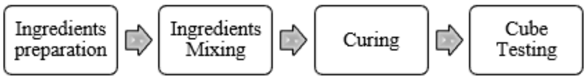

Figure2. B30 Concrete Production Steps

5. DATA ANALYSIS AND RESULTS

Producing a batch of B30 concrete is based on mixing ingredients in order to achieve the intended compressive strength. The best result is achieved when all taken sample's cubes meet specifications. Practically, not all cubes will have a nominal compressive strength, some of them may have higher or lower values. Lower values may pose a risk on the concrete performance in buildings. The Palestinian standard allows no more than 5% of the compressive strength below the target value. B30 compressive strength data have been collected from official test certificates issued by a local accredited laboratory. The gathered data of testing 25 samples of size 3 test cube is shown in table 1.

Table 1. Preliminary data for B30 compressive strengthtests

Sample No.	Compressive strength after 28 days in (Kg/cm^2)		
	Cube 1	Cube 2	Cube 3
1	336	347.5	356
2	309.5	388.8	349.8
3	348.4	409.5	385.9
4	357	368	336.5
5	329.5	319	381
6	285.5	316	408.2
7	393.4	386.8	321.5
8	268.2	329.3	330.1
9	306.8	376.7	335.8
10	343.6	335.2	383.2
11	464.7	389.4	370.5
12	334.3	296.4	381.8
13	374.5	323.4	320.7
14	353.7	327.6	368.3
15	406.7	321.2	377
16	395.1	402.4	358.5
17	335.3	304.2	414.2
18	425.6	330.3	308.9
19	461.9	395	316
20	325.1	353	352.7
21	326.2	352.8	277.2
22	327.5	374.9	395.1
23	303.5	342.9	314
24	331.5	369	377
25	299.5	305.3	287.8

Before estimating the process capability, control charts for variables were used to make sure that the process is in-statistical control. But the basic assumption prior to the use of control charts is that the process output (compressive strength data) should be normally distributed. Histogram was used and shown in figure 3 to provide information about data distribution.

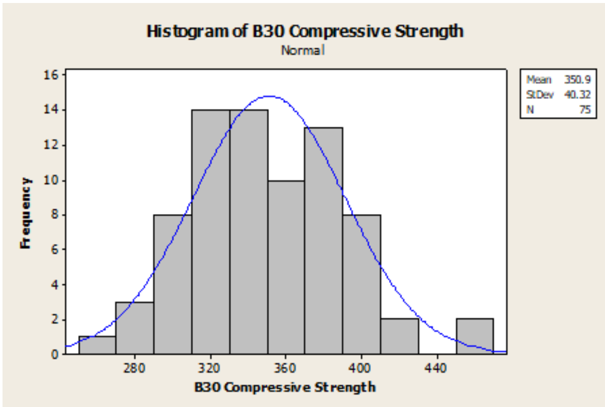

Figure3. B30 Compressive Strength Histogram

The shape of the histogram implies that the distribution of compressive strength is approximately normal. To enhance the assumption of normality, normal probability plot was tested using Anderson-Darling (AD) test at a significance level of 0.05. Figure 4 displays test results.

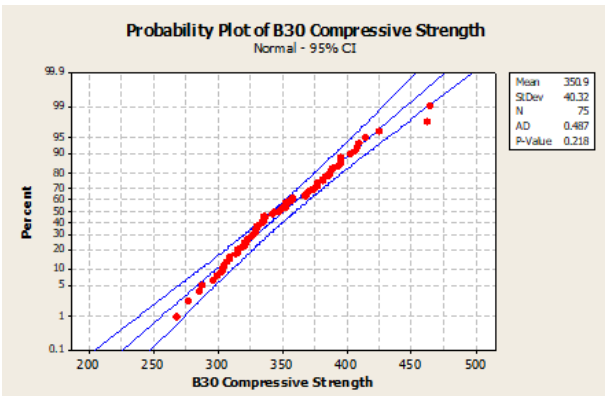

Figure4. B30 Compressive Strength Probability Plot

The value of AD (=0.487) is small; this means that the normality assumption is acceptable. Also, since the p-value = 0.218 is greater than 0.05, we are unable to reject the null hypothesis that the distribution of compressive strength is normal. Now, the process behavior and stability can be investigated by using control charts which considered as one of the most important quality tools. For this purpose, X-bar and R charts were constructed and shown in figure 5.

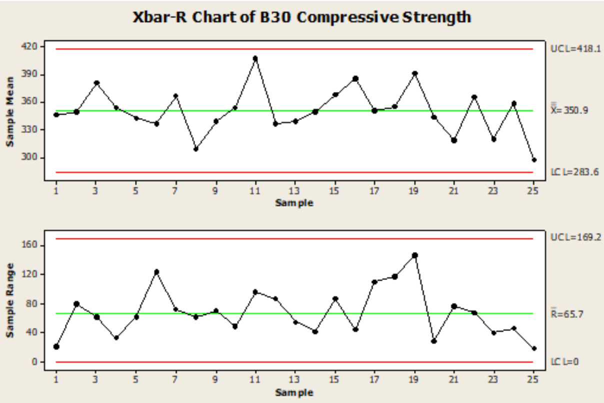

Figure5. B30 Compressive Strength Control Charts

Based on charts behavior, the process of producing B30 concrete was in statistical control and stable. Hence, no assignable causes were detected to affect the process quality level. The stability of in-statistical control process is essential to interpret the process capability through using process capability ratios PCRs. According to the Palestinian standard, the B30 compressive strength should have a nominal value of 300 Kg/cm^2 (30 MPa) but not less than 285 Kg/cm^2. To assess the process capability, the resulting estimator of one sided lower process capability ratio C_{pl} was calculated to be 0.57 as shown in figure 6. This low value was due to high value of process variability that affects process ability to meet the specification negatively. The cause of this high level of variability can be attributed to change in ingredients, gauges and scales, labor and mixers.

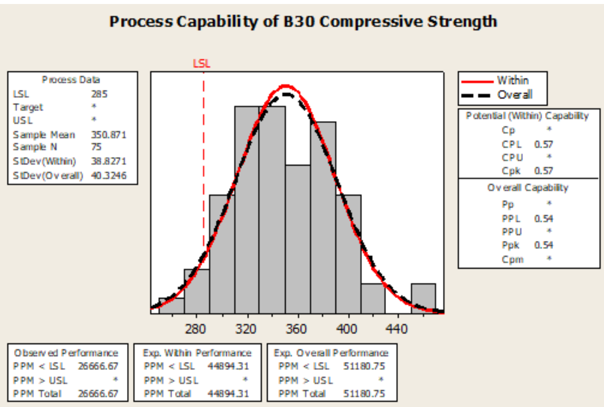

Figure6. B30 Compressive Strength Process Capability Analysis

In order to improve the process capability, management should conduct investigations and adopt the other quality tools such as cause-effect diagram, check sheet, Pareto chart and so on. Figure 7 shows a suggested root cause diagram that can be used to take corrective actions to remove excessive process variability. This diagram is considered as a roadmap for the management to improve the production process by eliminating excess variability causes as much as possible.

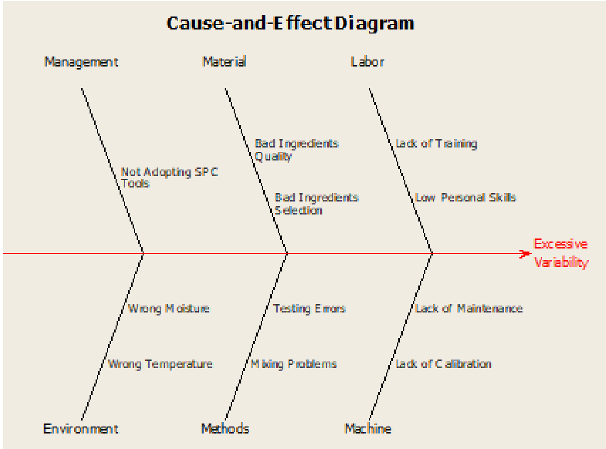

Figure7. Excessive Variability Cause-Effect-Diagram

Finally, it is clear from control charts that the company was afraid of providing concrete with low compressive strength, therefore, they opts for an over-design by adding excess ingredients. This addition let to increase the overall average of strength but at the same time affects the process variability in a negative manner. Raising the overall averages cannot guarantee that each batch will be conforming to specifications. Adding extra ingredients led to more waste in materials and cement. Applying quality tools correctly, using more advanced weigh-scales can help the producer to produce conforming concrete batches with optimal ingredients quantity to reduce variability and cost. Monitoring the current practices of the producer showed that they are not aware of having a clear documented and planned procedures to implement SPC tools for continuous improvement that would lead to customer satisfaction and more business excellence.

6. CONCLUSION

The aim of this work is to show how the Palestinian construction materials manufacturers can benefit from adopting the SPC tools for achieving process improvement that can save money and materials. It was shown that SPC tools and techniques are applicable in construction organizations and the mentioned case study results can be generalized to other construction companies even with different practices. The producers can monitor their B30 concrete strength and take corrective actions to improve the processes rather than just waiting the tests results and to optimize the processes to gain the best mixture or ingredients instead of spending more materials than required.

The used tools helped the organization to diagnose their production process stability and capability as a first step of adopting continuous improvement approach, in line with exploring the possible root causes of quality problems. Also, these tools can improve productivity and prevent defects prevent unnecessary adjustments.
The study concludes that the construction organizations should have a system of documentation, data selection

and analysis, training programs and management commitment through adopting the quality tools as an essential part of their quality management systems. Although the producers don't perform compressive strength tests, they should have a data transformation system with the certified testing laboratories to analyze their process performance for further improvement in the future.

Finally, each construction organization can use DOE is a systematic approach to analyze the process influential variables on concrete quality and to determine their appropriate levels for optimizing process performance. DOE can be used to isolate and estimate the process sources of variability since the organization has more than one concrete mixer as a suggestion for future work.

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References:

Adinyira, E., Ayarkwa, J., & Aidoo, I. (2014). Knowledge and Usage of the Seven Basic Quality Control Tools By Producers of Precast Concrete Products in Ghana. *Journal of Construction Project Management and Innovation.*

Aichouni, et al. (2017). Statistical analysis of concrete strength variability for quality assessment: Case study of a Saudi construction project. *International Journal of ADVANCED AND APPLIED SCIENCES.* https://doi.org/10.21833/ijaas.2017.07.015

Aichouni, M. (2012). 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. *International Journal of Civil & Environmental Engineering.*

Al-Saedi, A., Pasławski, J., & Nowotarski, P. (2019). Quality Management to continuous improvements in process of Ready Mix Concrete production. *IOP Conference Series: Materials Science and Engineering.* https://doi.org/10.1088/1757-899X/518/2/022019

Alam, A., Habib, Z., Sheikh, R., & Hasan, A. (2016). A Study on the Quality Control of Concrete Production in Dhaka City. *Journal of Mechanical and Civil Engineering.*

Alghamdi, H., & Bach, C. (2013). Quality As Competitive Advantage. *INTERNATIONAL JOURNAL OF MANAGEMENT & INFORMATION TECHNOLOGY.* https://doi.org/10.24297/ijmit.v8i1.690

Antony, J., Lim, S. A. H., & Arshed, N. (2015). A critical assessment on SPC implementation in the UK food industry. *WMSCI 2015 - 19th World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings.*

Caspeele, R., Sykora, M., & Taerwe, L. (2014). Influence of quality control of concrete on structural reliability: Assessment using a Bayesian approach. *Materials and Structures/Materiaux et Constructions.* https://doi.org/10.1617/s11527-013-0048-y

El-namrouty, K. (2012). The Impact of Construction Sector on Palestinian Economy-Case Study:(Gaza Strip). *American Academic & Scholarly Research Journal.*

Gejdoš, P. (2015). Continuous Quality Improvement by Statistical Process Control. *Procedia Economics and Finance.* https://doi.org/10.1016/s2212-5671(15)01669-x

Godina, R., Matias, J. C. O., & Azevedo, S. G. (2016). Quality improvement with statistical process control in the automotive industry. *International Journal of Industrial Engineering and Management*.

Gohel, J., & Sarkar, D. (2017). COMPARATIVE STUDY OF CUSUM WITH V-MASK AND EWMA CONTROL CHARTS FOR STRENGTH MONITORING OF READY MIXED CONCRETE. *Interanational Journal of Advaned Technology in Engineering and Science (IJATES).*

Hakimi, S., Zahraee, S. M., & Mohd Rohani, J. (2018). Application of Six Sigma DMAIC methodology in plain yogurt production process. *International Journal of Lean Six Sigma.* https://doi.org/10.1108/IJLSS-11-2016-0069

Ieren, T. G., Kuje, S., Asongo, A. I., & Eraikhuemen, I. B. (2020). Application of Statistical Quality Control in Monitoring the Production, Packaging and Marketing Process of Sachet Water. *Journal of Scientific Research and Reports*. https://doi.org/10.9734/jsrr/2020/v26i930307

Karakhan, A. A., & Alsaffar, A. E. (2013). Measure and analyze the problems of concrete mixture production via six sigma DMAIC tools: Central concrete mix plant as a case study. *Applied Mechanics and Materials.* https://doi.org/10.4028/www.scientific.net/AMM.313-314.771

Lade, a D., Nair, a S., Chaudhary, P. G., & Gupta, N. R. (2015). Implementing Six Sigma Approach for Quality Evaluation of a RMC Plant at Mumbai, India. *IOSR Journal of Mechanical and Civil Engineering* Ver. I. https://doi.org/10.9790/1684-12210104

Lee, S. P., Wong, D. S. H., Sun, C. I., Chen, W. H., & Jang, S. S. (2015). Integrated statistical process control and engineering process control for a manufacturing process with multiple tools and multiple products. *Journal of Industrial and Production Engineering.* https://doi.org/10.1080/21681015.2015.1026419

Lim, S. A. H., Priyono, A., & Mohamad, S. F. (2019). Introducing a Six Sigma Process Control Technique in a Food Production Line: Step-by-step Guideline and Critical Elements of the Implementation. *2019 IEEE 6th International Conference on Industrial Engineering and Applications, ICIEA 2019*. https://doi.org/10.1109/IEA.2019.8715119

Madanhire, I., & Mbohwa, C. (2016). Application of Statistical Process Control (SPC) in Manufacturing Industry in a Developing Country. *Procedia CIRP*. https://doi.org/10.1016/j.procir.2016.01.137

Magar, V. M., & Shinde, V. B. (2014). Application of 7 Quality Control (7 QC) Tools for Continuous Improvement of Manufacturing Processes. *International Journal of Engineering Research and General Science.*

Memon, I. A., Ali, A., Memon, M. A., Rajput, U. A., Abro, S. A. K., & Memon, A. A. (2019). Controlling the Defects of Paint Shop using Seven Quality Control Tools in an Automotive Factory. *Engineering, Technology & Applied Science Research.* https://doi.org/10.48084/etasr.3160

Mengesha, Yonatan; Singh, Ajit Pal; Amedie, W. Y. (2013). Quality Improvement Using Statistical Process Control Tools in Glass Bottles Manufacturing Company. *International Journal for Quality Research.*

Mohd Yunus, M. F., Taib, C. A., & Iteng, R. (2016). A Preliminary Study on the Application of Statistical Process Control (SPC) Towards Process Efficiency: Case Study in Food Industries. *Sains Humanika*. https://doi.org/10.11113/sh.v8n4-2.1055

Montgomery, D. C. (2009). Introduction to Statistical Quality Control, Sixth Edition. In John Wiley & Sons, Inc.

Morales, S. N., Adán Valles, C., Torres-Argüelles, V., Erwin Martínez, G., & Andrés Hernández, G. (2016). Six Sigma improvement project in a concrete block plant. *Construction Innovation.* https://doi.org/10.1108/CI-01-2015-0003

Neyestani, B. (2018). Seven Basic Tools of Quality Control: The Appropriate Techniques for Solving Quality Problems in the Organizations. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.2947700

Oguz, C., Kim, Y. W., Hutchison, J., & Han, S. (2012). Implementing lean six sigma: A case study in concrete panel production. *IGLC 2012 - 20th Conference of the International Group for Lean Construction.*

Parmar, P. S., & Deshpande, V. A. (2014). Implementation of Statistical Process Control Techniques in Industry : A Review. *Journal of Emerging Technologies and Innovative Research.*

Shahin, A., Mazaher, G., & Arabzad, S. M. (2010). Proposing an Integrated Framework of Seven Basic and New Quality Management Tools and Techniques: A Roadmap. *Research Journal of Internatıonal Studıes-Issue.*

Şimşek, B., Pakdil, F., Iç, Y. T., & Güvenç, A. B. (2019). Building a Graphical User Interface for Concrete Production Processes: A Combined Application of Statistical Process Control and Design of Experiment. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-018-3408-7

Sousa, S., Rodrigues, N., & Nunes, E. (2017). Application of SPC and Quality Tools for Process Improvement. *Procedia Manufacturing.* https://doi.org/10.1016/j.promfg.2017.07.247

Subbulakshmi, S., Kachimohideen, A., Sasikumar, R., & Devi, S. B. (2017). An Essential Role of Statistical Process Control in Industries. *International Journal of Statistics and Systems.*

Suman, G., & Prajapati, D. R. (2018). Control chart applications in healthcare: A literature review. *International Journal of Metrology and Quality Engineering.* https://doi.org/10.1051/ijmqe/2018003

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