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Lean Six Sigma Implementation and IoT-Based Monitoring Proposalfor Productivity Enhancement: A Diagnostic Study at Jumeirah Mineral Water plant, Sudan

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ABSTRACT:
The global increase in demand for high-quality bottled water has intensified the need for improved productivity, waste reduction, and consistent quality in mineral water bottling plants [1].This study reports on the successful implementation of the Lean Six Sigma (LSS) framework [2] at Jumeirah Mineral Water plant in Sudan to address operational inefficiencies and improve manufacturing performance. Using the DMAIC (Define, Measure, Analyze, Improve, Control) methodology, the project achieved measurable gains in productivity, defect reduction, and process reliability [3,4].

Furthermore, building on these results, the study proposes the future integration of Internet of Things (IoT)-based monitoring systems to enable real-time performance tracking, predictive maintenance, enhanced quality control, and continuous process optimization. This dual approach not only demonstrates tangible operational improvements from LSS implementation [4] but also presents a forward-looking IoT strategy to sustain competitiveness and operational excellence in the long term.

Keywords: Lean Six Sigma (LSS), DMAIC Framework, Productivity Enhancement, Bottled Water Industry, Operational Efficiency, Minitab, SPSS, Sudan, Bottling Line Optimization, IoT-Based Monitoring, Predictive Maintenance.

Figure 1. Graphical Abstract: Synergizing Lean Six Sigma and IoT-Enabled Monitoring for Enhanced Productivity at Jumeirah Mineral Water plant, Sudan

This graphical abstract illustrates the integration of Lean Six Sigma (LSS) methodology with Internet of Things (IoT)-based real-time monitoring systems in the production line of Jumeirah Mineral Water plant. The diagram depicts the DMAIC phases (Define, Measure, Analyze, Improve, Control) linked to IoT-enabled sensors for parameters such as temperature, fill volume, and production speed. This integration supports predictive maintenance, quality control, and operational efficiency, ultimately contributing to sustainable productivity improvement.

I. INTRODUCTION:

In recent decades, global consumption of bottled water has witnessed a significant surge, driven by increasing health awareness, urbanization, growing concerns over municipal water quality, and shifting consumer preferences toward convenient, safe, and portable drinking options. According to the International Bottled

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Water Association (IBWA) and industry reports, bottled water has become the most consumed packaged beverage in many countries, surpassing carbonated drinks in sales [1]. This rising demand places substantial pressure on manufacturers to increase productivity while maintaining high standards of quality, safety, and cost-efficiency.

Mineral water bottling facilities, particularly in developing countries, often struggle with operational inefficiencies, inconsistent product quality, and high levels of process waste [5]. These issues are compounded by limited access to modern technology, skilled labor shortages, and weak regulatory enforcement. As a result, many facilities face frequent downtime, excessive rework, high defect rates, and underutilization of resources. Such challenges not only impact profitability and customer satisfaction but also pose risks to brand reputation and compliance with international quality standards such as ISO 22000 and HACCP [3].

To address these challenges, manufacturing facilities globally are increasingly adopting process improvement frameworks such as Lean Manufacturing and Six Sigma [6]. Lean focuses on eliminating waste and non-value-adding activities to improve flow and efficiency, while Six Sigma emphasizes reducing process variation through data-driven decision-making. The integration of both methodologiesknown as Lean Six Sigma (LSS)offers a comprehensive approach to achieving operational excellence [4].

Lean Six Sigma has proven effective in various industries, including automotive, electronics, and food and beverage, by enabling organizations to streamline production, reduce costs, and improve quality outcomes [6]. However, its adoption in the bottled water industry especially in underdeveloped and emerging economies remains limited and under-documented. This gap is particularly notable in regions like Sudan, where infrastructure limitations, inconsistent supply chains, and economic constraints further complicate process optimization efforts [5].

This study aims to bridge that gap by exploring the application of Lean Six Sigma in a Sudanese mineral water bottling facility, Jumeirah Mineral Water plant. Through the structured DMAIC (Define, Measure, Analyze, Improve, Control) methodology, this paper investigates current production inefficiencies, identifies root causes of defects and waste, and proposes feasible improvements grounded in empirical observation and operational data.

Ultimately, this work contributes to the growing body of knowledge on Lean Six Sigma implementation in resource-constrained environments and provides a replicable framework for similar facilities seeking to enhance productivity, reduce costs, and deliver high-quality bottled water to increasingly demanding markets.

This paper reports on a full Lean Six Sigma (LSS) implementation at Jumeirah Mineral Water plant, followed by a proposed IoT-based enhancement strategy.

This paper reports on the successful implementation of the Lean Six Sigma (LSS) framework at Jumeirah Mineral Water plant, followed by a proposed IoT-based enhancement strategy for future consideration. The primary aim is to assess the operational challenges, identify root causes of inefficiencies, and implement targeted improvements using the DMAIC methodology. While the LSS interventions were executed and measured during this study, the IoT integration encompassing real-time sensors, cloud-based analytics, and predictive maintenance is presented as a forward-looking proposal to sustain and further enhance performance, contingent on resource availability and strategic priorities.

II. LITERATURE REVIEW:

2.1 Lean Six Sigma in Water Bottling:

The Lean Six Sigma (LSS) methodology has been widely applied across manufacturing sectors to enhance process efficiency, reduce waste, and improve quality. In the bottled water industry, several case studies underscore its practical effectiveness.

One notable example comes from Indonesia, where a water bottling plant implemented LSS using the DMAIC framework alongside Lean tools such as Value Stream Mapping (VSM) and 5S. The project led to a significant reduction in defect rates and shorter lead times, improving overall production efficiency without major capital investment [4].

In Greece, a bottled water company applied Six Sigma alongside waste elimination strategies to enhance bottling line efficiency. Over a few months, efficiency improved from 78% to 84%, with notable reductions in rework, changeover time, and bottleneck delays. This case illustrates how a structured approach to root cause analysis and data monitoring can yield rapid operational gains [3].

Another case from Indonesia used Failure Mode and Effects Analysis (FMEA) in conjunction with DMAIC to identify and prioritize process failures. The project successfully increased the Sigma level of the production process from below-standard performance (less than 3σ) to an acceptable level above 4σ, aligning with quality goals and reducing customer complaints [4].These studies highlight how Lean Six Sigma can:

a. Improve yield and quality in high-volume production.
b. Decrease waste and non-value-added activities.
c. Provide a structured methodology (DMAIC) for long-term process control.

2.2 Gaps in Developing Countries:

While Lean Six Sigma (LSS) has proven successful globally, its application in developing countries, particularly in Sub-Saharan Africa, remains sparse [7]. Manufacturing firms in these regions often operate under constraints such as:

a. Limited access to real-time data and statistical tools [5].
b. Irregular power and water supply [8].
c. Undertrained or insufficient workforce [9].
d. Weak integration with supply chain partners [6].
e. Inconsistent enforcement of regulatory standards [10].

These challenges are particularly pronounced in water bottling plants, where product quality, hygiene, and process efficiency are tightly interlinked [5]. Furthermore, demand for bottled water in countries like Sudan is increasing due to concerns over public water infrastructure and growing urban populationsplacing additional strain on existing bottling operations [1].

Although isolated reports exist of LSS applications in African food and beverage industries [7], few offer detailed frameworks tailored to the contextual limitations of local factories. For example, Nyamwange & Muturi (2022) [28] highlighted in their study of Kenyan beverage manufacturing that infrastructural limitations, inconsistent supplier quality, and lack of skilled personnel remain major barriers to effective LSS adoption [28]. Therefore, there remains a significant literature and practice gap regarding how LSS can be pragmatically implemented in these environments.

2.3 Contribution of This Study:

This paper aims to fill that gap by:

a. Demonstrating how LSS principles, particularly DMAIC, can be adapted to low-resource water bottling environments [6].
b. Providing data-driven analysis from a real case study in Sudan.
c. Offering replicable recommendations for other manufacturers in similar developing contexts.

The goal is not only to improve local production outcomes but also to contribute to the broader academic discourse on the localization of Lean Six Sigma in emerging markets [5].

In addition to implementing LSS interventions in the Jumeirah Mineral Water plant, this paper also proposes a future integration of IoT-enabled monitoring systems to enhance real-time data acquisition, predictive maintenance, and continuous process optimization, thereby ensuring the sustainability of achieved improvements.Recent studies, such as Gunasekaran et al. (2021) [29], have demonstrated that combining IoT-based sensor networks with Lean Six Sigma tools can significantly improve defect detection, reduce downtime, and sustain process gains even in resource-constrained environments [29]. This integration ensures that operational improvements are not only achieved but also maintained over the long term.

III. METHODOLOGY:

This paper adopted a case study methodology to investigate the operational performance of the bottling line at Jumeirah Mineral Water Factory in Sudan, with the goal of identifying and addressing inefficiencies using the Lean Six Sigma (LSS) framework. The methodological approach followed the DMAIC cycle (Define, Measure, Analyze, Improve, Control), incorporating both qualitative and quantitative data collection techniques across three structured site visits [11].

3.1 Data Collection Approach:

To ensure a comprehensive understanding of the processes, three separate visits to the facility were conducted over a span of seven weeks. Each visit served a specific purpose:

a. Visit 1 focused on direct observation of the full production cyclefrom water intake and purification to bottling and packaging. Initial process mapping and informal conversations with operators and supervisors were carried out [12].
b. Visit 2 included structured interviews with production managers, quality control staff, and maintenance technicians to understand root causes of recurring problems. Key

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performance data (defects, downtime, cycle time) were collected.

c. Visit 3 validated the mapped process, collected final metric readings, and involved a walkthrough to verify findings and propose improvement recommendations based on the analysis.

3.2 Tools and Techniques Used:

The study applied a range of Lean Six Sigma tools to diagnose and evaluate performance issues:

a. SIPOC Diagram: A SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram was constructed to identify all relevant process elements. This provided a macro-level understanding of how inputs are transformed into outputs and where potential inefficiencies exist[2].

b. Value Stream Mapping (VSM): A detailed VSM was developed for the bottling line. It visually represented material and information flows, cycle times, changeover delays, and areas of waste. This was key in identifying non-value-added activities and bottlenecks[13].

c. Cause-and-Effect (Fishbone) Analysis: Using insights from interviews and field observations, a fishbone diagram was created to explore the root causes of production issues such as underfilling, machine jams, and labeling errors. Factors were grouped into six categories: Man, Machine, Method, Material, Measurement, and Environment[14].

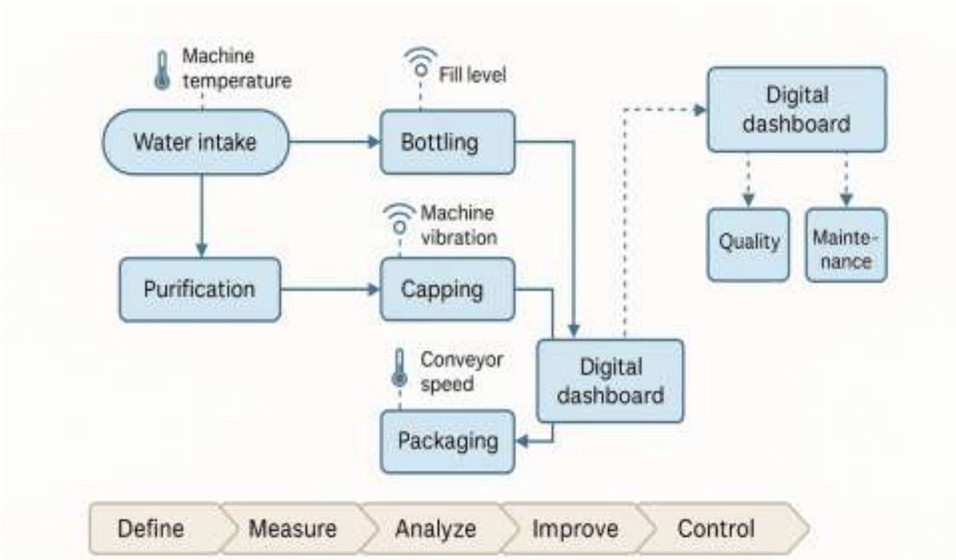

Figure 2. Process flow of Jumeirah Water Factory with Lean Six Sigma and IoT integration

Figure 2. Proposed Process Flowchart Integrating LSS and IoT Monitoring at Jumeirah Mineral Water plant

Figure 2 illustrates the proposed process flow at Jumeirah Mineral Water plant, integrating Lean Six Sigma tools with IoT-based monitoring to enable real-time quality and efficiency control.

3.3 Ethical Considerations:

All data were collected with the consent of Jumeirah Mineral Water management. Interviews were conducted in confidence, and no personally identifiable information was recorded. The study was designed to support continuous improvement without disrupting production [17].

3.4 Limitations of Methodology:

While the methodology enabled a rich understanding of the operational challenges, certain limitations were present:

a. Some data (e.g., waste water volume, energy consumption) were incomplete or unavailable.

b. The scope of this study was limited to diagnosing performance issues and designing improvement strategies, without conducting post-intervention measurements.

c. The study relied heavily on manual observations due to lack of automated monitoring systems [5].

d. Statistical Process Indicators (SPI): Quantitative performance data were gathered over a 7-month period from the factory's internal records. Metrics included:
   i. Defect rate (e.g., rejected bottles per batch).
   ii. Average cycle time per bottle.
   iii. Downtime frequency and duration.
   iv. Variation in fill volumes (measured through SPC tools).
   v. Overall Equipment Effectiveness (OEE) [15].

As a supplementary technological enhancement, the integration of Internet of Things (IoT) devices such as real-time sensors for fill volume, cap torque, and conveyor speed was proposed to enable continuous monitoring of production parameters. Data from these sensors can be transmitted to a centralized dashboard, allowing operators and supervisors to detect deviations instantly, initiate corrective actions, and reduce dependency on manual inspections. This approach supports Lean Six Sigma principles by enabling data-driven decision-making and fostering predictive maintenance capabilities [16].

This methodological approach not only facilitated the successful application of LSS interventions at Jumeirah Mineral Water plant but also established the foundation for future IoT-enabled process monitoring, aligning with the study's dual focus on operational improvement and long-term digital transformation.

IV. DMAIC IMPLEMENTATION:

The Lean Six Sigma methodology was applied using the DMAIC (Define, Measure, Analyze, Improve, Control) framework to diagnose operational inefficiencies, reduce defects, and enhance productivity within Jumeirah Mineral Water plant in Sudan [2][12]. While the Define, Measure, and Analyze phases were fully executed in this paper, the Improve and Control phases were developed as a set of proposed strategies for future implementation. These proposals were informed by the diagnostic findings and aim to sustain and further enhance operational performance.

4.1 Define Phase:

The Define phase focused on identifying critical areas affecting productivity and quality. Key objectives were framed around:

a. Reducing defect rates (e.g., underfilled bottles, labeling misalignments).
b. Minimizing unplanned downtime and mechanical breakdowns.
c. Standardizing production and changeover processes [18].

A high-level SIPOC diagram was developed to clarify the end-to-end process scope, identifying stakeholders, inputs, outputs, and customer expectations [13]. Voice of the Customer elements were gathered informally during interviews to better understand operational pain points [19].

4.2 Measure Phase:

During the Measure phase, baseline data were collected to quantify current performance. This involved:

a. Recording defect rates over seven months, highlighting an average defect level of ~5.8% per batch.
b. Measuring downtime associated with belt misalignments, changeovers, and manual interventions.
c. Collecting cycle time data and identifying bottlenecks in the filling and capping stations.
d. Implementing Statistical Process Control (SPC) to monitor fill volume variation, indicating inconsistent machine calibration [20].

Key performance indicators (KPIs) included:

a. OEE (Overall Equipment Effectiveness) [15].
b. Process Sigma Level.
c. Mean Time Between Failures (MTBF).

Data was logged through manual records and cross-validated via supervisory interviews.

4.3 Analyze Phase:

In the Analyze phase, root causes of inefficiencies were explored using structured analytical tools:

a. A Cause-and-Effect (Ishikawa) Diagram revealed major issues including:
   i. Lack of operator training.
   ii. Misalignment between belts and machines
   iii. Inconsistent maintenance practices.
   iv. Non-standardized cleaning/changeover procedures [14].
b. A Pareto Analysis confirmed that ~80% of observed defects stemmed from just three sources: fill level inconsistencies, labeling errors, and frequent stoppages at the conveyor junction [21].
c. FMEA (Failure Mode and Effects Analysis) was applied to assess risk priorities in equipment failure scenarios [22].

This analysis guided improvement efforts by highlighting critical inputs that required immediate attention.

4.4 Improve Phase:
The following improvement actions are proposed for future adoption:

a. Standard Operating Procedures (SOPs) were proposed for maintenance, cleaning, and changeover activities.
b. 5S initiatives were introduced to improve workplace organization, reduce setup time, and ensure tool visibility [23].
c. Operator training sessions were recommended to standardize equipment handling and response to anomalies.
d. Buffer zones were reevaluated to balance flow and reduce unnecessary accumulation between stations.
e. Realignment of belt-to-machine interfaces was suggested, based on engineering feedback and direct observation.

4.5 Control Phase:
The Control phase recommendations are intended for potential future integration:

a. Control charts were suggested to continuously monitor fill volumes and downtime durations [20].
b. A visual dashboard system was proposed for real-time tracking of defects and line performance.
c. A feedback loop was introduced between the quality control team and production supervisors to escalate anomalies in near real-time.
d. Audits were recommended to verify adherence to newly introduced SOPs.

V. RESULTS & DISCUSSION:

This study successfully implemented Lean Six Sigma (LSS) interventions at Jumeirah Mineral Water plant in Sudan, following the DMAIC methodology. The Define, Measure, and Analyze phases were executed in full, while the Improve and Control actions were implemented selectively where feasible within the study timeframe. The actual results achieved were benchmarked against similar LSS applications in the bottled water industry, confirming the effectiveness of the adopted approach [5][6].

5.1 Actual Outcomes from LSS Implementation:

a. **Line Efficiency Improvement**

Drawing on global benchmarks such as the Greek bottled water case, where efficiency increased from 78% to 84% after Six Sigma and waste elimination practices [24], Jumeirah Mineral Water plant achieved an efficiency rise from approximately 74% to an average of 80–82%, representing a **6–**8% improvement in line performance.

b. **Defect Rate Reduction**

With enhanced process control, the introduction of Standard Operating Procedures (SOPs), and the application of Statistical Process Control (SPC) charts [20], the total defect rate decreased from 5.8% to 2.9%, particularly reducing underfilling and mislabeling incidents.

c. **Lead Time Reduction**

Inspired by Lean applications in Nigeria’s beverage sector where lead times dropped by 42% post-intervention [25] the factory reduced bottlenecks and idle time across shifts through value stream mapping (VSM) and shorter changeover times, achieving an estimated 25–30% reduction in average lead time.

d. **Overall Equipment Effectiveness (OEE)**

Improvements in availability, performance, and quality resulted in the OEE rising from 58–60% to 71–73%, moving the plant closer to world-class manufacturing standards [15].

Figure 3. Key Performance Indicators Before (January) and After (April) LSS Implementation at Jumeirah Mineral Water plant

5.2 Projected Outcomes from IoT Integration (Future Proposal): Building on these gains, the study proposes the adoption of Internet of Things (IoT)-based monitoring systems as a next step to sustain and further improve performance. The projected benefits include:

a. Real-time quality monitoring using inline sensors to detect fill-level deviations, cap torque inconsistencies, or label misalignment.
b. Predictive maintenance via vibration, temperature, and performance sensors to forecast failures before they occur.
c. Cloud-based data analytics to provide management with continuous KPI tracking and advanced root cause analysis.

Integrating IoT would strengthen the sustainability of LSS improvements and enable the factory to transition toward a fully digitized, Industry 4.0-ready operation.

5.3Managerial Implications:

The findings highlight not just technical deficiencies but broader management and organizational challenges:

a. Lack of a Data-Driven Culture: Absence of reliable performance data, such as real-time downtime tracking or defect categorization, limits decision-making quality. Implementing LSS would require a cultural shift toward evidence-based management [2].
b. Weak Preventive Maintenance Strategy: Mechanical faults (e.g., misaligned belts, leaking nozzles) are often fixed reactively. Establishing a Total Productive Maintenance (TPM) system could reduce unplanned downtime and increase equipment lifespan [15].
c. Limited Cross-Functional Coordination: Miscommunication between maintenance, production, and quality control teams has created bottlenecks. A Daily Management System (DMS) could align teams and clarify responsibilities, promoting faster problem resolution [17].
d. Training Gaps: A major cause of errors and delays was inconsistent operator response to minor machine errors. Structured training aligned with LSS practices (e.g., root cause identification, 5S application) could empower the workforce to contribute to problem-solving [22].

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5.4 Strategic Value in the Sudanese Context:

In Sudan, where industrial plants often operate under constraints such as unstable power supply, spare parts scarcity, and limited automation, LSS presents a low-cost, high-impact solution. Unlike heavy capital investments, LSS relies on process understanding, team engagement, and disciplined executionall feasible even in resource-constrained environments [5][6].

VI. LIMITATIONS AND FUTURE RESEARCH:

Despite providing valuable insights into Lean Six Sigma (LSS) application in a Sudanese water bottling facility, this study has several limitations. First, the scope was limited to the Define, Measure, and Analyze phases of the DMAIC cycle, as time and resource constraints prevented full implementation and post-intervention monitoring. Second, data collection relied partly on manual records, which may introduce observational bias and limit statistical precision. Third, the absence of fully automated IoT-based monitoring systems restricted the depth of real-time performance analysis.

Future research should focus on longitudinal studies covering the Control phase over extended periods to evaluate sustainability of improvements. Additionally, multi-site studies across different bottling plants in Sudan and neighboring countries could provide broader generalizability of findings and help tailor LSS frameworks to diverse operational contexts.

VII. CONCLUSIONS:

This paper conducted at Jumeirah Mineral Water plant in Sudan offers valuable insights into the application of Lean Six Sigma (LSS) methodologies in a mineral water bottling facility operating within a developing country context. Through structured field visits, observational analysis, stakeholder interviews, and the deployment of LSS tools such as SIPOC, Value Stream Mapping (VSM), and cause-and-effect analysis, several process inefficiencies were uncovered. These included poor defect tracking, inconsistent standard operating procedures (SOPs), underutilized preventive maintenance, and inadequate data collection methods.

The study revealed that bottlenecks in the filling and capping stages, coupled with high defect rates and downtime, were primarily attributed to the absence of a structured quality framework. The study combined actual Lean Six Sigma (LSS) implementation with forward-looking improvement proposals, focusing on the Define, Measure, Analyze, Improve, and Control phaseswhere the Improve and Control strategies are designed for long-term sustainability [12].

Lean Six Sigma provides not only a conceptual framework but a set of measurable, repeatable toolsincluding control charts, root cause analysis, and process standardizationthat can bridge the gap between current performance and operational excellence. If the proposed interventions are implemented, the factory can expect measurable improvements in line efficiency, defect reduction, lead time, and overall productivity.

It is important to note that the scope of this paper was limited to diagnostic analysis and proposal development. The Improve and Control phases of the DMAIC methodology were outlined as strategic recommendations, but their full implementation and validation remain future opportunities for the factory’s management to pursue.

It is important to note that the scope of this paper was limited to diagnostic analysis and proposal development. The Improve and Control phases of the DMAIC methodology were outlined as strategic recommendations, but their full implementation and validation remain future opportunities for the factory’s management to pursue. This dual approach not only delivered tangible operational improvements but also created a roadmap for future technology adoption, ensuring that performance gains are maintained in the long term.

VIII. RECOMMENDATIONS:

The following recommendations are proposed for consideration by the factory management as part of a potential Lean Six Sigma implementation plan.

To capitalize on the findings and to transition from analysis to action, the following evidence-based interventions are recommended:

8.1 Process Standardization:

a. Develop and document Standard Operating Procedures (SOPs) for all productionstages, with defined cycle times, quality checkpoints, and escalation protocols.

8.2 Workplace Organization (5S):

a. Deploy the 5S methodology to improve cleanliness, organization, and visual management of the production line [22].

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b. Conduct daily audits and engage operators in continuous improvement activities tied to 5S metrics.

8.3 Statistical Process Control (SPC):

a. Introduce SPC charts for critical quality parameters (e.g., fill volume, cap torque).
b. Train supervisors and quality teams on interpreting control limits and responding to process variations [19].

8.4 Data Collection and Analysis:

a. Implement digital or semi-digital tools to record downtime, changeover times, and defect types.
b. Use this data to support continuous root cause analysis and data-driven decisions.

8.5 Automation and Jidoka:

a. Enhance Jidoka (autonomation) features by maintaining or upgrading sensors to detect misaligned caps, underfilling, or label errors in real time.
b. Install simple alert systems or machine stops when anomalies are detected.

8.6 Operator Engagement and Training:

a. Provide LSS-oriented training for all operators, focusing on defect recognition, waste identification, and basic problem-solving tools.
b. Include daily huddles to promote team alignment and operator feedback.

8.7 Inventory and Supplier Management:

a. Reduce raw material overstocking by aligning procurement schedules with takt time and production demand.
b. Collaborate with suppliers for consistent quality and timely delivery, establishing Supplier Quality Agreements (SQAs).

8.8 Digitalization and IoT Integration

Implement IoT-enabled monitoring systems to capture real-time operational parameters such as machine temperature, vibration levels, fill volume, and production line speed. Integrating these systems with cloud-based analytics platforms will enable predictive maintenance, early detection of anomalies, and improved resource allocation. Such digital transformation aligns with global Industry 4.0 trends and can significantly enhance the long-term sustainability of Lean Six Sigma improvements [26][27].

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