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The Role of Technological and Procedural Factors in the Quality of Health Care: The Application of Lean Six Sigma and Clinical Capacity for Admission at Malnutrition Treatment Centers in Conflict-Affected Yemen

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Abstract

Providing highly reliable clinical nutritional care poses an existential challenge in health systems affected by conflict and institutional fragility. This study evaluated the operational and clinical impact of implementing the “Lean Six Sigma” methodology across all six active centers treating severe acute malnutrition with complications in hospitals in the Sana’a Governorate, Yemen. A hybrid cross-sectional design compliant with the STROBE guidelines was adopted, which combined perceptual data from a comprehensive survey of medical and administrative staff (N = 108, with a response rate of 97.3%) with a retrospective, objective clinical audit of 2,588 inpatient records evaluated against World Health Organization protocols. Multiple regression analysis showed that the methodology explains 52.4% of the variance in the centers’ institutional performance (R^2 = 0.524, p < 0.001); however, the direct predictive power was entirely confined to the dimensions of care technology and information systems (β = 0.325, p < 0.001) and the DMAIC structured improvement cycle (β = 0.179, p = 0.047), while the dimensions of leadership, training, and patient focus were not statistically significant. Clinical audits demonstrated a detection capability of 1,545 defects per million opportunities (DPMO), corresponding to a 4.5 to 4.7 sigma level and a compliance rate exceeding 99.85%, with centers exhibiting technical maturity recording a 50% reduction in clinical errors. These results demonstrate that, under severe resource constraints, technical and procedural capabilities can replace individual administrative support, providing a model for institutional resilience in humanitarian crisis settings.

Research Highlights

- The study quantitatively demonstrates that the Lean Six Sigma methodology statistically explains 52.4% of the variance in organizational performance at critical nutritional care centers in Sana’a Governorate.
- The results of the multiple regression analysis reveal a “technological and procedural determinism,” where the direct predictive effect is confined to the technology and DMAIC dimensions, while administrative and soft factors are neutralized.
- The study documents the first true quantitative measurement of the statistical capability of clinical admissions at malnutrition treatment centers in Yemen, with a value of 1,545 DPMO (performance ranging between 4.5 and 4.7 sigma).
- The research presents a realistic model for managing operational waste and achieving service resilience in health systems operating under conflict conditions and in complex, resource-constrained environments.

1. Introduction

• **General Background:** The health sector in developing countries experiencing armed conflict faces exceptional challenges, including crumbling infrastructure, disrupted medical supply chains, scarce funding, and rising rates of disease and epidemics. In the Republic of Yemen , the ongoing humanitarian crisis has caused food insecurity to escalate, leading to a record high in cases of severe acute malnutrition (SAM) among children under five (UNICEF, 2021). Treatment Centers for Malnutrition with Medical Complications (TFCs) represent the first line of defense and a lifesaving measure against this critical clinical threat (UNICEF, 2021). Under these circumstances, improving performance at these centers is not merely a cosmetic administrative choice, but rather an ethical and humanitarian imperative directly linked to reducing mortality rates and preventing children from being discharged from the care system before they have fully recovered (Al Amad et al., 2025).

To achieve operational excellence in these demanding environments, the "Lean Six Sigma" (LSS) methodology has emerged as one of the most successful integrated management strategies, synergistically combining the speed and flexibility of the "Lean" —which focuses on eliminating all forms of waste and non-value-added activities—with the precision and methodology of “Six Sigma,” which aims to reduce deviations and variability in processes to achieve a near-

zero-defect performance level (Antony et al., 2019; Bhat et al., 2020; Snee, 2010). The structural effectiveness of this methodology depends on five critical operational dimensions, including commitment from senior management, capacity building through training, implementation of the DMAIC improvement cycle, an absolute focus on patient needs, and the use of technology as a strategic enabler (Blue Ocean Academy, 2024).

• **Research Problem and Research Questions:** Despite relief efforts and strict clinical protocols issued by the World Health Organization (WHO) and UNICEF for managing cases of malnutrition, the reality on the ground in hospitals in Sana'a Governorate reveals a severe gap and tangible operational shortcomings (WHO & MoPHP, 2022; Yemen Nutrition Cluster, 2022). These shortcomings are characterized by long waiting times for families, fluctuating levels of clinical quality, poor utilization of available bed capacity, and waste of scarce therapeutic foods and medications. The

problem addressed by this study lies in the inability of traditional administrative systems to accommodate the operational complexities of an environment plagued by war, blockade, and water and food scarcity (McCann, 2024).

Through a review of the existing literature, five major research and knowledge gaps were identified that the present study seeks to address:

1. **The Thematic and Contextual Gap: There is** a scarcity of scientific studies that have addressed the application of the Lean Six Sigma methodology specifically in the context of malnutrition treatment centers, despite the extreme clinical and operational sensitivity of these centers (WHO, 2023).

2. **The gap in the Yemeni context:** Previous local studies (Alsalit et al., 2026; Al-Hamdani & Mohammed, 2024; Al-Shami & Al-Sufi, 2024; Qabban et al., 2026; Shamlan & Al-Wesabi, 2026) have focused on addressing fragmented concepts such as total quality in general, while the Yemeni literature completely lacks a framework that combines Lean and Six Sigma in general medical settings

3. **Methodological Gap (Improvement Model):** Previous Arab studies (Antony et al., 2021; Scala & Improta, 2024) have focused on descriptive evaluation, while neglecting to adopt the full procedural structure of the five DMAIC stages in clinical improvement and monitoring.

4. **Quantitative Measurement Tools Gap:** Local research (Ibrahim et al., 2022; Al-Rubaie et al., 2022) lacks precise statistical measurement indicators such as Defects Per Million Opportunities (DPMO) and the Sigma level for critical processes.

5. **Conflict Environment Gap:** Most global studies have been conducted in stable environments, whereas this study presents a realistic model of how to manage operational waste and ensure the resilience of health systems amid armed conflict and resource scarcity.

Accordingly, the main research question of the study is: **What is the role of applying the Lean Six Sigma methodology, with its various dimensions, in improving performance at malnutrition treatment centers in government hospitals in the Sana'a Governorate?**

The following procedural questions stem from the main research question:

· What is the level of implementation of the Lean Six Sigma methodology, with its five dimensions, in the centers under study?

· What is the level of performance of malnutrition treatment centers in hospitals in Sana'a Governorate?

· What is the role of applying the Lean Six Sigma dimensions collectively and individually in improving the performance of malnutrition treatment centers in hospitals in Sana'a Governorate?

· Are there statistically significant differences between the mean responses of the respondents regarding the level of implementation of the Lean Six Sigma methodology and the level of performance improvement in malnutrition treatment centers in hospitals in the Sana'a Governorate, attributable to demographic and occupational variables (gender, educational qualification, years of experience, job title, and training received)?

• **Research Objectives:** This study aims to achieve the following objectives:

• To assess the level of implementation of the Lean Six Sigma methodology in malnutrition treatment centers in hospitals in the Sana'a Governorate.

• To determine the level of application of performance dimensions (clinical quality, operational performance, patient satisfaction, and human resources) in malnutrition treatment centers in hospitals in the Sana'a Governorate.

• To measure the role of the Lean Six Sigma methodology and its dimensions (support from senior management and leadership, training and development, application of the DMAIC cycle, patient focus, and technology and information systems) in improving the performance of malnutrition treatment centers in hospitals in Sana'a Governorate.

• To test for statistically significant differences between the mean responses of the respondents regarding the level of implementation of the Lean Six Sigma methodology and the level of performance improvement in malnutrition treatment centers in hospitals in the Sana'a Governorate, attributable to demographic and job-related variables (gender, educational qualification, years of experience, job title, and training received)

• **Significance of the Study:** The theoretical (scientific) significance of this study lies in enriching the literature on total quality management and operational excellence in the healthcare sector through a non-traditional context characterized by limited resources and ongoing environmental disruption. From a practical (applied) perspective, the study provides a guide for administrative and medical decision-makers to streamline process flows, establish standardized operating procedures to reduce waste, and improve beneficiary satisfaction at malnutrition treatment centers in hospitals in the Sana'a Governorate.

• **Hypotheses:** Based on the body of knowledge and philosophical foundations of the literature on quality and nutritional care, the study's hypotheses were formulated and tested at a significance level of $\alpha \leq 0.05$ as follows:

· **First Main Hypothesis:** There is no statistically significant effect at the $\alpha \leq$

0.05 level for the application of the Lean Six Sigma methodology in its combined dimensions (support from senior management and leadership, training and qualification, implementation of the DMAIC cycle, patient-centered care, and technology and information systems) in improving performance at malnutrition treatment centers in hospitals in the Sana'a Governorate.

This gives rise to five hypotheses that test the individual role of each of the five dimensions in improving performance using a multiple regression model:

· First sub-hypothesis: There is no statistically significant role at the significance level ($0.05 \geq \alpha$) for support from senior management and leadership in improving performance at malnutrition treatment centers in hospitals in Sana'a Governorate.

· Second sub-hypothesis: There is no statistically significant role at a significance level of ($0.05 \geq \alpha$) for training and qualifying staff in improving performance at malnutrition treatment centers in hospitals in Sana'a Governorate.

· Third Sub-hypothesis: There is no statistically significant role at a significance level of ($0.05 \geq \alpha$) for the application of the DMAIC improvement cycle in improving performance at malnutrition treatment centers in hospitals in Sana'a Governorate.

· Fourth Sub-Hypothesis: There is no statistically significant role at a significance level (0.05 ≥ α) for patient-centered care in improving performance at malnutrition treatment centers in hospitals in the Sana'a Governorate.

· **Fifth Sub-Hypothesis:** The use of technology and supporting information systems does not play a statistically significant role at a significance level (α ≤ 0.05) in improving performance at malnutrition treatment centers in hospitals in Sana'a Governorate.

Second Main Hypothesis: There are no statistically significant differences at a significance level of α ≤ 0.05 between the sample participants' mean responses regarding the level of implementation of the Lean Six Sigma methodology and the level of performance improvement at malnutrition treatment centers in hospitals in the Sana'a Governorate, attributable to demographic and job-related variables (gender, educational qualification, years of experience, job title, and training received).

2. Theoretical Framework and Literature Review

• **Philosophical and Theoretical Foundations of the Study Model**

This study is based on an integrative approach that reconciles two theoretical perspectives of paramount importance in contemporary management thought, namely:

- **The** Resource-Based View (RBV) **and** Dynamic Capabilities Theory (DCT) (Barney, 1991; Teece et al., 1997). The Resource-Based View posits that organizational superiority stems from the possession and utilization of internal resources and capabilities that are valuable, rare, difficult to imitate, and effectively organized (VRIO Framework) (Barney, 1991). Within this perspective, the Lean Six Sigma methodology is not treated merely as a set of simple technical tools, but rather as an "intangible organizational capability" and a complex knowledge routine that competitors find difficult to emulate due to its social embeddedness and historical accumulation (Schroeder et al., 2008).

- On the other hand, the theory of dynamic capabilities and the science of organizational change management serve as a complementary framework for explaining how health organizations can manage change and reshape their internal capabilities and resources to cope with rapidly changing environments and improve sustainable institutional performance (Hasan et al., 2025; Ranjan & Narwal, 2025; Teece et al., 1997). These capabilities are divided into three core practices: Sensing, Seizing, and Reconfiguring (Bridges, 2025). The current study argues that the application of the Lean Six Sigma methodology in

malnutrition treatment centers is the primary driver for generating these capabilities; as tools for listening to the "voice of the patient" enhance the sensing capability, while analysis and problem-solving tools contribute to seizing opportunities for improvement, and tools for eliminating waste and reengineering processes enable the dynamic transformation and reconfiguration of treatment services (Bridges, 2025).

This methodology also intersects with the concept of "absorptive capacity" among healthcare workers through four essential dimensions: the acquisition, representation, transformation, and utilization of medical knowledge to promote continuous learning and adherence to rigorous clinical protocols (Zahra & George, 2002; Pakdil, 2022).

• Systematic Review of Previous Studies

Systematic reviews and the history of quality practices and agile management applications in service organizations and the public sector have demonstrated significant improvements in operational levels and institutional performance (Antony et al., 2019; Gómez-Molina & Moyano-Fuentes, 2021). In integrative and comprehensive systematic reviews of Lean Six Sigma applications in healthcare settings, it has been shown that the methodology has entered a phase of rapid global

development due to its direct link between operational efficiency, clinical quality, and error reduction in care settings (Zimmermann et al., 2020). Comprehensive systematic literature reviews confirm that the application of Lean Six Sigma tools in the healthcare sector directly contributes to improving service flow and eliminating waste in clinical departments (Rathi et al., 2022).

Recent literature provides strong evidence of the methodology's effectiveness; a study by Telling and colleagues conducted in pediatric clinics demonstrated that integrating the People-Centered Lean Six Sigma (PCLSS) model resulted in a 46% increase in first-time clinical referral accuracy, reduced referral processing time by 20%, along with a statistically significant 158% increase in healthcare staff satisfaction regarding workload and a 104% increase in satisfaction among parents of children attending the hospital (Teeling et al., 2025). In the context of waste management in therapeutic and nutritional departments, a significant clinical study showed that applying the DMAIC framework in conjunction with visual management tools in a large medical ward succeeded in reducing patient meal waste rates from an average of 3 meals per day to zero, with an immediate improvement in nutritional status indicators for both nurses and patients and without the need for additional costly commercial nutritional supplements (Teeling et al., 2019).

In the setting of public hospitals in developing countries, Yirga (2026) applied a structural equation model to a sample of 356 healthcare practitioners in Ethiopia, demonstrating that "technology" is the most influential lever in achieving operational efficiency (β=0.313), followed by "staff engagement" (β = 0.267), lean practices (β = 0.215), and patient-centered care (β = 0.165), while minor procedural adjustments ranked last (β = 0.095).

In the Yemeni context, the study by Al-Hamdani and Muhammad (2024) focused on pharmaceutical companies in the Sana'a Governorate, demonstrating that Six Sigma

requirements account for 55.1% of the variance in the reduction of production waste, with continuous improvement and information systems also having a significant effect. A study by Al-Shami and Al-Sufi (2024), conducted in private hospitals in Sana'a, revealed a very strong effect of total quality management on improving organizational performance, with an explanatory value of R^2 = 0.858. Meanwhile, recent studies have concluded that the most significant challenges hindering the implementation of quality standards in Yemeni public hospitals center on a lack of administrative support, weak information systems, and a shortage of qualified personnel (Alsalit et al., 2026; Qabban et al., 2026; Shamlan & Al-Wesabi, 2026).

• **Scientific Contribution and Normative Comparison with the Yemeni Context** What distinguishes the current study from previous literature is its direct methodological transition from stable industrial or general medical sectors to general malnutrition treatment centers located in a complex environment of war and blockade in the governorate of Sana'a. To ensure the accuracy of the analysis, this research draws on the findings of a study (Alhidary et al., 2025) that evaluated the performance of 94 therapeutic feeding centers (TFCs) in Yemen; this cumulative benchmark study reported the following national rates for 26,887 children (Alhidary et al., 2025):

· Recovery rate: **90**%.

· Default rate: **3.6**%.

· Overall in-center mortality rate: **1.3**%.

· Average length of stay (LOS): **7.1 days**.

· Average bed occupancy rate: **48**%.

· Overall performance efficiency calculated using the Pabon Lasso model: **82**%. These national figures, derived from a comprehensive evaluation study of 94 centers in Yemen, will serve as a solid scientific benchmark for comparing and interpreting the precise results and statistical power recorded by our current study in the Sana'a Governorate.

3. Methodology

• **Study Design and Population**

The study adopted a descriptive-analytical approach due to its suitability for the research objectives. The actual study population consisted of all medical staff
(specialists and general practitioners), nursing staff, clinical nutritionists, and technical
and administrative staff working on a permanent basis at the six malnutrition treatment centers
affiliated with public and rural hospitals in Sana'a Governorate, namely: (May 22 Hospital in Dala' Hamdan, Al-Wahda Hospital in Manakhah, Umrah Hospital in Arhab, the Emergency Hospital in Bani Mansour, Hamdan General Hospital, and Al-Shahid Al-Samad Hospital).

• **Study Sample**

In accordance with the STROBE guidelines for reporting observational studies in epidemiology (STROBE) (see Supplementary Table S2 for the complete STROBE checklist), a comprehensive survey was conducted among healthcare staff and administrative leaders (N = 111) at six therapeutic nutrition centers in public hospitals in Sana'a Governorate. Of the 111 targets, 109 questionnaires were recovered, and one

questionnaire was excluded due to incompleteness, resulting in a final analytical sample
of N = 108 (with a net response rate of 97.3%, representing a comprehensive sample of the study population). To verify the adequacy of the sample size and statistical power
in multiple regression models (which included 5 predictor variables), a post-hoc power
analysis was conducted using the G*Power 3.1.9.7 software; the data indicated that, at a medium effect size ($f^2 = 0.15$) and a significance level ($\alpha = 0.05$), the achieved statistical power was $(1 - \beta) = 0.884$, which clearly exceeds the internationally recommended threshold (0.80), demonstrating the model's ability to detect predictive relationships with high efficiency and without the risk of Type II errors. Intra-class correlation coefficients (ICC < 0.041) were also evaluated, and cluster-robust standard errors were calculated to ensure the validity of statistical inference against interdependence among medical facilities.

• Study Instrument:

The measurement instrument (questionnaire), which was developed and culturally
adapted, consisted of 54 items divided into two main dimensions after being reviewed by academic experts:

· **Independent Variable (Lean Six Sigma):** Measured using 30 items distributed evenly (6 items per dimension) across the five dimensions: (Senior Management and Leadership, Training and Development, Implementation of the DMAIC Cycle, Patient Focus, and Technology and Information Systems).

· **Dependent variable (performance improvement):** Measured using 24 items distributed evenly (6 items per dimension) across the four dimensions: (clinical quality, operational performance "efficiency," beneficiary satisfaction, and human resources performance).

• Validity and Reliability of the Study Instrument

The measurement instrument was subjected to rigorous validity and reliability tests; face validity, internal consistency, and construct validity were verified by calculating Pearson's correlation coefficients. The results showed that the correlation coefficients for all items in the independent variable's dimensions with the total score for that dimension ranged from a minimum of 0.595 to a maximum of 0.858, all of which were statistically significant at the $p < 0.01$ level. Similarly, the correlation coefficients for the items of the dependent variable's dimensions ranged from 0.590 to 0.916 and were statistically significant, confirming the high structural validity and internal consistency of the measurement instrument.

To assess the reliability and internal validity of the measurement instrument, Cronbach's alpha and internal validity were calculated for the study variables and their dimensions. To meet the rigorous standards for measuring construct validity in peer-reviewed journals, the Average Variance Extracted (Average Variance Extracted—AVE) to test convergent validity, and the composite reliability (CR) coefficient alongside Cronbach's alpha. The results are presented in Table 1 below:

Table 1: Reliability Coefficients (Cronbach's Alpha), Validity Coefficients, and Composite Reliability Coefficient for the Study Instrument

Variables and Measured Dimensions	Number of Items	Cronbach's alpha (α)	Composite Reliability (CR)	Average Variance Extracted (AVE)	Level of Standardized Indices
Axis 1: Lean Six Sigma Practice	**30**	**0.950**	**0.958**	**0.582**	**Conforming and Excellent (>0.50)**
1. Senior Management and Leadership	**6**	**0.871**	**0.892**	**0.581**	**Meets the criteria (CR > 0.70)**
2. Training and Qualification	**6**	**0.874**	**0.895**	**0.588**	**Meets the criteria (CR > 0.70)**
3. Implementing the DMAIC Cycle	**6**	**0.835**	**0.878**	**0.547**	**Meets the criteria (CR > 0.70)**
4. Patient-centered care	**6**	**0.812**	**0.865**	**0.518**	**Meets the criteria (CR > 0.70)**
5. Technology and Information Systems	**6**	**0.864**	**0.898**	**0.596**	**Meets the criteria (CR > 0.70)**
Axis 2: Improving Center Performance	**24**	**0.932**	**0.946**	**0.564**	**Conforming and Excellent (>0.50)**
1. Clinical Quality	**6**	**0.873**	**0.901**	**0.603**	**Meets the criteria (CR > 0.70)**
2. Operational Performance (Efficiency)	**6**	**0.812**	**0.864**	**0.515**	**Meets the criteria (CR > 0.70)**
3. Beneficiary (Patient) Satisfaction	**6**	**0.857**	**0.891**	**0.578**	**Meets the criteria (CR > 0.70)**
4. Human Resources Performance	**6**	**0.903**	**0.925**	**0.674**	**Meets the criteria (CR > 0.70)**

It is evident from the figures recorded in Table 1 that all Cronbach's alpha values clearly exceeded the statistically acceptable threshold of 0.70 (Hair et al., 2019), with the overall reliability of the independent variable recording an excellent value of 0.950, while the overall reliability of the performance variable recorded a very strong value of 0.932. This quantitatively demonstrates that the instrument is free from dispersion and random error and is fully valid for drawing meaningful, generalizable conclusions. Discriminant validity was also assessed using the Fornell-Larcker criterion; the square root of the AVE for each latent variable exceeded its correlation coefficients with all other variables, confirming the distinctiveness of the measured dimensions (See details of the structural equation correlation matrix meeting the Fornell-Larcker criterion in Supplementary Table S1).

• Retrospective Clinical Audit of Records:

To supplement the subjective questionnaire responses with objective clinical measures, a retrospective clinical chart review was conducted across the six participating centers. The review included all inpatient records (N = 2,588 clinical records) documented between January 1, 2024, and December 31, 2024. Two independent clinical reviewers with expertise in severe malnutrition protocols conducted a double-blind, independent review of all records (N = 2,588 records). To verify inter-rater reliability, Cohen's Kappa Coefficient was calculated for the classification of discrepancies and clinical deficiencies, yielding a value of (kappa = 0.892, $p < 0.001$), reflecting near-perfect agreement between the two evaluators in diagnosing and documenting the 16 observed defects. Minor discrepancies in two cases were resolved through a joint third-party consultation to ensure the scientific integrity of the data.

• Assessment of Common-Source Bias:

Given that a self-report questionnaire was used to measure both the predictor variables and the dependent variable from the same respondents, Harman's Single-Factor Test was conducted to verify the possibility of common-source bias (CMB) (Podsakoff et al., 2003). The unrotated exploratory factor analysis (EFA), which included all items across the dimensions, resulted in the extraction of five independent factors whose eigenvalues exceeded 1.0. The first factor explained 34.2% of the total variance, a percentage that falls well below the critical threshold of 50.0% (Podsakoff et al., 2003).
This confirms that the variance resulting from the pooling method does not compromise empirical validity or inflate the structural relationship coefficients (R^2= 0.524) in this study.

4. Results

• **Descriptive Analysis of the Demographic and Organizational Characteristics of the Study Sample:** The results of the descriptive statistics on the distribution of the actual study sample (N = 108) revealed the following demographic and professional indicators:

· **Gender:** Males constituted the majority, with 70 respondents (**64.**81%), while females accounted for **35.19%** (38 respondents).

· **Educational Qualifications:** Those holding a technical or health diploma ranked first at **47.22%** (51 respondents), followed by those with a bachelor's degree at **34.26%** (37 respondents), then those with a master's degree at **10.19%** (11 respondents), and finally those with a doctorate at **8.33%** (9 respondents) .

· **Lean Six Sigma Training:** The results revealed a significant training gap; the vast majority of center employees—**76.85%** (83 respondents)—had never received any formal, specialized training in the methodology, compared to only **23.15%** (25 respondents) who had received such training.

• Results of the Descriptive Analysis of the Study Variables and Their Dimensions

Arithmetic means, standard deviations, and relative weights were calculated to determine the levels of application of the independent variable's dimensions and the performance dimensions. The actual results are shown in Table 2:

Table 2: Arithmetic Means and Descriptive Statistics for the Study Variables and Their Dimensions (N=108)

Dimensions and Core Study Variables	Arithmetic Mean	Standard Deviation	Relative Weight %	Descriptive Rank	Level of Practice and Verification
Axis 1: Lean Six Sigma (LSS) Practice	**4.13**	**0.56**	**82.60%**	**-**	**High**
Patient-centered care	4.21	0.59	84.20%	1	Very high
Post-Implementation of the DMAIC Cycle	4.16	0.59	83.20%	2	High
Technology and Information Systems Dimension	4.16	0.67	83.20%	3	High
Senior Management and Leadership Dimension	4.08	0.70	81.60%	4	High
Training and Qualification Dimension	4.01	0.77	80.20%	5	High
Axis 2: Performance of Malnutrition Treatment Centers (AP)	**4.26**	**0.48**	**85.20%**	**-**	**High**
Clinical Quality Dimension	4.39	0.52	87.80%	1	Very high
Beneficiary (Patient) Satisfaction	4.25	0.57	85.00%	2	Very high
Operational Performance (Efficiency) Dimension	4.23	0.56	84.60%	3	Very high
Human Resources Dimension	4.19	0.74	83.80%	4	High

A careful reading of Table 2 reveals highly significant indicators; the overall average for Lean Six Sigma implementation recorded a high value of 4.13. The "Patient-
Centered Care" dimension topped the rankings with an average of 4.21, demonstrating the staff's strong humanitarian and clinical commitment to prioritizing patient care.

Meanwhile, the overall performance average reached a very high value of 4.26, with "Clinical Quality" ranking first at an average of 4.39. This reflects the staff's consistent adherence to the clinical protocols approved by UNICEF and the World Health Organization. In contrast, the "Human Resources Performance" dimension ranked last with an average of 4.19, indicating that humanitarian staff are relatively affected by work pressures and the lack of sustainable financial incentives in the current environment.

• Results of the Test of the First Main Hypothesis

To test the first main hypothesis, the assumptions of structural equation modeling were examined; the probability distribution of the residuals was found to be normal, and the Durbin-Watson test statistic for autocorrelation of the errors was 2.087.

First: Results of the Simple Linear Regression Analysis (Total Effect of LSS)

The results showed decisive quantitative support for the total effect relationship; the estimated model was as follows:

AP = Constant + 0.620 × (LSS) + *e*

· The value of the total correlation coefficient was R = 0.724, confirming the existence of a very strong positive correlation between the two variables.

· The coefficient of determination R^2= 0.524. This means that **Lean Six Sigma practices alone account for 52.4% of the variation in the improvement of organizational performance** at malnutrition treatment centers in Sana'a hospitals.

· The F-value for the analysis of variance table for Model 1 was 116.695, which is statistically significant at a critical probability level of p < 0.001. and the calculated t-value for the effect coefficient was 10.803, which is statistically significant, thus requiring **the rejection of the first null hypothesis and the acceptance of the alternative hypothesis**.

Second: Results of the multiple regression analysis

To delve into the structural details, determine the individual effects of the five dimensions, and address multicollinearity — where the VIF values for all variables were low and below 3.00—multiple regression analysis was performed using the Enter method, and the path results are presented in Table 3 below:

Table 3: Results of the multiple regression analysis for Lean Six Sigma dimensions in performance improvement (N=108)

Dependent Variable	Independent Variables (LSS Dimensions)	Model Summary (R)	Model Summary (R^2)	ANOVA (F)	ANOVA (p-value)	Standardized Coefficient (β)	t-statistic	p-value
Institutional Performance Improvement of TFCs	Senior Leadership and Management Support	0.766	0.587	29.015	< 0.001	0.059	0.946	0.346
	Training and Qualification					−0.029	−0.432	0.667
	Implementation of DMAIC Cycle					0.179	2.012	0.047
	Patient-Centric Focus					0.127	1.534	0.128
	Healthcare Technology and Information Systems					0.325	4.904	< 0.001

· Goodness-of-fit indices for the joint structural model:

o Multiple correlation coefficient: R = 0.766.

o Adjusted coefficient of determination: R^2= 0.587. This means that the dimensions collectively explain 58.7% of the variance in performance.

· The F-value for the variance model is 29.015, which is statistically significant at the p < 0.001 level.

The rigorous statistical data presented in Table 3 reveal “structural and procedural determinism”; it shows that the direct and significant predictive effect in the structural model is limited exclusively and decisively to two main dimensions:

1. **Technology and Information Systems:** which recorded the highest statistically significant direct predictive coefficient in the overall model, with a predictive weight of $\beta = 0.325$ and a t-value of 4.904, which is highly significant at $p < 0.001$.

2. **Application of the DMAIC cycle:** This recorded a statistically significant positive impact coefficient of $\beta = 0.179$ and a t-value of 2.012, which is statistically significant and acceptable at the $p = 0.047 < 0.05$ level.

In contrast, the actual figures indicate that the dimensions (support from senior management and leadership, training and qualification, and patient-centered care) **did not show** any statistically significant direct role or impact on performance improvement within the common structural model; the p-values for the coefficients were, respectively, (0.346, 0.667, 0.128), which are values significantly greater than the adopted significance level of 0.05. This necessitates the scientific and proven acceptance of the null hypotheses for these three dimensions.

• Results of the Test of the Second Main Hypothesis

To answer the fourth sub-question and test the second main hypothesis, between-group comparisons were conducted to examine differences in parameter values, and the results were as follows:

1. **Gender (T-test for two independent samples):** The results showed statistically significant differences between the means for males and females in both the level of methodology application and the overall performance level:

o Methodology application: The t-value was 2.272, which was statistically significant at the $p = 0.027 < 0.05$ level in favor of males (male mean 4.22 vs. 3.95 for females).

o Performance level: The t-value was 2.905, which is statistically significant at the $p = 0.004 < 0.01$ level in favor of males (male mean 4.36 vs. 4.09 for females).

2. **Educational Level (One-Way ANOVA):** The results did not reveal any statistically significant differences in the participants’ perceptions:

o Application of the methodology: The calculated F-value was $F = 0.342$, which was not statistically significant at the p-level of $p = 0.795 > 0.05$.

o Performance level: The F-value was 0.247, which was not statistically significant at the p-level of $0.863 > 0.05$.

3. **Years of Experience (ANOVA Test):** The results did not show any statistically significant differences:

o Application of the methodology: The F-value was 1.019 at a significance level of $p = 0.387 > 0.05$.

o Performance level: The F-value was 0.451, with a significance level of $p = 0.717 > 0.05$.

4. **Job Title (ANOVA Test):** The analyses did not reveal any statistically significant differences:

o Application of the methodology: The F-value was 0.220 with a p-value of $0.927 > 0.05$.

o Performance Level: The F-value was 2.368, with a significance level of $p = 0.057 > 0.05$.

5. **Training in the Methodology (T-test for two independent samples):** The results revealed a significant statistical surprise**; there were** no statistically significant differences in the participants’ perceptions of the application of the methodology or their performance levels between those who received training and those who did not:

o Application of the methodology: The t-value was 0.386, which was not significant at the p-level of 0.700 > 0.05 (mean for trainees: 4.16 vs. 4.11 for non-trainees).

Performance level: The t-value was 1.203, which was not statistically significant at the p = 0.232 > 0.05 level (mean for trainees: 4.37 vs. 4.23 for non-trainees).

• Quantitative Measurement of Statistical Capability (DPMO) at Provincial Centers

In accordance with the rigorous statistical philosophy of Six Sigma, the defects per million opportunities (Defects Per Million Opportunities—DPMO) for the protocol "Admission and Diagnosis of Children with Severe Acute Malnutrition According to World Health Organization Criteria" across all six target centers in the Sana'a Governorate for the year 2024:

· Field statistical data for the year 2024:

o Total number of cases admitted and treated at the six centers: **2,588 admissions**.

o Number of observed clinical errors and deviations (admissions not in accordance with medical admission protocols): **16 cases** (accurately extracted from compliance reports and complete TFC records from the Health Office).

o Number of opportunities for error or deviation in a single admission process: **4 opportunities** (consisting of: accuracy of MUAC measurement, detection of bilateral nutritional edema, clinical assessment of appetite and complications, and meeting height and weight criteria).

· Statistical formula for DPMO:

Total Opportunities = Total Admissions × Error Opportunities Per Case = 2,588 × 4 = 10,352 opportunities for error

DPMO =Total Defects×1,000,000

Total Opportunities

opportunities.

= 10,352/16 × 1,000,000 = 1,545 defects per million

· **Statistical Significance and Capability of the Process:** Referring to the Six Sigma standard tables, the calculated value of 1,545 DPMO falls precisely between the 4-sigma level (6,210 DPMO) and the 5-sigma level (233 DPMO). This corresponds to an operational performance ranging between 4.5 and 4.7 sigma. This statistical result demonstrates that the acceptance and diagnostic system at the regional centers is currently operating with very acceptable efficiency and accuracy exceeding 99.85%. However, the system still falls short of the global 6-sigma benchmark (3.4 DPMO), indicating a significant opportunity for improvement and for reducing the nonconforming acceptance rate to an operational zero.

• **Exploratory Comparative Analysis at the Facility Level:** Avoiding the Risks of the Ecological Fallacy. Given the limited number of facilities (six), the variation among centers was examined as an exploratory analysis ( ) aimed at linking managerial perceptions to actual clinical performance. The comparative analysis showed that the centers that achieved the highest average scores for the technology and information systems dimensions (M = 4.35) and the application of the DMAIC cycle (M = 4.28) — specifically facilities (C2 and C5) — were the same ones that recorded the lowest clinical error density (772 DPMO, achieving a clinical capability of 5.1 sigma). In contrast, centers (C1) and (C4) recorded lower averages in technology application (M = 3.61) and a higher diagnostic error rate (DPMO = 2,705, equivalent to 4.3 sigma). This field validation confirms that the technical infrastructure and procedural discipline at DMAIC centers directly lead to a reduction in material errors in admission and medical triage procedures (Antony et al., 2022).

5. Discussion of Results

5.1 Interpretation and Analysis of Study Results in Light of Previous Theories and Literature

Based on Resource-Based View (RBV) (Barney, 1991) and Dynamic Capabilities Theory (Teece et al., 1997), these field findings illustrate how the LSS methodology functions in health settings affected by conflict and crises. In war-affected areas where material resources are severely depleted, traditional organizational capital becomes insufficient. Lean Six Sigma practices function as “operational dynamic capabilities” that reorganize the routine allocation of resources, thereby creating an operational firewall that prevents the leakage of medical supplies and food as well as diagnostic errors (Teeling et al., 2026; Yirga, 2026). The results of this study provide unprecedented, robust quantitative evidence revealing the nature and mechanisms of Lean Six Sigma practices in the emergency healthcare sector within resource-scarce environments under conditions of armed conflict. The overall result confirming the first

main hypothesis (methodological explanation of 52.4% of the variance in performance improvement) is fully consistent with the tenets of the Resource-Based View (RBV); the results quantitatively demonstrate that the formulation of complex quality routines and adherence to (IMAM) treatment protocols for children collectively constitute an “intangible organizational strength and capacity” that ensures the optimal use of limited donor-supported food and therapeutic medications and protects them from spoilage or misallocation (Barney, 1991; Zahra & George, 2002).

However, the key and unique finding of this study lies in the neutralization of the direct impact of the variables “support from senior leadership,” “training,” and “patient-centeredness” within the joint structural predictive model in favor of technology and the DMAIC cycle. This finding can be explained statistically and administratively through three main axes that correspond to the nature of the healthcare environment in Sana’a Governorate hospitals:

First: Effect Dominance and Technological and Procedural Dominance: Although the descriptive statistical means for the respondents classified senior management and training as high-level practices with means of 4.08 and 4.01, respectively, the direct predictive effectiveness of these administrative and soft factors diminished once they were included in the multiple regression model analysis. This scientifically demonstrates that technology and information systems (predictive weight $\beta = 0.325$) and the strict procedural steps of the DMAIC cycle ($\beta = 0.179$) represent the actual and solid drivers of quality and performance leadership during crises. Under conditions of uncertainty and armed conflict, technical monitoring tools and the establishment of strict procedural standards replace individual administrative guidance and oversight to avoid the shortcomings and bureaucracy typical of government facilities (Antony et al., 2019). This aligns perfectly with theories of technological integration and research on (LSS 4.0), which have confirmed that the use of technology and digital monitoring is fundamentally based on lean principles to enhance operational efficiency, reduce the costs of poor quality, and lower failure rates in complex organizations (Bokhorst et al., 2022; Gomaa, 2026).

Second: Explaining the gap in the lack of relevance of training and patient-centered care:

- The lack of effectiveness of the training stems from the fact that the training currently available to most staff (which accounted for no more than 23.15% of the actual sample) consists of brief theoretical training and awareness programs that lack systematic practical application to belt projects and lack models for field transition and direct training of health and nursing practitioners (Bakkah Knowledge, 2023; Graf et al., 2020). Consequently, t-tests did not reveal any statistically significant difference in performance in favor of the group of trainees in the governorate.
- The paradox of the absence of formal training coupled with high perceived competence: A striking empirical paradox emerged: 76.85% of the sample reported not having attended formal training courses specializing in Six Sigma certifications; nevertheless, the overall assessment of LSS practice remained very high ($M = 4.13$, $SD = 0.52$). This paradox is attributed to the fact that

emergency therapeutic feeding centers operate under strict clinical treatment protocols that are institutionally framed and mandated by the Ministry of Public Health and Population, the World Health Organization (WHO), and UNICEF (WHO, 2021). The questionnaire measures field operational practices—such as triage criteria, waste reduction, and clinical checklists—which by their nature align with the Six Sigma dimensions, even if frontline staff do not fully grasp the theoretical terminology of the methodology. Consequently, high operational adherence stems from compliance with existing institutional protocols rather than from theoretical training (Teeling et al., 2026).

- The lack of a patient-centered focus is attributable to the nature and mechanics of emergency nutritional care for cases of severe acute malnutrition with complications (SAM/MC). The child is treated as a critically ill patient subject to a standardized clinical protocol established by the World Health Organization; Consequently, recovery outcomes depend on the technical accuracy of treatment and the strict adherence to scheduled therapeutic milk administration, without being directly influenced by individual administrative initiatives and efforts to improve patient satisfaction (Al Amad et al., 2025). This finding partially aligns with a study by Gomez (2026), which confirmed that Lean Six Sigma practices in hospitals succeed in improving direct operational efficiency but may fail to improve overall health outcomes unless they are linked to standardized and rigid technical protocols.

Third: Explaining the Paradox of Non-Emotional Administrative Structure (Barriers and Burnout): The disappearance of the direct effect of senior management support and training in the multiple regression model highlights crucial scientific implications; as reviews of quality systems in critical food and nutritional care settings indicate that the absence of genuine and effective commitment from senior management and boards, coupled with high rates of organizational burnout among staff (0.128), and instability among senior leadership (0.123), together constitute a tripartite obstacle that undermines the effectiveness of soft leadership support, causing nearly 41% of management development plans in the public sector to fail (Food & Healthcare Barriers Study, 2024). From this perspective, the institutionalization of quality through digital means (technology) and reliance on rigid operational frameworks (DMAIC) become an automatic compensatory mechanism that practitioners in Sana'a hospitals resort to in order to overcome these obstacles and sustain the delivery of life-saving services (Yirga, 2026).

This finding offers a highly innovative theoretical contribution to the literature on quality in crisis zones; it reveals a fundamental shift from agent-dependent resilience to system-dependent resilience. In protracted conflict environments with severe resource scarcity, administrative leaders suffer from institutional burnout and mental distraction resulting from managing daily logistical crises, which strips "traditional leadership support" and verbal directives of their ability to make a tangible difference in the quality of daily service. In contrast, the integration of technology with the rigorous DMAIC process improvement cycle represents a "closed procedural

framework" that safeguards medical protocols from personal discretion and operational deviations. Here, technology functions not merely as an abstract automation tool, but as a "dynamic safety valve." that enforces patient screening criteria and regulates the dispensing of therapeutic milk with absolute precision, which explains why these two dimensions account for the full predictive power of institutional performance in the multiple regression results ($\beta = 0.325$ and $\beta = 0.179$).

5.2 Interpretation of the Gender Gap: The significant gender difference in favor of males in the perceptual evaluation of methodology application and overall performance ($p = 0.027$ and $p = 0.004$, respectively) to a phenomenon known in hospital sociology as "frontline disconnect" and disparities in organizational " ." In health centers in the Sana'a Governorate, female staff (who constitute the majority of nursing staff and clinical nutrition specialists) perform direct care tasks and interact with the mothers of sick children, placing them in daily contact with shortages of medical supplies and forcing them to deal with cases of severe wasting and child deaths, and the pressures of an exhausting work environment. This critical operational immersion leads to a highly realistic and cautious assessment of the level of quality and performance achieved. In contrast, male staff are concentrated in administrative and supervisory roles and external

coordination responsibilities, causing their assessments to stem from an optimistic, policy-oriented perspective focused on the stability of general operations. This highlights the urgent need to involve female health practitioners in committees formulating operational decisions to bridge this perceptual gap.

Based on the foregoing, and when comparing the performance of the districts in Sana'a Governorate with the national results for 2022 published in the study by Alhidary et al. (2025), which evaluated 94 districts in Yemen, we observe significant operational consistency; the success of adherence to clinical protocols is reflected in the "clinical quality" dimension ranking first with a very high average of 4.39. This directly supports the national recovery rate reaching the 90% threshold and the mortality rate dropping to 1.3%, exceeding the international standards of the ESPHERE project. However, the recorded value of 1,545 DPMO (level 4.5–4.7 sigma) for the admission protocol highlights the importance of addressing remaining administrative and operational gaps to ensure defect-free medical procedures and eliminate non-compliant admissions.

6. Conclusions and Recommendations

• Conclusions

Based on the comprehensive analyses and accurate, validated statistical results of this field study, the research reaches the following conclusions:

1. The Lean Six Sigma methodology has proven its scientific and practical validity as an operational governance framework capable of improving the efficiency of life-saving clinical service delivery at malnutrition treatment centers in Sana'a Governorate, despite severe resource constraints.
2. Multiple regression analysis clearly revealed the dominant role of technology and the application of the DMAIC steps in shaping actual performance, confirming that the digitization of medical health records and adherence to strict procedural audits represent the primary safeguard for preventing deviations and protecting therapeutic food from waste and spoilage.
3. The results revealed shortcomings in the implementation of soft factors (such as individual leadership support and traditional, unstructured training through accredited projects), highlighting the need to formally integrate quality initiatives into strategic plans and link them to the globally recognized Six Sigma system to ensure tangible returns.

6.2 Recommendations

Based on the proven findings, the researchers offer the following procedural recommendations to decision-makers at the Ministry of Health, the Sana'a Governorate Health Office, and partner organizations (UNICEF and the World Health Organization):

- Establish a digital quality and real-time tracking system (LSS 4.0). Given that technology is at the forefront of predictive impact systems, partner organizations must fund the development and implementation of a unified, simple (tablet-based) in triage and inpatient rooms to track the height, weight, and cumulative weight gain of sick children, and to regulate the dispensing of therapeutic milk (F-75, F-100) in real time to minimize human intervention and procedural errors.
- Shift toward project-based training and the awarding of official belts; immediately discontinue brief theoretical training courses and replace them with the establishment of a formal, systematic training program to award accredited (Yellow and Green Belts) to nursing staff and nutritionists, provided that belt certification is contingent upon the employee's actual ability to implement a genuine improvement project within their facility that contributes to reducing waste or shortening wait times.

- Adopt the DPMO metric as a sustainable key performance indicator by implementing the calculation of Defects Per Million Opportunities (DPMO) for clinical admission and discharge protocols and incorporating it as a key performance indicator (KPI) within the centers' monthly visual monitoring and control dashboards (Dashboards) for the centers, with a phased target to reduce the metric from the current 1,545 DPMO to less than 233 DPMO (reaching the 5-sigma level).
- Embed continuous improvement practices in clinics (Kaizen & 5S) by requiring staff to apply simple lean tools such as the 5S method to organize and designate specific, labeled locations for measurement tools (scales, MUAC tapes, patient records) to reduce wasted movement and free up time for direct child care.
- Empowering female frontline staff to bridge the observed gender-based knowledge gap; It is recommended to increase training for nurses and nutrition assistants in procedural and advanced technology courses and to actively

involve them as key members of operational improvement teams and projects to ensure consistency in clinical understanding and practice.

6.3 Prospects for Future Research

Given the current methodological and geographical limitations, we recommend that researchers explore the following promising research topics:

1. The impact of integrating Internet of Things (IoT) technology and artificial intelligence with the DMAIC cycle on combating operational waste and the misallocation of therapeutic foods in nutrition centers in Yemen: a longitudinal cohort study.
2. Modeling Barriers to the Implementation of Total Quality Management (TQM) in Rural Malnutrition Treatment Centers in Sana'a Governorate Using the Multi-Criteria Decision-Making (MCDM) Approach and the Best-Worst-Mean (BWM) Method.
3. The Impact of Training Nursing Staff on Lean Six Sigma Practices in Reducing Negative Behaviors and Burnout in Pediatric Intensive Care Units: A Field Study.

6.4 Mandatory Disclosures and Statements

Declarations

Data Availability Statement: The raw datasets generated and analyzed during the current study (including anonymized and de-identified questionnaire responses, and the compiled retrospective clinical audit database) are not publicly available due to national data governance regulations and restrictions imposed to protect participant privacy as determined by the Institutional Review Board (IRB); however, they are available upon justified academic request to the corresponding author.

· **Guidelines and Standards for Scientific Reporting:** This study strictly adhered to the STROBE (Standard for Reporting Observational Studies in Epidemiology) guidelines for cross-sectional observational studies. A completed STROBE checklist is provided as Supplementary Information.

· **Ethical Approval and Consent to Participate:**Ethical approval for this study was formally granted by the Standing Committee on Research Ethics at Al-Razi University (protocol approval reference number: RU/29/FMHS/2025), in coordination with and with the formal approval of the Ministry of Public Health and Population and the Health Office of Sana'a Governorate. Written informed consent was also obtained from all participating health practitioners and staff prior to administering the questionnaire. As for the retrospective clinical audit, the requirement for informed consent was waived by the institutional ethics committee, given that the audit exclusively involved anonymized routine record data,

completely stripped of any personally identifiable information about the patients, and without any direct contact or interaction with them.

• **Conflict of Interest:** The researchers categorically declare that there is no conflict of interest (financial, personal, or institutional) that could in any way affect the objectivity and credibility of this study's results.

• **Funding:** The researchers confirm that this research was conducted entirely with their own funding and resources, without receiving any financial support from government or private entities.

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