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Application of Statistical Quality Control Tools for Analyzing and Improving Rebar Manufacturing Processes: A Case Study of Zliten Iron and Steel Factory

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Abstract:
The iron and steel industry is one of the fundamental pillars of economic development and infrastructure expansion. Rebar used to reinforce concrete structures, is a key product in this industry, where its quality plays a crucial role in ensuring structural safety and durability, necessitating continuous quality control**.** This study explores the application of Statistical Quality Control (SQC) techniques to improve the quality of rebar produced at the Zliten Iron and Steel Factory in Libya. Data related to rebar with a diameter of 14 mm, commonly used in concrete structures, were collected from production lines and analyzed using the Minitab software. The analyses involved the construction of X-bar and R control charts to monitor process variations and identify deviations that may indicate quality issues**.** The results revealed specific instances of process instability, and corrective measures were proposed to enhance product consistency. The study demonstrated that implementing SQC techniques could significantly improve product quality and reduce defects, aligning with both Libyan and international standards. The study recommends continuing the use of SQC tools and training staff to ensure the sustainability of quality improvements.

Keywords: Statistical Quality Control, Control Charts, Quality Improvement, Rebar Manufacturing, Zliten Iron and Steel Factory.

1 .Introduction

The iron and steel industry is a cornerstone of the economy and infrastructure in many countries, including Libya, as it supports construction, automotive manufacturing, and heavy machinery sectors.

Rebar is an essential component of reinforced concrete structures, providing tensile strength to withstand loads and maintain stability [1]. Poor product quality can lead to severe consequences, including structural collapses and significant economic losses. Therefore, implementing stringent quality control mechanisms throughout all manufacturing stages is indispensable. Manufacturing rebar, which aims to produce rods with consistent mechanical properties and dimensions, requires adherence to strict quality standards. Variations in rebar quality, such as differences in diameter and tensile strength, can negatively impact the safety of structures. Here lies the importance of Statistical Quality Control (SQC) techniques.

SQC has become an integral part of modern manufacturing processes, providing systematic methods to monitor, control, and enhance product quality. These techniques employ statistical tools to analyze process data, identify variations, and ensure that production remains within specified quality limits [2]. The application of SQC not only reduces waste and production costs but also enhances the reliability of manufactured products. Established in 2013, Zliten Iron and Steel Factory is one of the largest private steel factories in Libya, with an annual production capacity ranging between 180,000 and 220,000 tons. Despite its importance, the factory faces ongoing challenges related to process variations and inconsistent raw material quality, which affect product quality.

The primary objective of this paper is to evaluate the effectiveness of SQC techniques in stabilizing processes and improving product quality at Zliten Iron and Steel Factory. Specifically, control charts will be used to evaluate the factory's capability to meet set standards and detect process deviations. Additionally, process capability analysis will determine the extent to which production meets quality requirements. By identifying areas for improvement and proposing corrective actions, this study aims to contribute to the enhancement of quality control practices in the iron and steel industry. The significance of this paper lies in its ability to improve manufacturing practices at Zliten Iron and Steel Factory and to provide a model for other factories seeking to adopt advanced quality control methodologies. Moreover, the study highlights the broader importance of SQC techniques in achieving high-quality standards in the global steel industry [4][3].

1.1 Research Problem

Rebar production processes at Zliten Iron and Steel Factory face increasing challenges in quality monitoring and control. Variations in production processes lead to difficulties in meeting required quality standards, negatively affecting product reliability and increasing production costs. The importance of developing effective solutions lies in employing statistical techniques capable of identifying sources of variation and controlling them. Accordingly, this study focuses on exploring the effectiveness of SQC techniques in improving production processes and reducing defects in rebar manufacturing.

1.2 Objectives of the Study

This study aims to achieve the following objectives:

- Highlight the importance of employing statistical quality control tools in rebar production processes at Zliten Iron and Steel Factory.
- Evaluate the effectiveness of statistical control charts in detecting and analyzing process deviations.

2. Literature Review

Quality control is a fundamental component of the steel industry, especially in the production of rebar, which is a key material in the construction and building sector. Below are examples of studies addressing quality control in steel manufacturing:

2.1 Study of the Mechanical Properties of Rebar in Libyan Factories

Authors: Al-Rouimi et al. (2019) [5].

- **Objective:**
  This study conducted a scientific comparison of the mechanical properties and chemical analysis of rebar samples produced by Libyan factories.
- **Findings:**
  Chemical and mechanical analyses were performed, and the results showed that rebar from the Sidi Al-Saiah plant had higher hardness due to a higher carbon content.
- **Summary:**
  The study provided a detailed comparison of the mechanical and chemical properties of rebar from different factories, highlighting differences in hardness based on carbon composition.

2.2 Application of Statistical Quality Control Tools in Hot Rolling Processes

Authors: Mustafa Ahmed et al. (2023) [6].

- **Objective:**
  This study applied statistical quality control (SPC) techniques to monitor and control the quality of tinplate coils produced at the hot rolling plant of the Libyan Iron and Steel Company, aiming to improve quality and reduce defects.
- **Findings:**
  The use of control charts and Pareto diagrams revealed unwanted variations, allowing for corrective actions to be taken before these variations turned into final product defects.
- **Summary:**
  A quantitative approach was used to analyze production data and technical inspection reports, resulting in significant improvements in product quality.

2.3 Enhancing Process Stability in the Steel Industry

Authors: Gupta et al. (2023) [7].

- **Objective:**
  This study investigated the efficiency of statistical control charts in improving production quality and reducing variations in the steel industry.
- **Findings:**
  The implementation of control charts reduced process variations by 30% and increased productivity by 15%.

- **Summary:**
  The study emphasized the importance of using control charts as an essential tool for process monitoring in the metallurgical industry.

The current study aims to fill a gap in the literature by comprehensively applying statistical quality control techniques at Zliten Iron and Steel Factory. It focuses on analyzing the effectiveness of these techniques in improving the quality of rebar and reducing variations while providing practical recommendations to enhance process efficiency.

3. Overview of Statistical Quality Control Techniques

Statistical quality control (SQC) provides essential tools for monitoring and improving manufacturing processes. Control charts, originally developed by Walter Shewhart, are widely used to detect process variations and determine when corrective actions are required [8]. Process capability analysis is another critical aspect, helping to identify whether processes can consistently produce products within specified limits. Other SQC tools, such as Pareto charts, scatter plots, and histograms, offer valuable insights into process performance and areas needing improvement. The theoretical foundation of SQC is based on applying statistical methods to control and enhance manufacturing processes. By using these techniques, manufacturers can identify and address sources of variation, leading to more stable and predictable operations. This results in higher product quality, reduced waste, and increased efficiency. Moreover, SQC plays a crucial role in early defect detection, minimizing rework and waste while maintaining customer satisfaction.

4. Statistical Quality Control Techniques Used

The study utilized the following Statistical Quality Control (SQC) techniques to monitor and analyze the manufacturing processes:

4.1 Control Charts

- **X-bar and R Charts:**
- These charts were employed to monitor the production process by observing variations in the diameter of rebar samples:
  - The **X-bar chart** monitors the average diameter of each sample over time to identify whether the process remains stable. Any points outside the control limits indicate potential issues that require investigation.
  - The **R chart** monitors the range of variation within individual samples. A consistent range within control limits indicates process stability, while points outside the limits signal abnormal fluctuations requiring attention.

5. Methodology

To achieve the objectives of this study, which focuses on improving the quality of rebar produced at Zliten Iron and Steel Factory using Statistical Quality Control (SQC) tools, the following methodology was employed:

5.1 Description of the Manufacturing Process

The main steps involved in the rebar manufacturing process at Zliten Iron and Steel Factory were analyzed. These steps include:

- **Preparation of Raw Materials:**

  Scrap metal is collected as shown in Figure (1), and inspected to ensure it is free of contaminants and impurities. The scrap is then melted in an electric arc furnace to produce molten steel.
- **Casting to Billets:**
  The molten steel is poured into molds to form billets, which are the raw material for rebar production. Stringent inspections are conducted on the billets to ensure their quality.
- **Reheating and Rolling:**
  The billets are reheated and passed through multiple rolling mills to achieve the desired mechanical properties and dimensions of the rebar. This process ensures that the required specifications are met.

- **Cooling and Cutting:**

  The rebars are cooled in a controlled manner to achieve the desired structural properties and are then cut to specified lengths.

- **Final Inspection and Testing:**

  The finished products undergo quality tests, including measurements of diameter, tensile strength, and yield strength, to ensure compliance with Libyan and international standards.

Figure 1: Illustrates the process of collecting iron scrap.

5.2 Data Collection Methods

To evaluate and improve the quality of rebar, data were collected using the following methods:

- **Types of Data Collected:**
    - **Diameter Measurements:**

      The diameter of the rebar was measured at several points to ensure consistency. The target diameter for this study was 14 mm, and five measurements were taken for each sample.

    - **Surface Inspection:**
      A visual inspection was carried out to identify surface defects, such as cracks or irregular patterns.
- **Sampling Procedures:**
    - **Sample Selection:**

      A total of 25 samples of rebar with a diameter of 14 mm were randomly selected from production batches. Five measurements were taken for each sample to improve data accuracy and minimize random errors.

- **Data Analysis Tools:**

  The collected data were analyzed using Minitab statistical software to apply SQC techniques.

5.3 Data Analysis Using SQC Techniques

- **Control Charts:**
    - **X-bar Chart:**

This chart was used to monitor the average diameter of each sample over time, aiming to detect deviations in the process. Any point outside the control limits indicates a potential issue requiring investigation.

- **R Chart:**

This chart was used to monitor variability within samples. Continuous variation within control limits indicates a stable process, whereas points outside the limits suggest abnormal fluctuations.

6. Analysis and Discussion of Results

6.1 Data Collection and Presentation

Data on the dimensions of rebar with a diameter of 14 mm were collected from Zliten Iron and Steel Factory over one month. Measurements were taken for 25 samples, with five measurements for each sample to ensure accuracy and minimize random errors. The data were summarized in tables, as follows:

- **Table 1:** Shows the diameter measurements (in millimeters) for each sample.
- **Table 2:** Presents the calculated averages (X-bar) and ranges (R) for each sample based on the five measurements.

Table 1: Shows the diameter measurements (in millimeters) for each sample**.**

Samples No.	observation				
	1	2	3	4	5
1	14.1	14.2	13.9	14.0	14.1
2	13.8	13.9	14.0	13.9	13.7
3	14.2	14.1	14.3	14.2	14.0
4	13.9	14.0	14.1	13.9	14.2
5	14.0	14.1	14.0	13.9	13.8
6	14.3	14.2	14.1	14.0	14.2
7	13.9	13.8	13.9	14.0	13.7
8	14.1	14.2	14.3	14.0	14.1
9	13.8	13.9	14.0	14.1	13.9
10	14.0	13.9	14.1	14.0	14.2
11	13.6	13.7	13.5	13.8	13.6
12	14.2	14.1	14.0	14.2	14.3
13	13.9	14.0	13.8	13.9	14.1
14	14.1	14.0	14.2	14.1	13.9
15	13.8	13.7	13.9	13.8	14.0

16	14.3	14.2	14.4	14.3	14.1
17	14.0	13.9	13.8	14.0	13.9
18	14.1	14.2	14.0	14.1	14.3
19	13.7	13.8	13.9	13.7	13.6
20	14.2	14.3	14.1	14.2	14.0
21	13.9	14.0	13.8	14.1	13.9
22	14.0	14.1	14.2	13.9	14.0
23	14.5	14.6	14.4	14.5	14.7
24	13.8	13.9	14.0	13.7	13.9
25	14.1	14.0	14.2	14.1	14.3

Table 2: Presents the calculated averages (X-bar) and ranges (R) for each sample based on the five measurements

Samples .No	القياس					المتوسط (X−bar)	المدى (R)
	1	**2**	**3**	**4**	**5**		
1	14.1	14.2	13.9	14.0	14.1	14.06	0.3
2	13.8	13.9	14.0	13.9	13.7	13.86	0.3
3	14.2	14.1	14.3	14.2	14.0	14.16	0.3
4	13.9	14.0	14.1	13.9	14.2	14.02	0.3
5	14.0	14.1	14.0	13.9	13.8	13.96	0.3
6	14.3	14.2	14.1	14.0	14.2	14.16	0.3
7	13.9	13.8	13.9	14.0	13.7	13.86	0.3
8	14.1	14.2	14.3	14.0	14.1	14.14	0.3
9	13.8	13.9	14.0	14.1	13.9	13.94	0.3
10	14.0	13.9	14.1	14.0	14.2	14.04	0.3
11	13.6	13.7	13.5	13.8	13.6	13.64	0.3
12	14.2	14.1	14.0	14.2	14.3	14.16	0.3
13	13.9	14.0	13.8	13.9	14.1	13.94	0.3
14	14.1	14.0	14.2	14.1	13.9	14.06	0.3
15	13.8	13.7	13.9	13.8	14.0	13.84	0.3
16	14.3	14.2	14.4	14.3	14.1	14.26	0.3
17	14.0	13.9	13.8	14.0	13.9	13.92	0.2
18	14.1	14.2	14.0	14.1	14.3	14.14	0.3

19	13.7	13.8	13.9	13.7	13.6	13.74	0.3
20	14.2	14.3	14.1	14.2	14.0	14.16	0.3
21	13.9	14.0	13.8	14.1	13.9	13.94	0.3
22	14.0	14.1	14.2	13.9	14.0	14.04	0.3
23	14.5	14.6	14.4	14.5	14.7	14.54	0.3
24	13.8	13.9	14.0	13.7	13.9	13.86	0.3
25	14.1	14.0	14.2	14.1	14.3	14.14	0.3

6.2 Control Charts Analysis

Control charts were generated using Minitab 19 software as shown in Figure (2), specifically X-bar and R charts, to monitor the process and identify variations:

- **X-bar Chart:**
    - Control limits were calculated with an Upper Control Limit (UCL) of 14.194 mm and a Lower Control Limit (LCL) of 13.852 mm.
    - Most points fell within the control limits, except for samples 11 and 23, which were outside the limits, indicating abnormal variations requiring investigation.
- **R Chart:**
    - The R chart showed that all values fell within the control limits, indicating no significant fluctuations in sample variability.

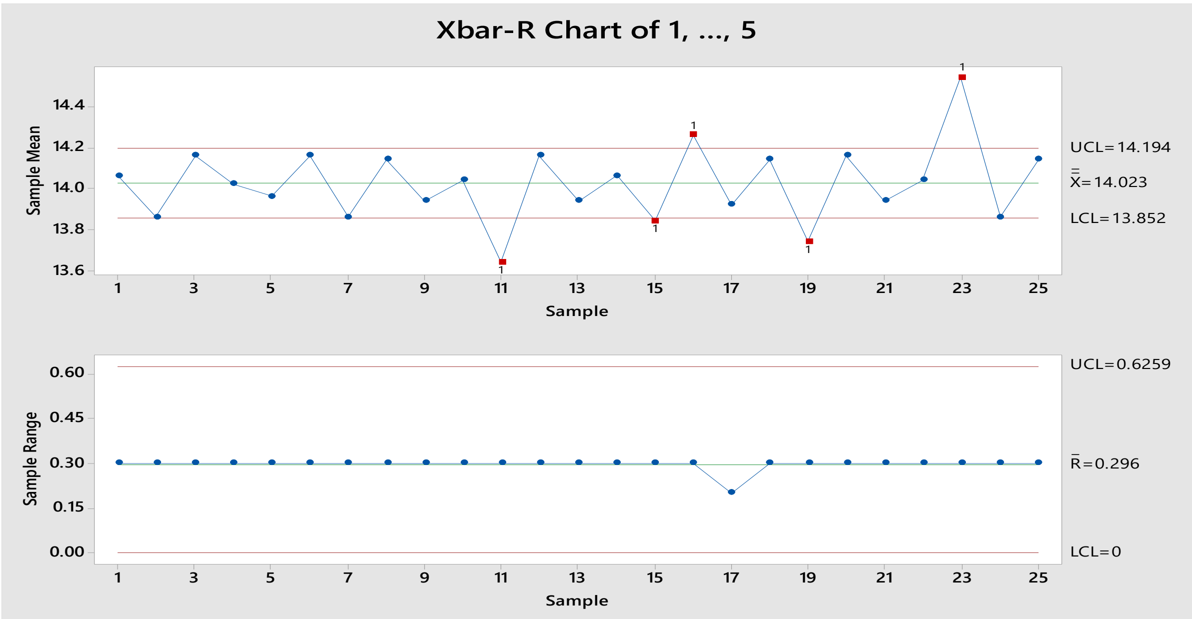

Figure 2: Schematics of X-bar and R charts.

The control charts highlighted areas of potential concern in process stability and provided critical insights for further investigation.

6.3 Out-of-Control Points in the X-bar Chart

The out-of-control points are represented by samples 11 and 23, which indicate the presence of significant issues requiring investigation. Additionally, samples 19 and 16 suggest potential problems, but at a lower level of severity.

- **Sample 11 (below LCL):**

This may indicate a decline in the quality of raw materials, an issue with the measuring device, or a problem in the production process.

- **Sample 23 (above UCL):**

This may point to an unexpected increase in diameter, potentially caused by variations in the production process or the use of inconsistent materials.

These findings suggest that specific corrective actions are necessary to address the identified anomalies and improve process consistency.

6.4 Proposed Solutions for Addressing Issues

The out-of-control points observed in samples 11 and 23 indicate significant issues that require thorough investigation. It is essential to examine the processes and materials used in these samples to identify the potential causes of the abnormal variations, such as changes in raw materials, equipment malfunctions, or human errors. Corrective actions should be implemented to prevent the recurrence of such problems.

Key recommendations include:

- **Improving Process Stability:**

Regular maintenance of equipment and ensuring consistency in the quality of raw materials are critical steps toward enhancing process stability.

- **Analyzing Problematic Samples:**

Conduct detailed analysis of the samples that exhibited excessive variation to identify and address possible causes, such as errors in equipment calibration or changes in the physical properties of the materials used.

- **Advanced Statistical Tools:**

Utilize advanced tools, such as Six Sigma or other statistical methodologies, to identify and minimize sources of variation, thereby improving overall process reliability and consistency.

7. Conclusions and Recommendations

7.1 Conclusions

This study employed Statistical Quality Control (SQC) tools to analyze the quality of rebar produced at Zliten Iron and Steel Factory. The findings reveal that the production process is generally stable; however, abnormal variations were identified in certain samples that require immediate attention. Control charts showed that most values fall within acceptable limits, except for samples 11 and 23, which demonstrated deviations warranting further investigation. While the process is largely stable, these anomalies indicate areas for improvement. The results highlight challenges related to reducing process variation and enhancing production performance. Addressing these challenges is critical to achieving compliance with international and local standards and ensuring overall production efficiency.

7.2 Recommendations

1. Strengthen the quality control system by implementing advanced statistical tools, such as dynamic control charts, to detect and promptly correct any deviations in real-time.
2. Establish close collaboration with raw material suppliers to ensure the receipt of materials that meet the required specifications. This can be achieved by enforcing strict quality standards for suppliers and regularly reviewing material specifications.
3. Adopt quality improvement methodologies such as Six Sigma or Lean Manufacturing to identify and minimize sources of abnormal variation in production processes.
4. Raise employee awareness about the importance of quality control and provide training on the use of statistical quality tools.

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