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A COMPREHENSIVE APPROACH TO ENERGY CONSUMPTION MONITORING IN PLASTIC MANUFACTURING: INTEGRATING CUSUM AND I-MR CONTROL CHARTS

Amarathunga Sachini Anupama Perera[1] and A.M. Razmy[2]
[1,2]Department of Mathematical Sciences, Faculty of Applied Sciences,
South Eastern University of Sri Lanka

[1]anupamapereraas@gmail.com

Abstract

Purpose: This research endeavors to redefine energy consumption monitoring in plastic manufacturing by scrutinizing the accuracy of Specific Energy Consumption (SEC), proposing an integrated approach employing CUSUM and I-MR control charts. The study aims to foster continuous improvement in energy management practices.

Design/Methodology/Approach: This study refines energy consumption monitoring in plastic manufacturing through a robust methodology combining literature review and statistical tools, specifically CUSUM and I-MR control charts. By analyzing data from January 2023, the approach addresses limitations in Specific Energy Consumption (SEC) metrics, providing a dynamic means to detect and rectify subtle shifts in process means over time.

Findings: The research uncovers significant inaccuracies in SEC values, highlighting the imperative for a more comprehensive methodology. The application of CUSUM and I-MR charts proves effective in identifying and addressing deviations, offering nuanced insights into the dynamics of energy efficiency.

Practical Implications: This collaborative research has practical implications for the plastic manufacturing industry. The proposed methodology enables proactive identification and rectification of energy consumption deviations, contributing to enhanced cost optimization and sustainability. Manufacturers can utilize the insights gained to improve process efficiency and achieve substantial energy savings.

Research Limitations: Acknowledging context-specificity to plastic manufacturing, the study recommends further research for generalizability. Assumptions of stability and the exclusion of external factors influencing energy consumption are recognized limitations.

Originality/Value: The research contributes to existing knowledge by presenting a comprehensive methodology for energy consumption monitoring, addressing the limitations of SEC. The integration of CUSUM and I-MR charts provides a unique approach to detecting and managing subtle shifts in process means, offering a practical tool for optimizing energy efficiency.

Keywords: Energy monitoring, Energy saving, I-MR chart, Plastic manufacturing, Process efficiency

1. Introduction

Efficient energy management plays a pivotal role in contemporary manufacturing operations, offering organizations opportunities to curtail costs, heighten efficiency, meet regulatory standards, and fortify competitiveness. The prevalent method for monitoring energy consumption in plastic manufacturing factories

relies on Specific Energy Consumption (SEC). However, this study underscores those inaccuracies in SEC values can lead to erroneous assessments of energy efficiency, thereby impacting cost optimization strategies negatively. In response to these challenges, our study proposes a robust method for monitoring energy consumption in plastic manufacturing, emphasizing the need for diverse metrics alongside SEC for accurate energy performance evaluation. The findings stress the importance of precise SEC values for effective cost optimization strategies and advocate the use of control charts as valuable tools for monitoring energy consumption and detecting process mean shifts. Additionally, the study underscores the necessity for ongoing research to minimize energy waste and emphasizes the regular review and adjustment of energy management practices to maximize energy savings.

Problem with SEC

The widely used metric of Specific Energy Consumption (SEC) in manufacturing has notable limitations. SEC lacks consideration for factors influencing energy usage, is susceptible to measurement errors and manipulation, and can be misleading when assessing energy savings, particularly with variable output levels. This study proposes a more robust approach to monitor energy consumption in plastic manufacturing, emphasizing the importance of diverse metrics alongside SEC for a comprehensive evaluation of energy performance. The goal is to overcome SEC's shortcomings and provide a more accurate understanding of energy usage in the industry.

Control Charts for Monitoring Process

In our pursuit of advancing energy management, we challenge the conventional use of Specific Energy Consumption (SEC) and introduce Figure 1 and Figure 2, illustrating a significant disparity between actual energy consumption, SEC predictions, and Regression estimates. This serves as a compelling foundation for delving into Control Charts.

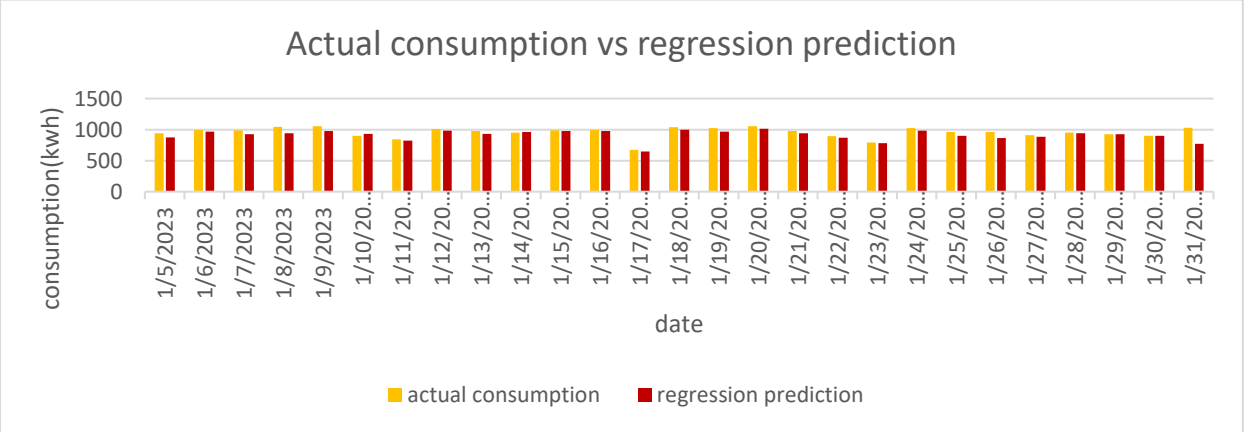

Figure 1 Comparison between actual consumption and regression prediction

Control charts, such as CUSUM and I-MR, emerge as effective tools for monitoring and controlling energy consumption in manufacturing.

2. Literature Review

Our study aligns with previous research, exemplified by Ji et al. (2020), Liu et al. (2020), Ma et al. (2021), and Zhang et al. (2019), which affirm the efficacy of CUSUM, Moving Average, and I Charts in diverse manufacturing contexts. These charts prove instrumental in detecting small and large changes in energy consumption, identifying energy-saving opportunities, and setting production process, energy consumption targets.

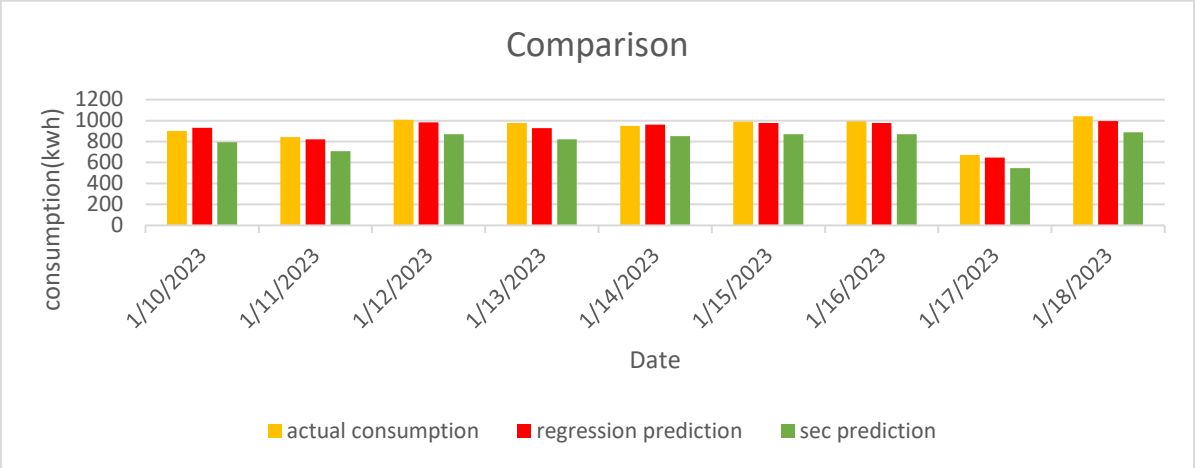

Figure 2 Comparison between actual consumption, regression, and SEC prediction

3. Methodology

To develop control charts, the difference observed in the energy consumption during January 2023 were used. In the methodological exploration, we employ control charts to monitor the energy gap by comparing actual and predicted energy consumption. The I-MR chart, a valuable tool for tracking process variation over time, is utilized to establish control limits and identify outliers, ensuring accurate monitoring.

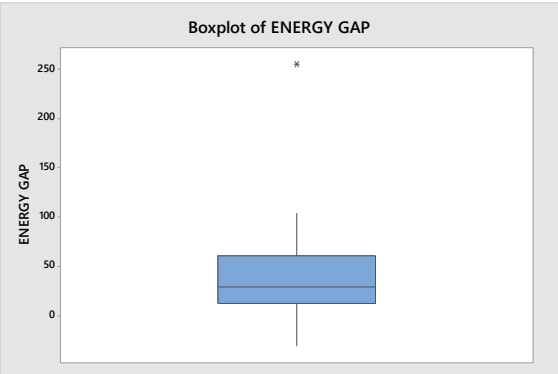

Figure 3 Box plot of energy gap

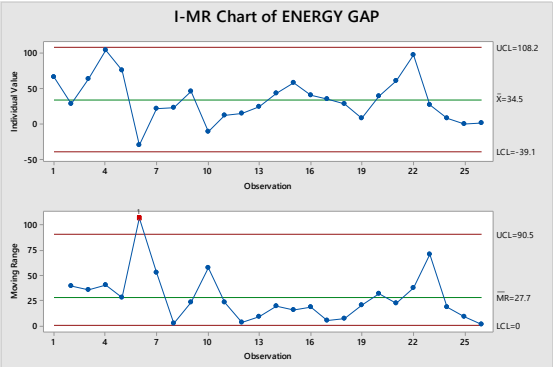

Figure 4 I-MR chart of energy gap

4. Results and Discussion

Our analysis, depicted in Figure 1 showcases that while the energy consumption remains generally under control, there are instances of significant deviations, especially on January 31st. To address these anomalies, we employ both CUSUM and I-MR charts for continuous monitoring and improvement of energy consumption. I-MR chart allows identifying any changes in the energy gap over time and taking corrective action before any significant deviations occurred. Overall, the I-MR chart was an effective tool for monitoring and improving the performance of the photovoltaic module. While the I-MR chart is useful for monitoring the energy gap, it is not the tool used for setting energy targets a tool for setting energy targets is needed.

The CUSUM chart, designed to identify subtle shifts in energy consumption, effectively tracked cumulative deviations in Figure 5 with a 25.3 kWh target. However, it revealed a failed one-point beyond control limits test in January 2023, indicating significant deviations (points 4, 5, and 27). This failure suggests a notable change in

the mean value of the process, necessitating investigation into potential causes. The CUSUM chart's key utility lies in early detection of minor changes, enabling prompt corrective action for quality maintenance and serving as a valuable tool for monitoring and controlling energy usage by setting targeted mean energy consumption. For optimal use, realistic targets based on baseline energy consumption and organizational energy-saving goals should be set, with regular adjustments based on evolving processes and energy-saving objectives.

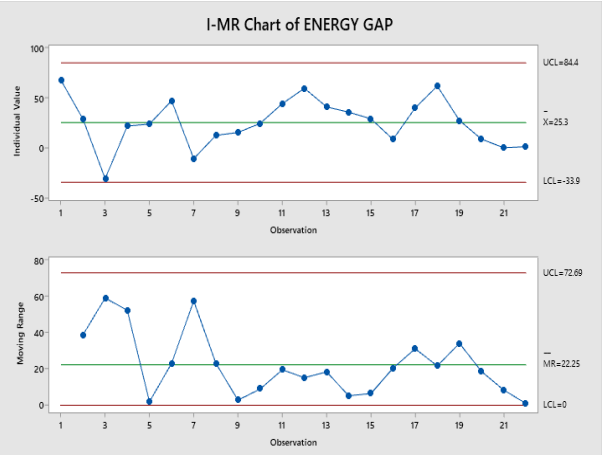

Figure 4: I-MR chart for energy gap

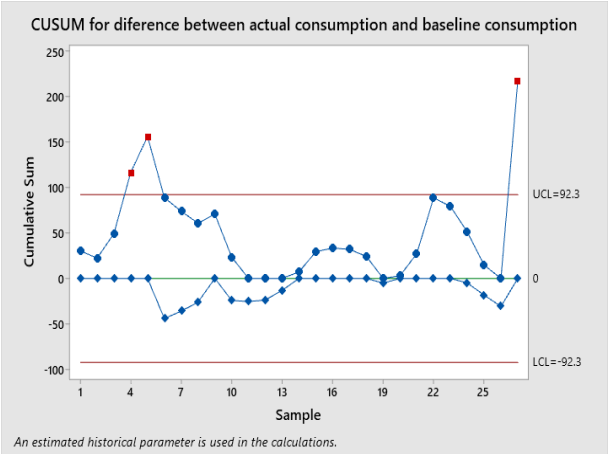

Figure 5: CUSUM chart for energy gap when target is 25.3kWh

Suggestions and Recommendations

CUSUM and I-MR charts prove invaluable for monitoring manufacturing process performance. The CUSUM chart, adept at detecting small shifts in energy consumption, complements the I-MR chart, which excels in monitoring process mean shifts and identifying patterns. The combined use of these charts facilitates comprehensive monitoring and enhancement of energy consumption and process efficiency over time, fostering cost savings and sustainability.

Crucially, we emphasize the need for a balanced approach when setting energy management targets, ensuring they are challenging yet realistic. Regular reviews and adjustments based on feedback from the production team are recommended to align targets with achievable goals and maximize energy savings while avoiding negative impacts on the production process.

Acknowledgement

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