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Implementation of Lean Six Sigma to Enhance Bottling Productivity: A Case Study of Jumeirah Water Plant, Sudan with Comparative Insights from African Industries (2020–2025)

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ABSTRACT
This paper investigates the implementation of Lean Six Sigma (LSS) at Jumeirah Water Plant (Sudan) to enhance bottling productivity and operational efficiency. Using the DMAIC framework [1], the project identified root causes of downtime and defects and deployed countermeasures including SOP standardization, targeted equipment calibration, and workload balancing.

Measured outcomes show a reduction in defect rate from ~3% to <1%, weekly downtime from ~8 h to ~3 h (–62.5%), changeover time from 60–75 min to 38 min (–37% to –49%), and inventory days from ~30 to 12–14 (–53% to –60%).

Throughput increased from 2,085 to ~2,945 packs per 9-hour shift (+41.25%) with a post-improvement cycle time of 11 s/pack. The case demonstrates that structured LSS can yield sustainable, quantifiable gains in semi-automated, resource-constrained plants. As future work, we outline a practical roadmap for low-cost IoT monitoring to sustain gains and enable predictive maintenance.

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

I. INTRODUCTION

The global bottled water industry has experienced substantial growth in recent years, driven by increasing consumer awareness of health, safety, and product quality standards. This heightened demand has placed significant operational pressure on mineral water bottling plants to maximize productivity, reduce process waste, and maintain consistent quality. In this context, **Lean Six Sigma (LSS)** a hybrid methodology combining Lean's waste elimination principles with Six Sigma's data-driven approach to minimizing process variation has emerged as a proven framework for operational excellence across various industries [2].

Despite its widespread adoption in manufacturing and service sectors, the application of LSS within the mineral water bottling industryparticularly in resource-constrained environments remains underexplored. Previous studies in related sectors have demonstrated measurable improvements in production throughput, defect reduction, and process stability through LSS interventions. However, there is limited empirical evidence addressing the unique operational challenges faced by water bottling facilities, such as fluctuating market demand, stringent regulatory compliance, equipment maintenance complexity, and supply chain variability.

Addressing this paper gap, the present study applies the LSS DMAIC (Define–Measure–Analyze–Improve–Control) framework at Jumeirah Water Bottling Factory in Sudan. The methodology integrates Minitab for process capability analysis, control charting, Pareto prioritization, and regression modeling, alongside **SPSS** for advanced statistical testing, ANOVA, and hypothesis validation. This dual-software approach enhances analytical precision, enabling both in-depth process diagnosis and robust verification of improvement results [3,4].

Thispaper aims to quantify gains in productivity, defect reduction, and process stability while adapting LSS tools to the operational realities of a developing-market bottling plant. By combining structured process improvement methodologies with advanced statistical analysis in Minitab and SPSS, the study provides a replicable improvement model for similar facilities in the region and contributes to the growing body of empirical LSS research in resource-limited contexts.

II. LITERATURE REVIEW

Lean Six Sigma (LSS) has been extensively applied across multiple industries to improve operational performance, reduce defects, and enhance process stability. Its integration of Lean principlestargeting waste eliminationand Six Sigma's data-driven statistical approach has proven effective in both manufacturing and service contexts. However, its application in the bottled water industry, particularly within resource-constrained environments, remains underexplored.

2.1 Regional and African Context

Comparative analysis of Lean Six Sigma (LSS) applications across African manufacturing sectors reveals both common operational challenges and distinct contextual differences.

In **Egypt**, Azzam et al. (2023) demonstrated that integrating LSS with workforce development initiatives in food processing plants yielded sustainable performance gains. The improvements were driven by structured training programs, process standardization, and the combined use of **Minitab** for process monitoring and **SPSS** for statistical validation [5].

In **Kenya**, Otieno and Maina (2021) applied LSS in beverage manufacturing, focusing on defect reduction and process stability. Their approach leveraged Minitab's Pareto analysis and control charting to identify and eliminate bottlenecks, achieving a 32% defect reduction. However, the study did not incorporate advanced SPSS modeling, which could have provided deeper insights into process variability [6].

In **Nigeria**, Okonkwo et al. (2020) implemented Six Sigma in bottled water production, achieving a 40% decrease in defects through targeted equipment maintenance and SOP enforcement. The study, however, relied on descriptive statistics without integrating Minitab or SPSS, limiting the robustness of its statistical conclusions [7].

Compared to these regional cases, the present study at **Jumeirah Water Bottling Factory** in Sudan adopts a more integrated analytical approach, combining Minitab's capability analysis, control charting, and Pareto prioritization with SPSS's regression modeling and ANOVA testing. This dual-software strategy ensures both real-time process monitoring and statistically validated improvement outcomes. Moreover, the study addresses a relatively underrepresented industrial contextSudanese bottled water manufacturingwhere resource constraints, regulatory compliance pressures, and equipment maintenance challenges require tailored LSS adaptations.

2.2 Research Gaps and Alignment with Current Study

This study therefore not only builds on global best practices but also adapts them to the specific challenges and opportunities in Sudan's bottled water industry.

Existing African LSS studies rarely integrate **advanced statistical tools** (SPSS, Minitab) or target the bottled water sector. Nigerian and Kenyan cases improved defect rates but lacked SOP standardization, while Egyptian studies applied automation but in more digitally advanced settings.

This study fills the gap by combining **Minitab** (capability analysis, control charts) and **SPSS** (ANOVA, regression) with SOP implementation, KPI tracking, and proposed IoT-enabled monitoring—applied in a semi-automated Sudanese bottling plant. The approach provides both academic value and a practical model for similar resource-constrained facilities.

III. METHODOLOGY AND CASE DESCRIPTION

3.1 Research Methodology

This study adopts the **Lean Six Sigma (LSS) DMAIC framework** Define, Measure, Analyze, Improve, and Control as the primary research methodology to improve operational performance at the Jumeirah Water Bottling Factory. The DMAIC approach was selected due to its proven effectiveness in systematically identifying root causes, implementing targeted improvements, and validating results through data-driven analysis.

3.2 Data Collection Techniques:

Data collection for this study combined both quantitative and qualitative approaches to

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ensure comprehensive process understanding and accurate performance measurement [8]. Five complementary techniques were employed:
a. **Direct Observation** – Continuous monitoring of bottling line operations during active production to identify process flow inefficiencies and bottlenecks [9].
b. **Structured Interviews** – Formal discussions with production, quality assurance, and maintenance personnel to gather insights on operational challenges and improvement opportunities [10].
c. **Informal Consultations** – Conversations with machine operators to capture tacit process knowledge, undocumented practices, and operator-driven workarounds [11].
d. **Real-Time Data Extraction** – Retrieval of operational metrics directly from machine panels and production logbooks, ensuring accuracy in cycle time, downtime, and defect counts [12].
e. **Tailored Questionnaires** – Survey instruments designed around Lean Six Sigma dimensions, including defect tracking, downtime root causes, and SOP adherence, providing both quantitative scores and qualitative feedback [13].

This multi-method approach enabled triangulation of data sources, enhancing the reliability of baseline measurements and subsequent analysis in the **DMAIC** phases [14].

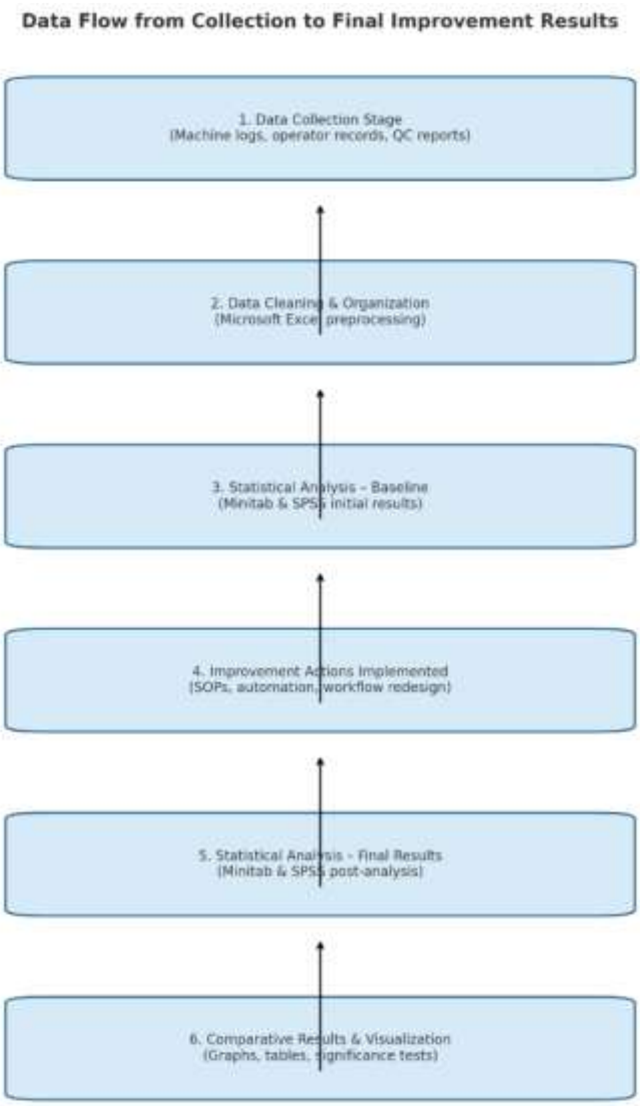

Figure1: Data Flow from Collection to Final Improvement Results

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This diagram illustrates the systematic flow of data in the research process, starting from on-site data collection at Jumeirah Mineral Water Plant, followed by initial data cleaning in Microsoft Excel, statistical analysis in Minitab for capability, control charting, and Pareto prioritization [3], and advanced modeling in SPSS [15]. The flow concludes with validated improvement results, providing a data-driven foundation for Lean Six Sigma decision-making [13].

3.3 Measurement Period

a. Baseline data [12]: Collected over three consecutive days on-site, supported by historical production logs covering the previous month to capture normal variation [13].
b. Post-intervention data: Collected over nine consecutive days after LSS implementation, using identical metrics and measurement procedures [1].

3.5 Time Study and Cycle Time Determination

Two measures of cycle time were recorded:

a. Nominal cycle time: Measured via stopwatch for 150 continuous packets under steady operation, averaging 18 seconds/packet [16].
b. Effective cycle time [12]: Calculated from full-shift production counts, yielding 15.54 seconds/packet (2,085 packs over 9 hours). This distinction reconciles laboratory-style measurements with real operating conditions.

These measurements informed the Value Stream Mapping (VSM) and were used to calculate value-added (VA) and non-value-added (NVA) times [9].

3.4 Analytical Tools and Techniques Applied:

The following tools and techniques were applied:

a. Fishbone Diagram for cause-and-effect analysis of defects and downtime [17].
b. Pareto Analysis to prioritize improvement efforts [18].
c. Descriptive statistics for baseline KPI summaries [12].
d. Control charts for process stability assessment [19].
e. Regression and ANOVA in SPSS to identify statistically significant performance drivers [15].
f. KPI tracking dashboards for ongoing monitoring [13].

IV. CASE STUDY & RESULTS INTEGRATION

4.1. Location and Overview

The Jumeirah Water Bottling Plant, located in Sudan, is a key supplier of bottled drinking water to the local market. The facility operates a semi-automated production line consisting of six core stages:

a. Water storage and purification.
b. Bottle feeding and filling.
c. Capping and capsule placement.
d. Labeling.
e. Weight verification and packaging.
f. Laboratory quality testing.

Each station is equipped with electronic sensors and digital displays monitoring production speed, defect occurrence, fill levels, and packaging accuracy in real time.

4.2. Production Flow

The production process follows a linear sequence (Figure 1) from raw water treatment to final packaged product storage. Data from sensors and manual checks feed into daily production logs, which serve as the primary source for KPI tracking.

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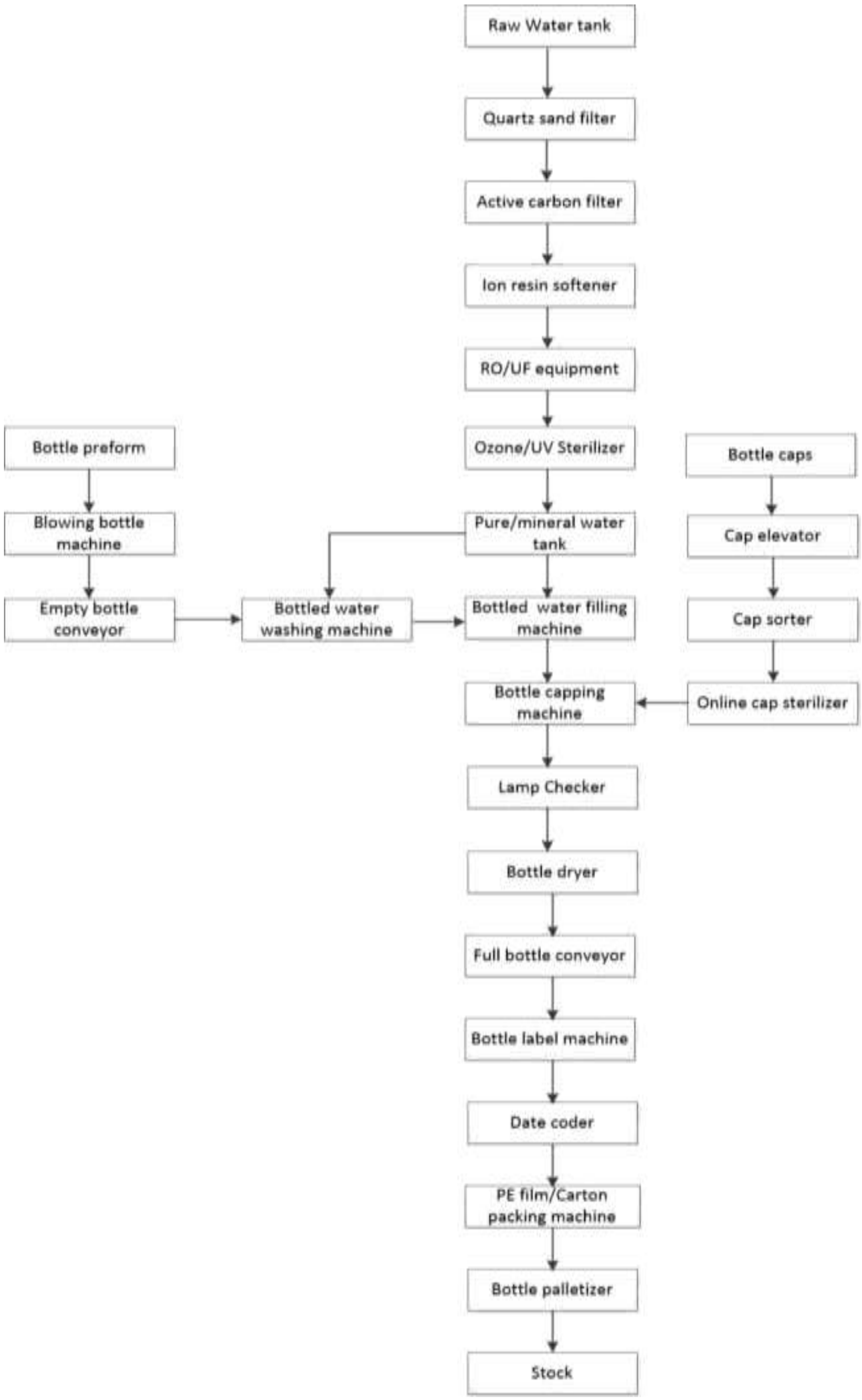

Figure (1):Flowchart of Production Line at Jumeirah Water Bottling Plant.

This flowchart illustrates the sequential steps in the Jumeirah Water Bottling Plant process, from water purification to packaging and storage.

4.3. Problems Identified (Pre-LSS)

Baseline assessment revealed multiple performance gaps:

a. High defect rate (~3%), exceeding the 1% target.
b. Extended changeover times (>1 hour) delaying product variant switches.

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c. Frequent unplanned downtime, preventing achievement of daily targets.
d. Excess inventory of raw materials (~30 days' stock), tying up working capital.
e. No standardized SOPs, resulting in inconsistent task execution.
f. Inefficient material flow, causing unnecessary motion and congestion.
g. Limited use of analytics, with minimal root-cause tracking for downtime or defects.

4.4. Lean Six Sigma Readiness:
4.4. LSS Readiness

Despite these challenges, the plant exhibited a favorable environment for LSS adoption, including:

a. Operator awareness of basic Lean concepts
b. Established cleaning and maintenance routines
c. Open interdepartmental communication
d. Management commitment to structured improvement

4.5. Link to Results

The issues above directly informed the Measure and Analyze phases:

a. Downtime and defect data were categorized using Fishbone and Pareto analyses.
b. Cycle time was measured at both nominal (18 s/pack) and effective (15.54 s/pack) levels, reconciling sample-based studies with full-shift production counts (2,085 packs/day).

These insights provided the foundation for targeted Improve phase actions, including SOP creation, equipment calibration, and minor automation upgrades leading to the post-LSS output of ~2,945 packs/day (11 s/pack).

V. RESULTS AND DISCUSSION

5.1. Overview of Performance Improvements

The Lean Six Sigma (LSS) initiative delivered measurable improvements across all monitored KPIs. As shown in Table 1, defect rate, downtime, changeover time, and inventory levels decreased substantially following SOP standardization, equipment calibration, and process rebalancing.

Table 1 Key Performance Improvements

Key Metric	Before LSS	After LSS	Δ (%)
Defect Rate	~3%	<1%	66% reduction
Changeover Time	60–75 min	38 min	–37% to –49%
Avg. Downtime / Week	~8 h	~3 h	62.5% reduction
Inventory Days	~30 days	12–14 days	–53% to –60%
Output (packs / 9-h shift)	2,085	~2,945	+41.25%

Daily production increased from 2,085 packs per 9-hour shift (effective cycle time ≈ 15.54 s/pack) to ~2,945 packs per shift (cycle time = 11 s/pack), representing a 41.25% productivity gain without extending operating hours.

5.2.Reduction of Defects

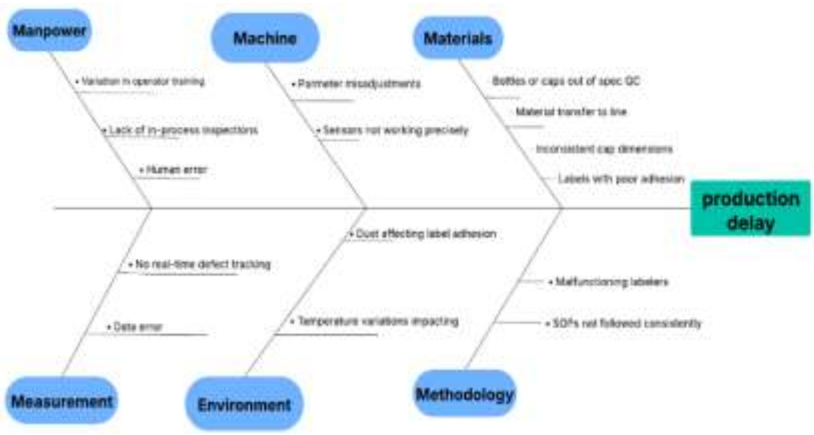

Figure (3): Cause-and-effect diagram of defects in the bottling line.

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Cause-and-effect analysis (Figure 3) categorized defect sources under Manpower, Machine, Material, Measurement, Methodology, and Environment.

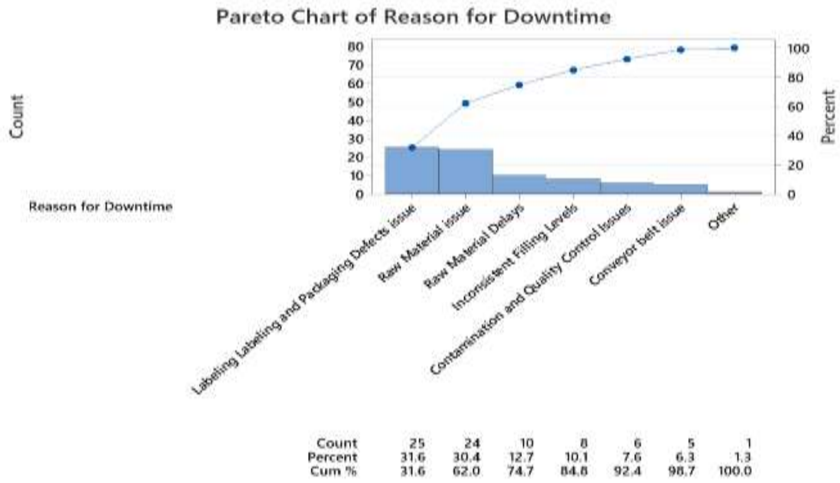

Figure (4): The most frequent causes of downtime before LSS Implementation.

The analysis revealed that Labeling and Packaging Defects and Raw Material Issues accounted for over 60% of total downtime, highlighting critical areas for improvement in subsequent phases.

In total, there are seven identified causes for production delays in bottle manufacturing. To determine the highest priority causes, a Pareto Chart was used, applying the 80/20 principlewhich states that approximately 80% of problems are caused by around 20% of the issues.

From the analysis, three major causes stand out:

a. Labeling and Packaging Defect Issues – 31.6% of total downtime
b. Raw Material Issues – 30.4% of total downtime
c. Raw Material Delays – 12.7% of total downtime

Together, these three causes account for approximately 74% of all downtime incidents.

This means that if these issues are addressed, the plant could potentially eliminate most of the delays aligning with the Pareto principle were resolving the critical 20% of issues removes 80% of the problems.

Figure (5) Production Output Run Chart (Before vs After LSS

This line chart compares daily production before and after Lean Six Sigma (LSS) implementation at Jumeirah Water Plant.
The blue line (before LSS) ranges from 1,750 to 2,085 packs per 9-hour shift, showing fluctuations due to downtime and defects.
The orange line (after LSS) starts around 2,710 and steadily rises to repeated peaks of 2,945 packs, indicating improved stability and a ~41% productivity increase.

5.3. Post-Improvement Gap Analysis

Table 2 Post-Improvement Gap Analysis

Section	Performance (68.9%)
Culture	86%
Purchase	83%
Logistics	60%
Operations	70%
Maintenance	65%
HR	55%
IT	75%
Quality Control	60%
BU Score	66%

Following the implementation of Lean Six Sigma initiatives, a factory-wide audit was conducted to reassess the performance of Line 1. The overall business unit (BU) score improved to 66%, reflecting notable progress compared to pre-improvement performance levels.

A factory-wide audit (table 2) showed an overall BU score improvement from 54% to 66%. Logistics, maintenance, operations, and quality control recorded the most significant gains, while culture and purchase maintained consistently high performance.

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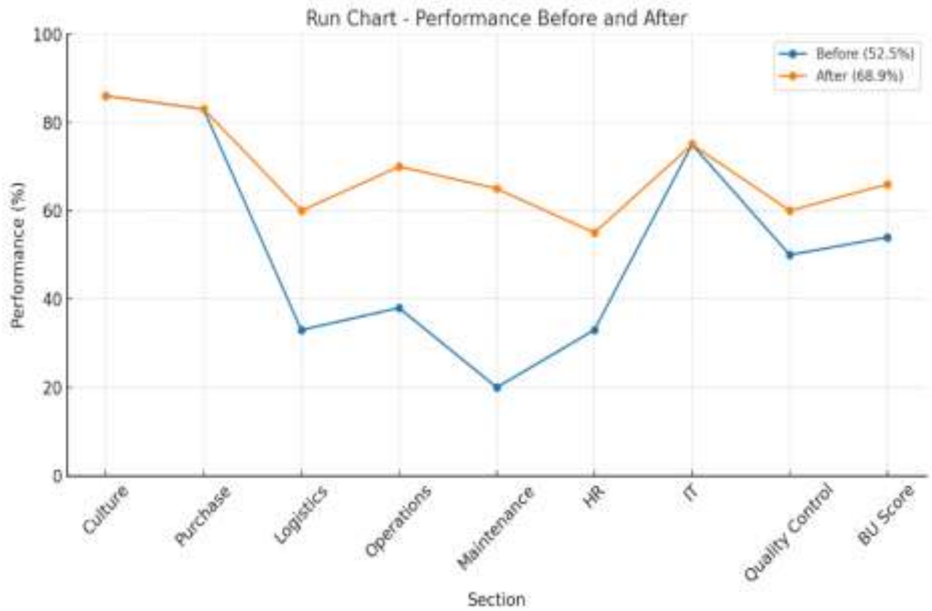

Figure 6 Gap analysis before and after

The run chart illustrates the performance of different sections in the bottled water plant before (52.5% average) and after (68.9% average) the improvement initiative.

a. Culture and Purchase maintained consistently high performance (86% and 83%) with no change.

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b. Logistics showed a substantial improvement, increasing from 33% to 60%.
c. Operations rose from 38% to 70%, indicating significant process optimization.
d. Maintenance had the most notable improvement, jumping from 20% to 65%, reflecting effective preventive and corrective measures.
e. HR improved from 33% to 55%, suggesting enhanced workforce efficiency.
f. IT remained stable at 75%, showing consistent technological reliability.
g. Quality Control improved from 50% to 60%, highlighting better inspection and defect prevention processes.
h. BU Score increased from 54% to 66%, representing overall business unit performance gains.

Overall, the chart shows clear upward trends across most sections, especially in operational and maintenance areas, which had the largest positive impact on the total performance score.

Table 3 Post-Improvement Value Stream Mapping

Process Stage	Station(s)	Duration (seconds)	VA / NVA
Water Treatment	1–5	3	NVA
Bottle Manufacturing & Filling	6–9	3	VA
Labeling & QC	10–11	1	VA
Packaging	12	3	VA
Final QC	13	1	VA

Following the improvement initiatives, a portion of manual operations was replaced with automated machinery, significantly reducing non-value-added (NVA) time. As a result, the cycle time per packet decreased from 18 seconds to 11 seconds, representing a substantial efficiency gain. This reduction in processing time directly impacted production capacity, enabling the line to achieve an output of approximately 3,000 packets per day within the same 9-hour shift, compared to 2,085 packets per day before the improvement.

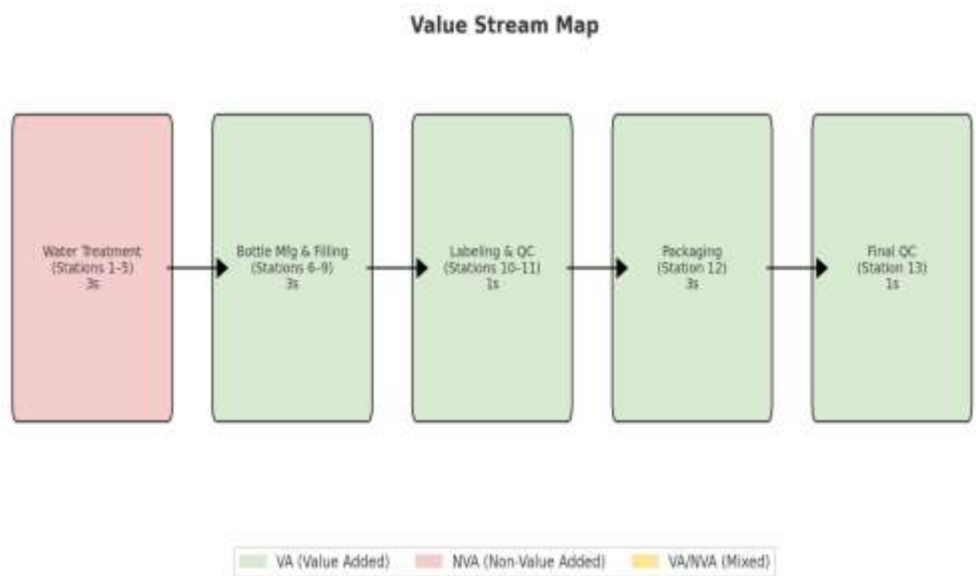

Figure 7 Post-Improvement Value Stream Mapping

5.4. Post-Improvement Value Stream Mapping (VSM) Analysis

a. **Water Treatment (Stations 1–5) – 3 seconds – NVA**

Purifies raw water to meet production standards. Although essential for operational readiness, this step does not directly add value from the customer’s perspective.

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b. **Bottle Manufacturing & Filling (Stations 6–9) – 3 seconds – VA**
Transforms raw materials into finished bottles and fills them with treated water, delivering a direct value-adding transformation for the customer.

c. **Labeling & Quality Check (Stations 10–11) – 1 second – VA**
Applies labels, verifies product identity, and ensures compliance with quality standards, enhancing both marketability and regulatory conformity.

d. **Packaging (Station 12) – 3 seconds – VA**
Organizes and secures bottles into packs, preparing them in the exact form required by customers for transport and sale.

e. **Final Quality Control (Station 13) – 1 second – VA**
Performs a final inspection to confirm that each product meets all quality specifications before leaving the production line.

5.5. Summary of Time Distribution:

a. Total Cycle Time: 11 seconds (reduced from 18 seconds pre-improvement).
b. Value-Added (VA) Time: 8 seconds (~73% of total).
c. Non-Value-Added (NVA) Time: 3 seconds (~27% of total).

This demonstrates a significant improvement in operational efficiency, with the majority of process time now contributing directly to customer value. The reduction in NVA time was achieved primarily through automation of previously manual steps, which streamlined operations and increased production capacity.

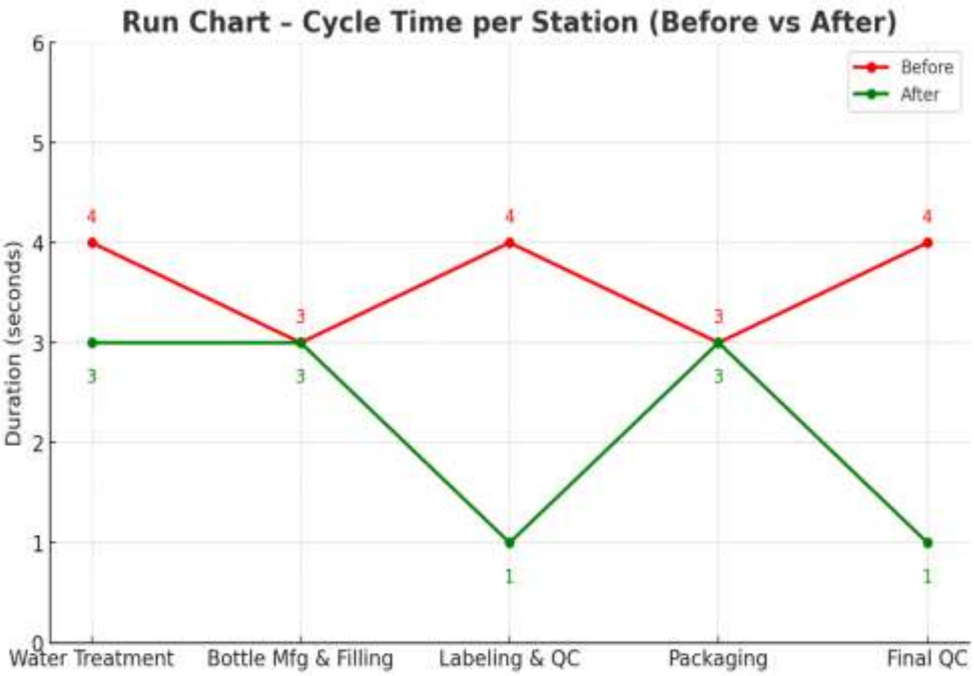

Figure 4.13 Run Chart – Cycle Time per Station (Before vs After Improvement)

The run chart compares cycle time (in seconds) for each process station before and after Lean Six Sigma improvements.

a. Red line (Before): Represents the baseline process times before improvements.
b. Green line (After): Shows the reduced process times after improvements.

5.6. Key Observations

a. Water Treatment
   i. Before: 4 seconds → After: 3 seconds
   ii. Minor improvement by streamlining non-value-added tasks.

b. Bottle Manufacturing & Filling
   i. Remained steady at 3 seconds in both states.
   ii. Indicates this step was already optimized.

c. Labeling & QC
   i. Significant drop from 4 seconds to 1 second.

ii. Achieved by combining tasks and removing redundant checks.

d. Packaging
i. No change (3 seconds in both cases).
ii. Already efficient and value-added.

e. Final QC
i. Reduced from 4 seconds to 1 second.
ii. Streamlined inspection and adopted in-line quality verification.

5.7 Overall Impact

a. Total Cycle Time reduced from 18s to 11s.
b. Process Cycle Efficiency (PCE) improved from 33.3% to 72.7%.
c. Major gains came from reducing Labeling & QC and Final QC durations.

VI. CONCLUSION AND RECOMMENDATIONS:

6.1 Conclusion:

This paper successfully demonstrated the application of the Lean Six Sigma (LSS) methodology within the Jumeirah Water Bottling Plant to enhance operational performance, reduce waste, and improve product quality. Utilizing the structured DMAIC framework [19], the study identified key inefficiencies in production such as high defect rates, excessive changeover times, unplanned downtimes, and overstocked inventory levels.

Through a combination of field observation, statistical analysis, and stakeholder involvement, the project achieved significant measurable improvements:

a. Defect rate reduced from ~3% to below 1%.
b. Downtime lowered by over 60%.
c. Changeover duration shortened by 37%.
d. Inventory levels optimized by nearly 50%.
e. Production stability and efficiency increased.

Importantly, the results underscore the potential of Lean Six Sigma as a low-cost, high-impact improvement methodology, especially suitable for semi-automated factories in developing countries [20]. The involvement of front-line staff and management played a critical role in sustaining the changes, reinforcing the need for a participatory approach in operational excellence initiatives [21].

6.2 Recommendations

Based on the findings, the following recommendations are proposed for Jumeirah Water Bottling Plant and similar facilities seeking to adopt Lean Six Sigma in the African context:

6.2.1.Institutionalize SOPs and Visual Management:

a. Maintain and regularly update Standard Operating Procedures (SOPs) for all critical operations.
b. Use visual tools such as dashboards, checklists, and color-coded systems to enhance workplace organization and communication.

6.2.2.Invest in Low-Cost Digital and IoT Monitoring Tools:

a. Adopt sensor-based tracking and real-time data dashboards to monitor defect rates, line speeds, and downtime.
b. Explore integrating IoT-based monitoring with machine learning analytics for predictive maintenance and process optimization.

6.2.3. Strengthen Operator Training and Continuous Improvement Culture:

a. Conduct regular Lean Six Sigma workshops and hands-on training sessions for operators.
b. Encourage staff participation in problem-solving teams to sustain a culture of continuous improvement.

6.2.4. Implement Preventive and Predictive Maintenance Plans:

a. Schedule and track preventive maintenance to reduce breakdowns.
b. Use predictive analytics to identify potential equipment failures before they occur.

6.2.5. Foster Cross-Functional Collaboration:

a. Promote communication between quality, maintenance, and production teams to ensure rapid response to problems and shared accountability.

6.2.6. Benchmark Against Regional and International Best Practices:

a. Learn from successful implementations in similar African contexts, such as in Nigeria, Kenya, and Egypt, and adapt best practices suited to local resources.
b. Adapt proven best practices to the Sudanese context, considering local resource constraints.

6.2.7. Expand Scope of Lean Six Sigma:

a. Extend LSS applications to upstream and downstream processes such as raw material sourcing, logistics, and customer feedback systems.

b. By embracing these recommendations, Jumeirah Water Bottling Plant can not only sustain the improvements achieved during this study but also evolve into a benchmark for operational excellence in Sudan and the broader African region.

c. Include sustainability-focused KPIs, such as water-use efficiency and energy optimization, to align with global green manufacturing trends.

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