

Determinants of Supply Chain Resilience of Operating Theatre Supplies in Lusaka District, Zambia: The Role of Demand Forecasting and Lead-Time Management

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Abstract

Background: Ensuring the consistent availability of operating theatre supplies is critical for safe surgical care. However, supply chain disruptions remain common in low- and middle-income countries (LMICs). In Zambia, commodity security policies have been implemented to improve the supply systems. However, their effectiveness in enhancing supply chain resilience is poorly understood. This study assessed the determinants of supply chain resilience for operating theatre supplies in Lusaka District, Zambia. **Methods:** A convergent parallel mixed-methods study was conducted among healthcare personnel involved in supply chain management across tertiary and first-level hospitals and the Zambia Medicines and Medical Supplies Agency (ZAMMSA). Quantitative data were collected from 120 respondents using structured questionnaires and analysed using descriptive statistics, chi-square tests, and multivariable logistic regression. Qualitative data were obtained from 15 purposively selected key informants and were analysed thematically. The findings were integrated using joint display analysis. **Results:** Demand forecasting capacity and effective lead-time management were both strongly associated with surgical supply chain resilience, with demand forecasting showing an adjusted odds ratio (AOR) of 22.0 (95% CI: 1.52 - 319.1; $p = 0.023$) and effective lead-time management showing an AOR of 12.8 (95% CI: 1.64 - 100.4; $p = 0.010$). Although inventory management showed a strong association at the bivariate level (COR = 12.70; 95% CI: 3.49 - 46.24; $p < 0.001$), it was not independently associated after adjustment (AOR = 0.60; 95% CI: 0.07 - 5.19; $p = 0.643$). Commodity security policies were

not statistically significant in the adjusted model. Qualitative findings highlighted gaps in logistics management information system utilisation, data-driven decision-making, and coordination across supply chain actors. **Conclusion:** The resilience of the supply chain for operating theatre supplies in Lusaka District was primarily associated with operational factors, particularly demand forecasting and lead-time management. Strengthening these functions, along with improving data use and operational coordination, was found to be essential for enhancing the effectiveness of commodity security policies that ensure uninterrupted surgical services.

Keywords

Supply Chain Resilience, Operating Theatre Supplies, Commodity Security, Demand Forecasting, Lead-Time Management, Logistics Management Information Systems (LMIS), Health Supply Chain, Mixed-Methods Study, Zambia

1. Introduction

The availability and accessibility of essential medicines are critical for delivering safe and effective surgical care (Vledder et al., 2019). However, health systems in low- and middle-income countries (LMICs) continue to face persistent supply chain challenges, including stockouts, procurement delays, and distribution inefficiencies, which compromise service delivery (Olaniran et al., 2022). These challenges are particularly pronounced in healthcare settings with limited resources, where disruptions in the supply chain directly affect healthcare outcomes (Dowling, 2011).

Supply chain resilience has emerged as a critical concept for addressing these challenges. Supply chain resilience refers to the ability of supply systems to anticipate, absorb, and respond to disruptions while maintaining uninterrupted surgical care (Aloqab et al., 2024). In the context of operating theatre supplies, resilience is especially important because of the time-sensitive and life-saving nature of surgical interventions (Glasbey et al., 2024). Inefficiencies in forecasting surgical demand, inventory management of surgical supplies, and lead-time monitoring can significantly affect the availability of surgical commodities and continuity of surgical care (Subramanian, 2021).

In Zambia, commodity security policies have been implemented to strengthen the availability and management of essential medicines. These policies aim to improve coordination, ensure adequate financing, and enhance accountability across the health system (Mekonen et al., 2024). Despite these efforts, health facilities continue to experience challenges such as stockouts, procurement delays, and inefficiencies in the management of specialised commodities, particularly operating theatre supplies (Yadav et al., 2021).

Despite ongoing reforms in Zambia's health sector, there is limited empirical

evidence on how commodity security policies translate into operational supply chain resilience, particularly for operating theatre supplies in Zambia. Existing studies have largely focused on general pharmaceutical supply chains, with limited attention to specialised areas such as surgical services (Mubambe et al., 2024). Therefore, this study assessed the determinants of supply chain resilience for operating theatre supplies in Lusaka District, Zambia. The findings are expected to inform policy implementation and strengthen supply chain performance for specialised healthcare commodities, such as surgical supplies.

2. Materials and Methods

2.1. Study Design

This study employed a convergent parallel mixed methods design, in which quantitative and qualitative data were collected and analysed concurrently. The study was conducted from January 2025 to February 2026. The quantitative component assessed the statistical associations between operational supply chain factors and resilience, while the qualitative component explored stakeholders' perspectives on the implementation of commodity security policies. Eligible participants were health personnel with at least six months' experience in forecasting, procurement, storage, or distribution of operating theatre supplies. These included pharmacists, pharmacy technologists, procurement officers, supply chain managers, theatre nurses, and selected hospital administrators.

2.2. Study Site

This study was conducted in Lusaka District, Zambia. The district was selected because of a high concentration of high-volume public health facilities and the district's status in hosting the central medical distribution facility. The study sites included two major tertiary hospitals in Zambia, the University Teaching Hospital (UTH) and Levy Mwanawasa University Teaching Hospital. In addition, five first-level hospitals, Chilenje, Chawama, Chipata, Matero, and Kanyama, and the Zambia Medicines and Medical Supplies Agency (ZAMMSA), the national medical supplies distributor.

2.3. Study Population

The study population comprised key informants, health personnel directly involved in the procurement, storage, distribution, and management of operating theatre supplies. Public health facilities in Lusaka District were selected. Key informants included pharmacists, pharmacy technologists, procurement officers, supply chain managers, theatre nurses, selected hospital administrators, and key ZAMMSA officials.

2.4. Sample Size Estimation

The sample size was determined using the guidelines proposed by Tabachnick for regression analysis (Tabachnick & Fidell, 2013).

$$N \geq 50 + 8m$$

where:

N = minimum required sample size;

m = number of predictors in the regression model.

The study included seven predictors: commodity security [including logistics management information system (LMIS) adoption], forecasting accuracy, inventory management practices, lead-time management, hospital-level professional role, and years of experience.

Therefore, the minimum required sample size was 106. However, the study targeted 120 respondents to enhance the sampling frame and account for possible non-responses.

For the qualitative component, 15 key informants, including hospital pharmacists, procurement officers, ZAMMSA officers, theatre nurses, and hospital administrators, were purposively selected for in-depth interviews to provide contextual and explanatory insights into the quantitative findings.

2.5. Sampling Procedure

Quantitative Sampling Frame by Facility

A proportionate stratified random sampling approach was used for the quantitative component to ensure representation across tertiary hospitals, first-level hospitals, and the ZAMMSA. Each participating hospital constituted a stratum, and respondents were selected proportionally based on the number of eligible staff involved in forecasting, procurement, storage, distribution, and management of operating theatre supplies.

The estimated total number of eligible staff across the selected facilities was approximately 170 participants. A target sample size of 120 respondents was distributed across facilities, based on staff size and operational relevance (**Table 1**). Tertiary hospitals with larger surgical workloads had more respondents than first-level hospitals.

Table 1. Quantitative sampling frame by facility and total sample size.

Facility	Estimated Eligible Staff	Sampled Staff	Completed Responses
University Teaching Hospital (UTH)	40	25	25
Levy Mwanawasa University Teaching Hospital	30	20	20
Chilenje First Level Hospital	20	15	15
Chawama First Level Hospital	20	15	15
Chipata First Level Hospital	20	15	15
Matero First Level Hospital	20	15	15
Kanyama First Level Hospital	20	15	15
Total	170	120	120

The allocation was guided using the following formula:

$$\text{Sample}_i = (\text{staff count}_i / \text{total staff}) \times 120$$

where staff count_i is the number of eligible staff members in each facility. Total staff = 170 (estimated total eligible staff across facilities). The target sample size was 120.

If a selected respondent was unavailable or declined to participate, the next eligible staff member from the same professional category and facility was invited to participate to maintain proportional representation.

For the qualitative component, purposive sampling was used to select 15 key informants with extensive experience in operating theatre supply chain management.

2.6. Data Collection

2.6.1. Quantitative Data Collection

Data collection involved the use of structured questionnaires for quantitative analysis. A structured, self-administered questionnaire was distributed to 120 respondents. When literacy or availability challenges arose, the questionnaire was administered as a one-on-one, interviewer-administered survey to ensure its completeness and accuracy. To ensure standardisation across both self-administered and interviewer-administered questionnaires, all respondents were provided with the same structured instrument and uniform instructions. The interviewer-administered questionnaires followed the exact wording and sequence of the self-administered version, with no modification of the questions. Neutral clarification was provided only when necessary to ensure understanding without influencing responses. In addition, respondents were assured of confidentiality and anonymity to minimise social desirability bias and encourage honest responses. The instrument consisted of closed-ended questions, a Likert scale, multiple choices, and categorical items. These covered demographic details, awareness, and the implementation of commodity security policies. In addition, the perceived impact on supply chain resilience was included in the instrument. The structured questionnaires focused on operational indicators, such as the frequency of stockouts, lead times in procurement, compliance with storage standards, and perceptions of policy effectiveness. These tools were pretested and refined to improve their reliability.

2.6.2. Qualitative Data Collection

The qualitative strand used semi-structured key informant interviews with 12 - 15 purposively selected participants. The interviews were conducted one-on-one, either face-to-face in a private setting or via secure online platforms, when necessary. An interview guide was used to explore stakeholders' perspectives on the implementation of commodity security policies, perceived barriers, and their influence on the surgical supply chain resilience. The interview guides explored themes such as policy awareness, operational challenges, coordination gaps, emergency preparedness, and strategic improvement. Each interview lasted approximately 30 -

60 minutes, was audio-recorded with consent, and transcribed verbatim for thematic analysis. Focus group discussions were not used in this study because individual interviews were more appropriate for eliciting candid insights from professionals in senior or specialised roles.

2.6.3. Instrument Validation and Pilot Testing

Prior to the main data collection, the questionnaire was piloted among approximately 10 health personnel at Chongwe District Hospital who were not part of the study sample. The pilot study assessed the clarity, comprehensibility, feasibility of administration, and content relevance of questionnaire items (Creswell & Creswell, 2018). Feedback from the pilot study was used to refine ambiguous or redundant items before the main study was conducted (Chhetri & Khanal, 2024). Content validity was ensured through expert review by supervisors and alignment of the questionnaire items with the study objectives and operationalised variables (Lawshe, 1975).

The internal consistency of the multi-item composite scales was assessed using Cronbach's alpha, with $\alpha \geq 0.70$ considered as acceptable. The supply chain resilience index consisted of nine items (score range: 9 - 45; $\alpha = 0.899$), LMIS adoption consisted of nine items (score range: 9 - 45; $\alpha = 0.887$), demand forecasting capacity consisted of six items (score range: 6 - 30; $\alpha = 0.841$), inventory management practices consisted of eight items (score range: 8 - 40; $\alpha = 0.892$), lead-time management consisted of five items (score range: 5 - 25; $\alpha = 0.773$), and stakeholder participation consisted of six items (score range: 6 - 30; $\alpha = 0.803$). These reliability values demonstrated acceptable to excellent internal consistency across all the study constructs.

2.7. Study Variables

2.7.1. Dependent Variable

The dependent variable in this study was supply chain resilience. It was measured using a composite resilience index derived from nine Likert-scale items assessing the adaptability, responsiveness, visibility, and recovery capacity of the operating theatre supply chain following supply disruptions (Boateng et al., 2018; Lamm et al., 2020). Each item was scored on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), producing a total possible score of 9 - 45.

The individual item scores were summed to generate an overall resilience score for each participant. A median score cut-off was used to categorise resilience into high and low resilience, consistent with similar scale development approaches in health systems research (Pallant, 2020). Respondents who scored above the median were classified as having high resilience, while those who scored at or below the median were classified as having low resilience.

2.7.2. Independent Variables

The main independent variables were demand forecasting capacity, commodity security policy implementation, inventory management practices, lead-time man-

agement, and stakeholder participation. Commodity security policy implementation was measured as a composite construct that included LMIS adoption. Each construct was measured using multiple Likert-scale items and summarised into composite indices.

Demand forecasting capacity was measured using six items (score range: 6 - 30), inventory management practices using eight items (score range: 8 - 40), commodity security policy implementation using nine items (score range: 9 - 45), lead-time management using five items (score range: 5 - 25), and stakeholder participation using six items (score range: 6 - 30). Similar to the dependent variable, median cut-off scores were used to classify responses into strong versus weak categories for the regression analysis.

Sociodemographic variables, such as sex, hospital level, years of experience, and professional role, were included as explanatory variables.

2.8. Data Analysis

Quantitative data were analysed using Stata version 17. Descriptive statistics, including frequencies and percentages, were used to summarise respondents' characteristics. The chi-square test was used to assess the associations between independent variables and the supply chain resilience of the operating theatre supplies. Variables with p -values < 0.20 in the bivariate analysis were included in the multivariate logistic regression model to avoid excluding potentially important predictors and control for confounding effects (Zhang, 2016). A multivariate analysis was conducted to identify the independent predictors of supply chain resilience (Zhang, 2016). Model stability was assessed prior to multivariable logistic regression analysis. Multicollinearity among the independent variables was evaluated using variance inflation factors (VIF), with a mean VIF of 2.1, indicating no significant multicollinearity. Given the relatively small number of low-resilience cases, a parsimonious model was applied by including only variables that met the inclusion criteria from bivariate analysis. A sensitivity analysis was also conducted to assess the robustness of the model estimates, and the direction and significance of the main predictors were consistent. Results were presented as crude odds ratios (COR) and adjusted odds ratios (AOR) with 95% confidence intervals, with statistical significance set at $p < 0.05$.

Qualitative data were analysed using thematic analysis (Braun & Clarke, 2006, 2021). The interview transcripts were coded and organised into codes, subthemes, and themes using MAXQDA. The analysis followed the six-step framework proposed by Braun and Clarke (Braun & Clarke, 2006), which includes familiarisation with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. The coding process was conducted by the principal researcher using an inductive approach. An initial codebook was developed based on recurring patterns identified during the familiarisation with the transcripts. The codes were then grouped into subthemes and broader themes through an iterative process. To enhance consistency, the coding

framework was continuously reviewed and refined during the analysis. Interview sufficiency was determined based on thematic saturation, where no new themes or insights emerged from subsequent interviews. This approach ensured that the data adequately captured the range of perspectives relevant to the study's objectives. This approach enabled the systematic identification of patterns in stakeholder perspectives regarding commodity security policy implementation and the challenges affecting the operating theatre supply chains.

The integration of quantitative and qualitative findings was achieved through joint display tables to facilitate the comparison of convergent, complementary, and divergent findings across the datasets (Fetters et al., 2013; Fetters & Guetterman, 2021). This mixed-method integration enhanced the depth of interpretation and strengthened the validity of the findings through methodological triangulation.

Incomplete quantitative responses were also evaluated. If missingness was <5%, listwise deletion was applied. If missingness was >5%, multiple imputation was conducted, followed by sensitivity analysis (Austin et al., 2021; Leurent et al., 2020).

2.9. Ethical Approval

Ethical approval was obtained from the University of Zambia Health Sciences Research Ethics Committee, approval identification number: 2023270451, Institutional Review Board number: 00011000, Institutional Organisation Registration number: 0009227. Further approval was granted by the Zambian National Health Research Authority (NHA), reference number: NHRA-2722/21/09/2025. Permission to conduct the research was obtained from the Provincial Health Office (PHO), reference number LSKPHO/101/8/1 and ZAMMSA. Written informed consent was obtained from all the participants before data collection. Participants were informed about the purpose of the study, their right to withdraw at any time without penalty, and the voluntary nature of their participation. To ensure confidentiality, no personal identifiers were collected, and all data were stored securely on password-protected devices accessible only to the research team members.

3. Results

3.1. Demographic Characteristics of Participants

3.1.1. Quantitative Survey Participants (N = 120)

A total of 120 respondents participated in the quantitative survey. Most participants were male (70.8%), aged 26 - 35 years (43.7%), and university educated (59.2%), with 32.2% having 4 - 6 years of work experience. Respondents were almost equally distributed between secondary (48.7%) and tertiary hospitals (51.3%), while over half (52.8%) worked in facilities performing more than 200 surgeries per month. Overall, 86.7% of respondents reported high supply chain resilience. Among the demographic variables assessed, only hospital level was significantly associated with resilience, with tertiary hospitals demonstrating lower resilience compared

to secondary hospitals ($p = 0.002$). No significant associations were observed for sex, age group, qualification, or years of experience (**Table 2**).

Table 2. Sample characteristics and their association with supply chain resilience in selected health facilities.

Variable	Characteristic	Total N = 120 (100%)	Supply Chain Resilience		<i>p</i> -value
			Low N = 16 (13.3)	High 104 (86.7)	
Sex	Male	85 (70.8)	14 (87.5)	71 (68.3)	0.115
	Female	35 (29.2)	2 (12.5)	33 (31.7)	
Age (Years)	18 - 25	7 (5.9)	2 (12.5)	5 (4.9)	0.670
	26 - 35	52 (43.7)	6 (37.5)	46 (44.7)	
	36 - 45	46 (38.7)	6 (37.5)	40 (38.8)	
	≥46	14 (11.8)	2 (12.5)	12 (11.6)	
Years of Work Experience	<1 year	20 (17.0)	2 (13.3)	18 (17.5)	0.075
	1 - 3 years	25 (21.2)	3 (20.0)	22 (21.4)	
	4 - 6 years	38 (32.2)	3 (20.0)	35 (34.0)	
	7 - 10 years	6 (5.1)	3 (20.0)	3 (2.9)	
	>10 years	29 (24.6)	4 (26.7)	25 (24.3)	
Highest Academic Qualification	Diploma	35 (29.2)	5 (31.3)	30 (28.9)	0.291
	Degree	71 (59.2)	11 (68.8)	60 (57.7)	
	Postgraduate	14 (11.7)	0 (0.0)	14 (13.5)	
Hospital Level	Secondary	58 (48.7)	2 (12.5)	56 (54.4)	0.002
	Tertiary	61 (51.3)	14 (87.5)	47 (45.6)	
Surgical Volume (Monthly)	<50	23 (25.3)	5 (33.3)	18 (23.7)	0.167
	50 - 100	14 (15.4)	0 (0.0)	14 (18.4)	
	101 - 200	6 (6.6)	0 (0.0)	6 (7.9)	
	>200	48 (52.8)	10 (66.7)	38 (50.0)	
Demand Forecasting Capacity	Weak	15 (12.5)	8 (50.0)	7 (6.7)	<0.001
	Strong	105 (87.5)	8 (50.0)	97 (93.3)	
Commodity Security Policies	Weak	24 (20.0)	8 (50.0)	16 (15.4)	0.001
	Strong	96 (80.0)	8 (50.0)	88 (84.6)	
Inventory Management	Weak	13 (10.8)	7 (43.8)	6 (5.8)	<0.001
	Strong	107 (89.2)	9 (56.3)	98 (94.2)	

Continued

Lead Time Management	Weak	16 (13.3)	9 (56.3)	7 (6.7)	0.001
	Strong	104 (86.7)	7 (43.8)	97 (93.3)	
Stakeholder Perspective	Negative	12 (10.0)	4 (25.0)	8 (7.7)	0.032
	Positive	108 (90.0)	12 (75.0)	96 (92.3)	

Note: Bold *p*-values show a statistical significance.

3.1.2. Qualitative Study Participants

Fifteen key participants were included in the qualitative component of this study (Table 3). The participants included six ZAMMSA officials involved in procurement and distribution processes and nine facility managers responsible for operating theatre commodities in selected first- and tertiary-level hospitals in Lusaka District.

Table 3. Demographic characteristics of qualitative participants (n = 15).

Participants Category	Number
ZAMMSA Officials	6
Facility Managers	9
Total	15

3.2. Distribution of Supply Chain Resilience Responses

The stacked Likert scale analysis revealed generally positive perceptions of supply chain resilience across all nine assessed dimensions (Figure 1). The highest levels of agreement were observed for the ability to identify alternatives during disruptions and the visibility of upcoming supply issues, indicating strengths in adaptability and information sharing within the supply chain system. However, a substantial proportion of neutral responses (25% - 40%) across all items suggested variability in respondent experiences and possible uncertainty regarding supply chain performance. This uncertainty may be attributed to inconsistent training, limited communication on supply chain processes, or variations in policy implementation across facilities. Among the assessed dimensions, stockouts disrupting operations emerged as a relative weakness, with lower agreement and comparatively higher disagreement levels. Figure 1 presents the distribution of responses for each item assessing supply chain resilience.

3.3. Crude and Adjusted Odds Ratios of Supply Chain Resilience

3.3.1. Crude Odds Ratios

In the unadjusted logistic regression analysis, several factors were associated with surgical supply chain resilience (Table 4). Female respondents had higher odds of reporting resilience than males, although the association was not statistically sig-

nificant ($COR = 3.25$; 95% CI: 0.69 - 15.24; $p = 0.134$). Regarding work experience, respondents with 7 - 10 years of experience had significantly lower odds of reporting resilience compared to the reference group ($COR = 0.11$; 95% CI: 0.01 - 0.98; $p = 0.048$), while other experience categories showed no significant associations. Hospital level was significantly associated with resilience, with tertiary hospitals demonstrating lower odds of resilience than secondary hospitals ($COR = 0.12$; 95% CI: 0.03 - 0.56; $p = 0.007$).

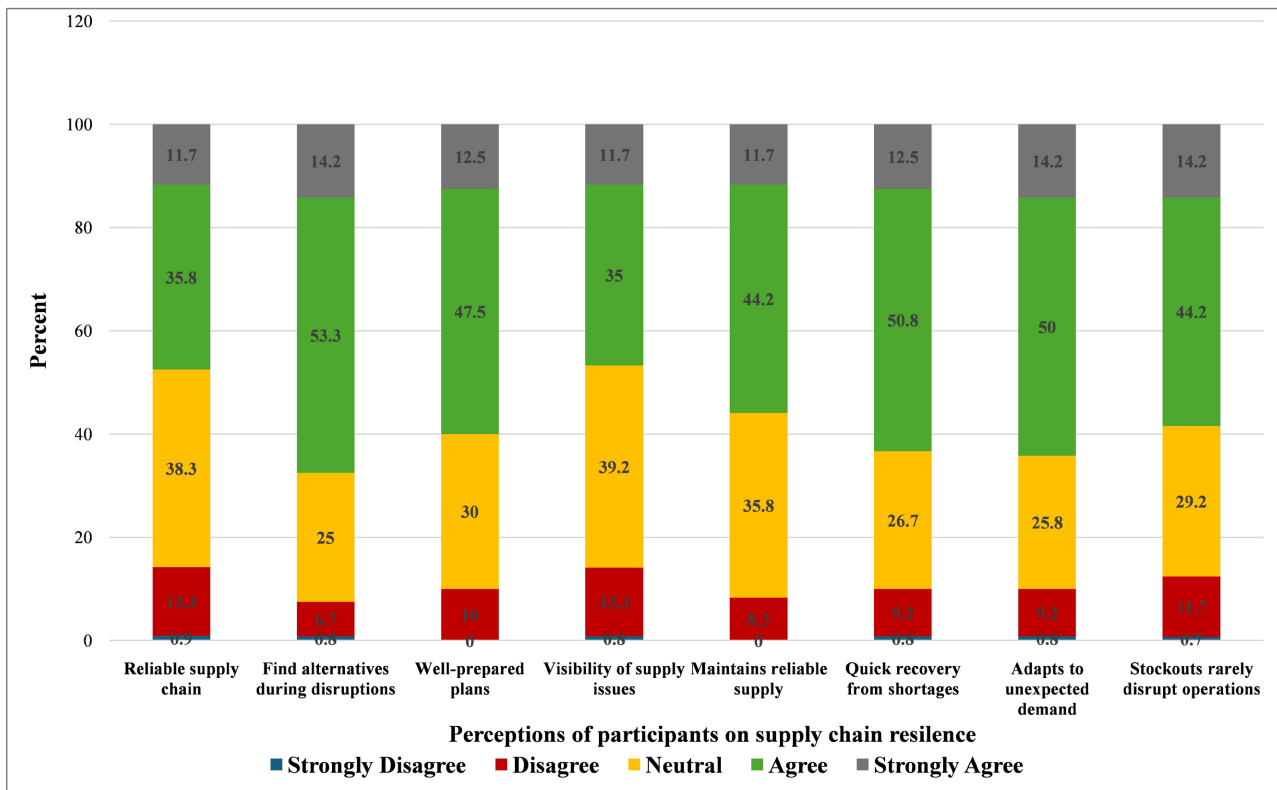


Figure 1. Distribution of responses for each item on supply chain resilience.

Operational supply chain factors showed strong positive associations with resilience. Facilities with strong demand forecasting capacity were significantly more likely to report resilience ($COR = 13.86$; 95% CI: 3.97 - 48.35; $p < 0.001$). Similarly, strong commodity security policies ($COR = 5.50$; 95% CI: 1.79 - 16.86; $p = 0.003$), effective inventory management ($COR = 12.70$; 95% CI: 3.49 - 46.24; $p < 0.001$), efficient lead time management ($COR = 17.82$; 95% CI: 5.07 - 62.55; $p < 0.001$), and positive stakeholder participation ($COR = 4.00$; 95% CI: 1.04 - 15.39; $p = 0.044$) were all significantly associated with higher odds of surgical supply chain resilience.

3.3.2. Adjusted Odds Ratios

After adjusting for potential confounders, several factors remained associated with supply chain resilience (Table 4). Female respondents showed higher adjusted odds of reporting resilience than male respondents, although this associ-

ation was not statistically significant (**Table 4**). Most demographic characteristics were not significantly associated with resilience in the adjusted model. However, respondents with 7 - 10 years of experience had significantly lower odds of reporting supply chain resilience compared to the reference category (AOR = 0.01; 95% CI: 0.0005 - 0.35; $p = 0.010$). Among the operational factors, facilities with strong demand forecasting capacity had significantly higher adjusted odds of supply chain resilience than those with weak forecasting capacity (AOR = 22.03; 95% CI: 1.52 - 319.19; $p = 0.023$). Similarly, strong lead-time management was significantly associated with higher odds of resilience (AOR = 12.82; 95% CI: 1.64 - 100.45; $p = 0.015$). However, commodity security policies and inventory management were not independently associated with resilience after adjustment. In the adjusted analysis, only demand forecasting capacity and lead-time management remained significantly associated with supply chain resilience, whereas inventory management and commodity security policies lost significance after adjustment (**Table 4**).

Table 4. Crude and adjusted logistic regression analysis of factors associated with supply chain resilience in selected health facilities.

Variable	Characteristic	COR (95% CI)	<i>p</i> -value	AOR (95% CI)	<i>p</i> -value
Gender	Male	ref			
	Female	3.25 (0.69 - 15.24)	0.134	4.21 (0.78 - 22.60)	0.094
Years of Experience	Reference category	ref			
	1 - 3 years	0.81 (0.12 - 5.46)	0.833	0.98 (0.02 - 53.34)	0.993
	4 - 6 years	1.30 (0.20 - 8.54)	0.787	0.22 (0.01 - 5.76)	0.367
	7 - 10 years	0.11 (0.01 - 0.98)	0.048	0.01 (0.0005 - 0.35)	0.010
	>10 years	0.69 (0.11 - 4.24)	0.693	0.13 (0.01 - 2.17)	0.153
Hospital Level	Secondary hospital	ref			
	Tertiary hospital	0.12 (0.03 - 0.56)	0.007	0.22 (0.02 - 1.97)	0.175
Demand Forecasting Capacity	Weak	ref			
	Strong	13.86 (3.97 - 48.35)	<0.001	22.03 (1.52 - 319.19)	0.023
Commodity Security Policy	Weak	ref			
	Strong	5.50 (1.79 - 16.86)	0.003	1.74 (0.22 - 13.72)	0.600
Inventory Management	Weak	ref			
	Strong	12.70 (3.49 - 46.24)	<0.001	0.60 (0.07 - 5.19)	0.643
Lead Time Management	Weak	ref			
	Strong	17.82 (5.07 - 62.55)	<0.001	12.82 (1.64 - 100.45)	0.015
Stakeholder Participation	Weak	ref			
	Positive	4.00 (1.04 - 15.39)	0.044	2.34 (0.34 - 16.13)	0.386

Note: Bold *p*-values show a statistical significance; COR = crude odds ratios; AOR = adjusted odds ratios; CI = 95% confidence interval.

3.4. Effect of Commodity Security Policy Implementation (Including LMIS Adoption) on Supply Chain Resilience

As was shown in **Table 4**, facilities that reported strong commodity security policies, including LMIS capacity, had significantly higher odds of reporting high supply chain resilience (COR = 5.50; 95% CI: 1.79 - 16.86; $p = 0.003$). However, this association was attenuated after adjusting for potential confounders (AOR = 1.74; 95% CI: 0.22 - 13.72; $p = 0.600$). Although LMIS adoption was assessed in the study, it was operationalised and analysed within the broader commodity security policy construct, which may explain its lack of independent statistical significance in the adjusted model.

Responses to the commodity security policy items indicated moderately positive perceptions of LMIS capacity across the health facilities (**Figure 2**). High levels of agreement were observed for the widespread use of logistics information systems, management of expiry dates, and use of stock data for decision-making. This suggested functional core competencies. However, the substantial neutral responses across most items highlight uncertainty regarding data accuracy, system reliability, and the extent of system procurement integration. Integration with procurement processes was a comparatively weak domain.

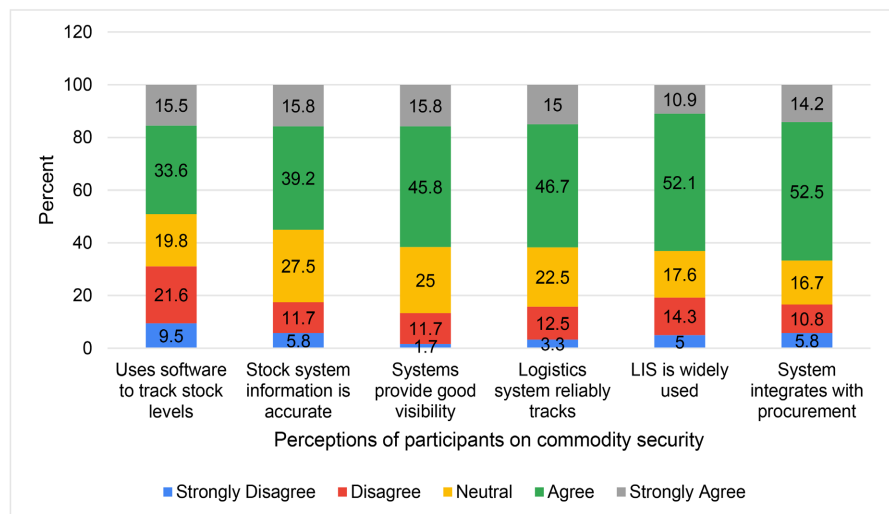


Figure 2. Distribution of responses for each of the items in commodity security policies.

Although the quantitative findings showed moderately positive perceptions of logistics system capacity, the high proportion of neutral responses regarding data accuracy and system reliability likely reflects the concerns revealed in the qualitative interviews. For example, one facility participant explained the following:

“If there’s an inaccurate or delayed data entry, this can affect our order quantities... this sometimes results in receiving less stock than what is required or the supply does not match our consumption.” (KII, First Level Hospital)

Similarly, a ZAMMSA official acknowledged that:

“Late reporting, poor quality reports... people just input zeros and just put the

quantity they need... the information that facilities are putting in the system is not accurate... it either means we over quantify or under quantify the products.” (KII, ZAMMSA Official 3).

These findings suggest that the neutral survey responses likely reflected uncertainty and limited confidence in data accuracy and system reliability rather than true satisfaction with the system (**Figure 2**). Although the electronic Logistics Management Information System (eLMIS) was widely utilized across facilities, persistent data quality challenges appeared to undermine trust in its capacity to effectively support procurement and forecasting decisions. Consequently, these limitations may negatively affect the resilience of the surgical supply chain. **Figure 2** presents the distribution of responses for each item assessing commodity security policies.

3.5. Influence of Demand Forecasting and Inventory Management on Supply Chain Resilience

As was shown in **Table 4**, facilities with strong demand forecasting capacity had significantly higher odds of reporting high supply chain resilience in both crude and adjusted analyses (COR = 13.86; 95% CI: 3.97 - 48.35; $p < 0.001$; AOR = 22.03; 95% CI: 1.52 - 319.19; $p = 0.023$).

Responses to the demand forecasting items indicated moderately positive perceptions of forecasting capacity across health facilities (**Figure 3**). High levels of agreement were observed for formal forecasting processes, perceived forecast accuracy, and the use of systematic forecasting methods. This suggested that foundational forecasting systems exist. However, the substantial neutral responses across all items highlight uncertainty regarding implementation consistency and responsiveness to sudden demand changes. Forecasting adaptability has emerged as a relatively weak domain.

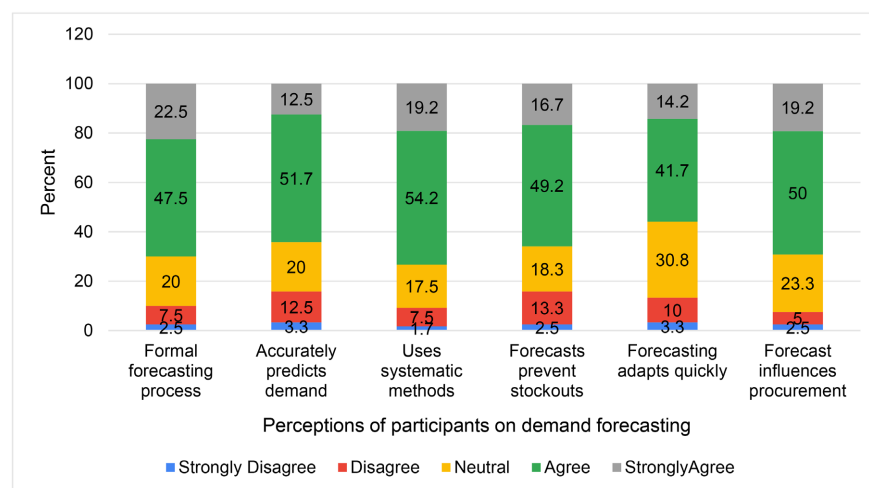


Figure 3. Distribution of responses for each item in demand forecasting.

Qualitative findings revealed that demand forecasting was largely consumption-based and relied on average monthly consumption (AMC), service statistics, and

demographic data. The findings demonstrate that health facilities primarily use previous consumption data to estimate their future needs.

“Yes, yes. Forecasting is sometimes performed using previous data. Therefore, we calculated the average monthly consumption and statistics, such as the number of people who visited the hospital. However, we do experience fluctuations in the medical workload and emergency cases, which makes it difficult to accurately predict demand at times.” (KII, First Level Hospital)

These narratives highlight that relying on past consumption data that uses simple moving averages for forecasting creates vulnerabilities, as sudden increases in patient load or emergencies can lead to an underestimation of demand. This reactive approach limits the supply chain’s ability to preempt shortages, making stock-outs more likely and reducing the hospital’s capacity to respond effectively to urgent cases.

This finding aligns with the quantitative results, which lead to the prediction that time predictability emerged as a weaker resilience domain, suggesting that reliance on historical consumption alone is insufficient in highly dynamic surgical environments.

3.5.1. Reliance on Historical Consumption Data

During the interviews, it was noted that health facilities primarily used previous consumption data to estimate future needs.

“We depend on past consumption data when performing quantification. What we consumed in the previous months guides the quantities that we request.” (Facility Manager, Tertiary Hospital)

ZAMMSA corroborated this approach but emphasised triangulation with demographic and service data from other sources.

“For operating theatre supplies, we consider three datasets. The first is logistics data, where we look at issues and consumption data. Issues refer to what we issue from ZAMMSA to the facilities through the pull system, and consumption refers to what the facilities actually consume. The other dataset we considered was demographic data. The third is service statistics in terms of the number of services the facilities use. Owing to stock-outs, for example, in logistics data, we may come up with assumptions to say that perhaps our issues are not accurate, or perhaps we were stocked out during this period. Depending on the outcome and the view of the assumptions, one dataset is usually selected. Thereafter, we formulate a demand and quantity.” (KII, ZAMMSA Official 1)

“Well, we place orders, usually, we use the eLMIS system. This is an electronic management information system where we place orders based on our consumption and needs. So, when we’re using eLMIS, it goes directly to ZAMMSA.” (KII, Chawama Hospital)

“We look at the trends from previous reports to estimate what will be needed”. (KII, ZAMMSA Official 2)

The findings demonstrate that reliance on historical consumption data provides a practical basis for demand planning, but is limited because of simple moving

average models. Simple moving average models do not address fluctuating demand. Although triangulation with demographic and service statistics can adjust for anomalies, this approach remains largely reactive and may not account for sudden workload spikes or emergencies. This dependence on past trends can perpetuate stockouts when consumption patterns change unexpectedly, highlighting the vulnerability of the surgical supply chain's ability to anticipate and respond to urgent surgical needs.

3.5.2. Workload Variability and Emergency Surgeries

The study findings demonstrated that unplanned emergencies and fluctuating surgical workloads undermined the forecasting assumptions.

"We do experience fluctuation in medical workload and emergency cases, which makes it difficult to accurately predict demand." (Facility Manager, First Level Hospital)

This indicates that demand forecasting based on historical consumption becomes unreliable when emergency surgery numbers increase unexpectedly. Because the system relies heavily on AMC, sudden spikes in surgical cases create demand that was not previously quantified, leading to a stock imbalance. Similarly, a ZAMMSA official noted the following:

"Then there's also an issue, because it's just an emergency, it also disrupts our schedule, that's why we don't even adhere, because too many emergencies are going to disrupt our schedule." (KII, ZAMMSA Official 3)

This statement shows that emergency orders not only increase demand but also interfere with the planned distribution cycles. When delivery schedules are disrupted to accommodate urgent requests, routine replenishment is also delayed. This creates a bottleneck in the surgical supply chain because warehouses must prioritise picking and dispatch processes, transport routes are altered, and other facilities may experience delayed deliveries.

Therefore, workload variability acts as a structural stressor that reduces supply chain resilience by weakening forecasting accuracy, disrupting distribution schedules, and increasing reliance on reactive rather than proactive supply chain management. This supports the quantitative findings that indicated reduced responsiveness within the supply chain as emergency-driven adjustments disrupt planned procurement and distribution schedules.

3.5.3. Stockouts, Overstocking, and Expirations

Qualitative findings demonstrated that poor forecasting and delayed deliveries sometimes resulted in overstocking of short-expiry items. Stakeholders who participated in this study noted that such mismatches between supply and actual consumption increased the risk of expiration, and delays in replenishment during periods of high demand also contributed to stockouts. This ultimately disrupted theatre operations and emergency preparedness.

"So, sometimes there are delays, yes. Therefore, when we are out of stock, we are forced to postpone elective surgeries that are planned. Then we get, we only pri-

oritise those emergencies.” (Facility Manager, Tertiary Hospital)

“We attempt to manage stock using FIFO principles, and sometimes we attempt to redistribute overstock to nearby facilities. However, you will find that delayed deliveries normally cause oversupply because of delayed supplies and short-expiry drugs or overstock. And this can lead to expiries if not redistributed in time.” (Facility Manager, Tertiary Hospital)

Facilities mitigated these risks through FIFO and redistribution, albeit with limited success. The study’s findings indicate that inaccurate forecasting driven by data quality issues and unpredictable demand weakens inventory management. This contributes to both stockouts and wastage, thereby reducing overall supply chain resilience. The simultaneous occurrence of stockouts and expiries highlights inefficiencies that weaken both absorptive and adaptive capacity, which are key components of supply chain resilience (SCR), as defined in the quantitative framework of this study.

3.5.4. Inventory Management Policies

As shown in **Table 4**, facilities with strong inventory management had significantly higher odds of reporting high supply chain resilience in the unadjusted analysis (COR = 12.70; 95% CI: 3.49 - 46.24; $p < 0.001$). However, after adjustment for potential confounders, the association was attenuated and no longer statistically significant (AOR = 0.60; 95% CI: 0.07 - 5.19; $p = 0.643$).

Responses to the inventory management items generally reflected positive perceptions of inventory practices across health facilities (**Figure 4**). High levels of agreement were observed regarding the existence of clearly documented policies, availability of surgical supplies, and maintenance of safety stock, suggesting a strong foundation for inventory control. Nevertheless, substantial neutral responses across several items indicated uncertainty about consistent policy adherence, the ability to respond effectively to sudden increases in demand, and the effectiveness of practices aimed at minimizing product expiry. Among the assessed domains, adaptability to sudden demand increases emerged as a relative weakness. **Figure 4** presents the distribution of responses for each item assessing inventory management practices.

Qualitative findings regarding stockouts, expirations, and redistribution practices further explained the statistical association observed in the crude analysis. This highlighted how weaknesses in forecasting and inventory coordination contributed to reduced supply chain resilience.

3.6. Effect of Lead Time Management on Supply Chain Resilience

As shown in **Table 4**, facilities with strong lead-time management had significantly higher odds of reporting high supply chain resilience in both the crude and adjusted analyses. In the unadjusted analysis, strong lead-time management was associated with markedly increased odds of resilience (COR = 17.82; 95% CI: 5.07 - 62.55; $p < 0.001$). This relationship remained statistically significant after adjustment for potential confounders (AOR = 12.82; 95% CI: 1.64 - 100.45; $p = 0.015$),

highlighting the important role of efficient lead-time performance in strengthening surgical supply chain resilience.

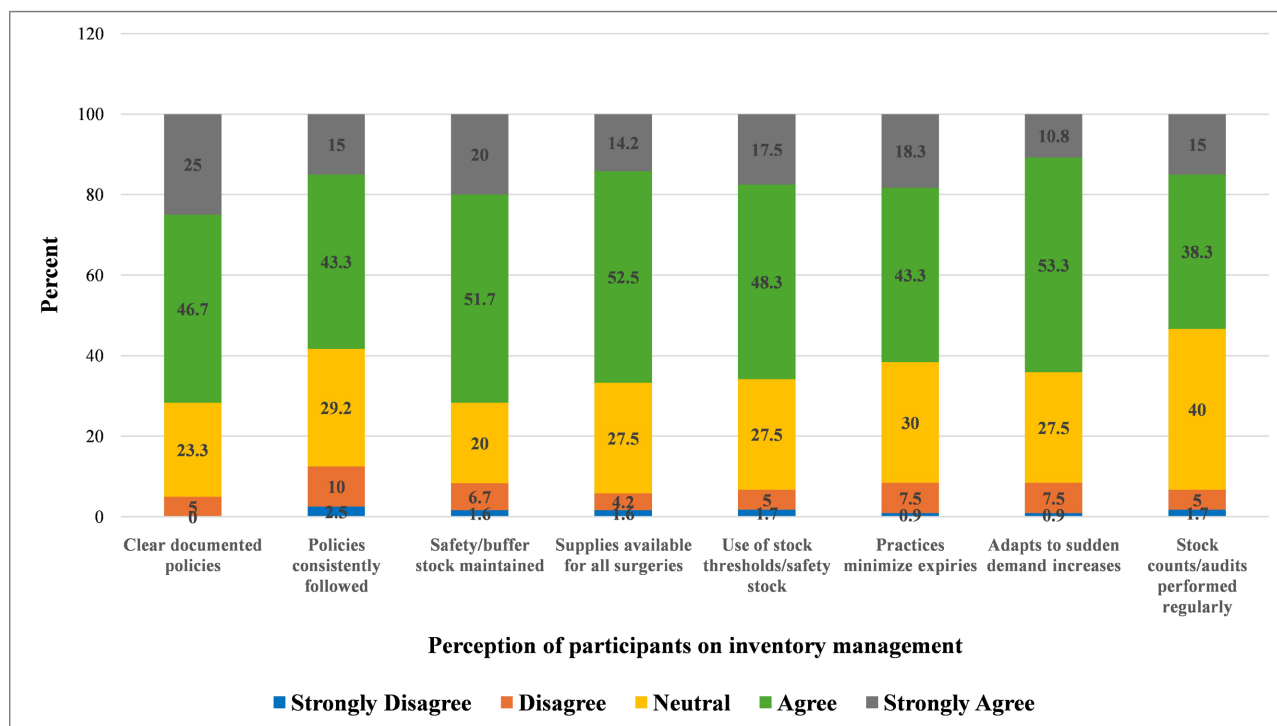


Figure 4. Distribution of responses for each item in inventory management policies.

Responses regarding lead-time management generally reflected positive perceptions across health facilities (**Figure 5**). High levels of agreement were observed for timely supply delivery and proactive institutional efforts to reduce lead times, indicating strong operational performance and commitment to improving supply chain efficiency. Nevertheless, substantial neutral responses across the assessed items suggested uncertainty regarding the predictability and consistency of lead times. Among the assessed domains, lead-time predictability emerged as a relative weakness. **Figure 5** presents the distribution of responses for each item assessing lead-time management.

The qualitative results showed that lead time management was a critical determinant of supply availability. Participants frequently cited missed delivery schedules, long procurement cycles and supplier delays as the major lead time disruptors.

It was evident from the participants' narratives that there were delayed deliveries and missed schedules, which significantly disrupted operational planning and impacted stock management within all hospital levels. Health facilities reported that ZAMMSA deliveries often fail to adhere to schedules.

"Delivery schedules are helpful, however, there are also times when deliveries are missed or delayed. This affects planning and stock management within the operating theatre." (KII, First Level Hospital)

"ZAMMSA, well, they are not on time, they do not stick to the schedule, other

suppliers, we find that to give them a contract, they fail to deliver.” (Facility Manager, Tertiary Hospital)

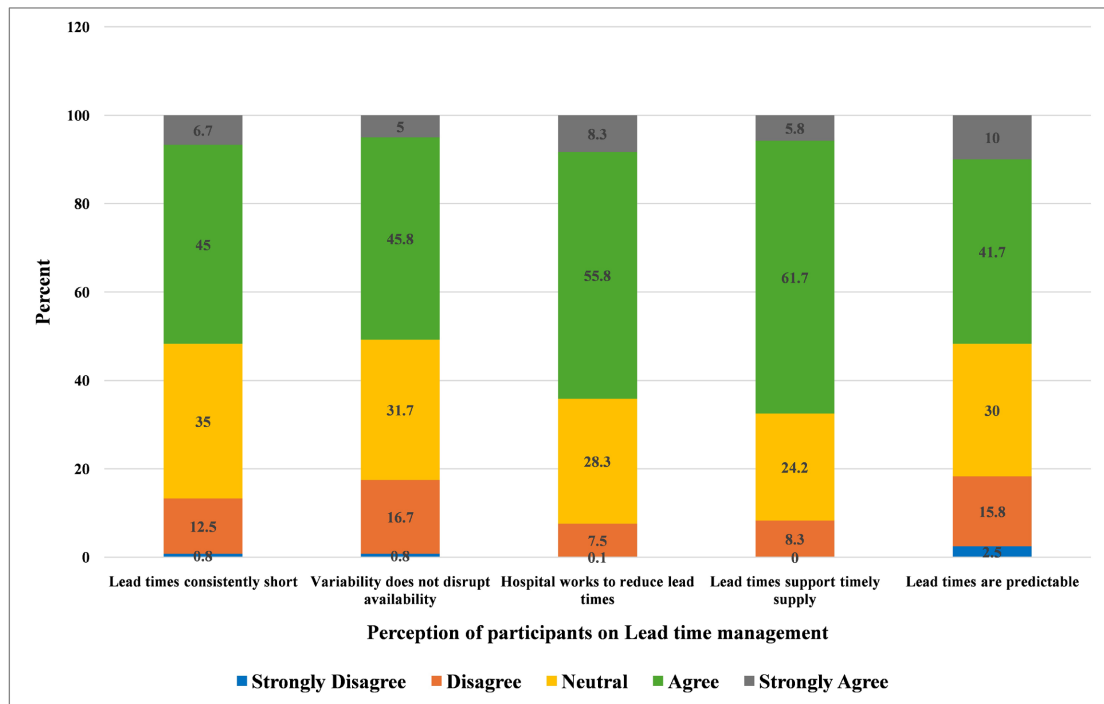


Figure 5. Distribution of responses for each of the items in lead time management.

ZAMMSA officials also highlighted the legal and administrative procurement requirements as contributors to the long lead times.

“So, I’ll tell you for emergencies, we either use direct bids or limited bids... But all these legal requirements are for attorneys, ZPPA is just for approval and everything... But all these legal requirements are for the attorney, ZPPA just for approval and everything..., so it means that we are behind schedule. Yeah, because those challenges are highlighted... we didn’t reach cycle six. Maybe we are even around somewhere three or four”. (KII, ZAMMSA Official 1)

“Okay. So, for procurement, approval processes, you find that, for example, in shared procurement, it has to be approved by the ZPPA, and also it has to go to the Minister of Justice for approval by the Attorney General even before contracts are issued.” (KII, ZAMMSA Official 4)

These procurement and regulatory constraints provided a qualitative explanation for the weaker performance observed in the lead time predictability domain in the quantitative findings, where delivery consistency and timeliness were identified as resilience gaps.

Although emergency procurement mechanisms exist, they were bound by bureaucratic procurement processes.

Coping Mechanisms during Delays

The qualitative findings revealed that health facilities adopted short-term coping

strategies, such as rationing and borrowing from nearby hospitals. This was a mechanism of averting the postponement of elective surgeries and referring patients from primary to tertiary level hospitals.

“We try to prioritise. And where necessary, where we fail to prioritise the cases, we normally postpone the theatre cases, or we try to refer the cases to the nearby facilities, where we can conduct the same theatre procedure.” (Facility, First Level Hospital)

“Usually, emergency orders are critical for us, especially during unplanned cases. Therefore, when these orders that we make in emergencies are delayed, we must resort to asking other facilities. For example, maybe we can call UTH, can you borrow us this? Then, we borrow it, use it, and then retain it once we receive it. Similarly, when we do not have enough stock, that is when we start rationing whatever we have.” (Facility Manager, Tertiary Hospital)

“So, sometimes there are delays, yes. So, when we’re out of stock, we are forced to postpone those elective surgeries that are planned for. Then we get, we only prioritised those emergencies.” (KII, Tertiary Hospital)

The findings reveal that inefficient lead time management reduced the system’s ability to respond to emergencies and sudden demand surges, thereby directly undermining surgical supply chain resilience. Although these coping mechanisms demonstrate short-term adaptive behaviour, they reflect a reactive system rather than a structurally resilient one. This is consistent with the moderate overall resilience levels observed in the quantitative assessment.

The qualitative findings regarding procurement delays, administrative approval processes, and emergency coping mechanisms provide a contextual explanation for the strong statistical association between lead-time management and supply chain resilience. These findings highlight that lead-time predictability was a critical determinant of operating theatre supply stability.

3.7. Stakeholder Perspectives on Commodity Security Policies and Supply Chain Resilience

As shown in **Table 4**, facilities reporting positive stakeholder participation had significantly higher odds of high supply chain resilience in the unadjusted analysis (COR = 4.00; 95% CI: 1.04 - 15.39; $p = 0.044$). However, after adjustment for potential confounders, the association was attenuated and no longer statistically significant (AOR = 2.34; 95% CI: 0.34 - 16.13; $p = 0.386$).

Responses relating to stakeholder perspectives demonstrated moderately positive perceptions of commodity security policies and their implementation across health facilities (**Figure 6**). High levels of agreement were observed regarding policy awareness and perceived improvements in supply availability, suggesting reasonable stakeholder acceptance and engagement at the conceptual level. Nevertheless, substantial neutral responses across several items indicated uncertainty surrounding the adequacy of training and staff involvement in policy implementation. In addition, most respondents agreed that resource constraints negatively

affected effective policy implementation, highlighting broader systemic and capacity-related challenges within the health sector. **Figure 6** presents the distribution of responses for each item assessing stakeholder perspectives.

The qualitative results revealed that during the interviews, the participants acknowledged that commodity security policies aim to ensure availability but emphasised a gap between policy intent and operational reality. This was largely driven by funding and coordination challenges.

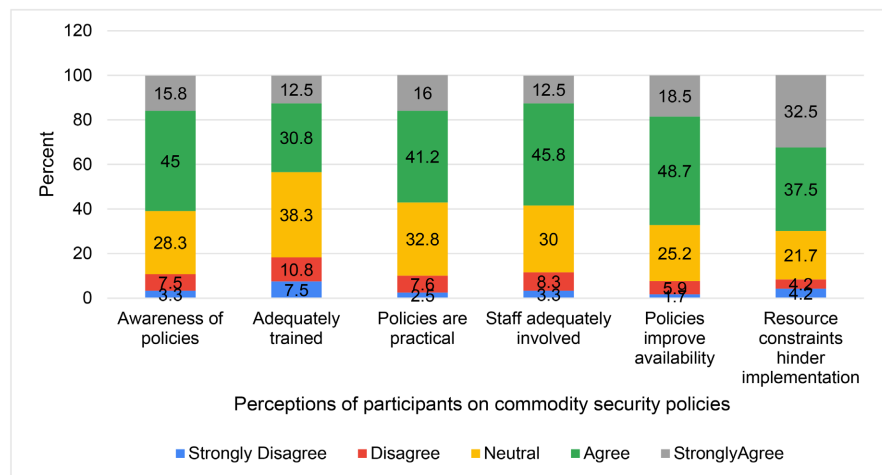


Figure 6. Distribution of responses for each of the items in stakeholder perspectives.

3.7.1. Policy Practice Gap

The findings reveal a gap between policies and practices. The health facility and ZAMMSA staff who participated in this study noted that policies were sound in principle but difficult to implement consistently.

“The current policy, I would say, is not. We looked at the schedules. Sometimes you may try to order what you have been given, and then at the end of the day, what you have been supplied and the current policy, which may not go together. At the end of the day, the current policy will make it look like it’s not effective to some extent.” (KII, First Level Hospital)

“Quantification happens, but what is procured depends on available funds.” (ZAMMSA Official 3)

“The initiation of normal policies, we can have... but then what also comes to the test is what is procured. The supply plan is based on the allocation of available funds. So yes, they will quantify for a lot, but then they will come and only buy what they plan for, looking at the availability of funds.” (ZAMMSA Official 3)

These findings indicated that while commodity security policies provide a structured framework for quantification and supply planning, their implementation is constrained by funding limitations and inconsistent supply fulfilment. The gap between the planned and procured quantities undermines the effectiveness of the policy and weakens supply chain resilience. This gap between quantification and actual procurement aligns with the quantitative findings, which demonstrated only moderate effectiveness of commodity security frameworks in strengthening sup-

ply chain resilience. This is because facilities could not reliably depend on scheduled deliveries to meet surgical demands.

3.7.2. Persistent Funding Gaps and Staffing Shortages Hindered Resilience

Qualitative findings revealed that inadequate budget allocations serve as a primary barrier to maintaining a consistent supply of operating theatre commodities. Although facilities may accurately quantify their needs, final procurement is often restricted by limited funds. This led to a significant gap between the required stock and the actual delivery of supplies. Consequently, this financial shortfall forced the removal of essential items from procurement plans, resulting in stockouts that impaired the hospital's ability to respond to emergency surgical cases.

“Funding is never adequate. You find that we can plan for maybe five million of those commodities, but the approved budget is two million, so there is also that gap in terms of funding allocation.” (KII, ZAMMSA Official 2)

“So yes, they will quantify for a lot, but then they will come and only buy what they will plan for, looking at the availability of funds. ...But if others may not be available, yes, they may not consistently be available, because maybe the quantities that were procured were less, or the funds were not enough, so others were removed.” (KII, ZAMMSA Official 3)

“Yes, we do have procurement challenges. Funding is sometimes limited, which reduces the quantity of items that we must procure. And this in turn affects our ability to maintain adequate stocks and respond to most emergencies.” (Facility Manager, Tertiary Hospital)

These narratives highlight that budgetary limitations not only constrain the volume of commodities procured but also disrupt the reliability of supply chains within the operating theatres. This creates a critical bottleneck, even when facilities could accurately forecast demand. Financial restrictions forced prioritisation or removal of essential items. Financially, it directly undermined the hospital's capacity to handle emergency surgical cases. The findings illustrate a systemic issue in which partial procurement due to funding gaps translated into stockouts, delaying urgent interventions and increasing vulnerability to patients. In essence, persistent funding shortages weaken resilience by making the surgical supply chain reactive rather than proactive, forcing hospital managers to constantly adjust to deficits rather than maintain their readiness. This financial constraint may further explain why tertiary hospitals, which managed more complex and higher surgical demands, demonstrated comparatively lower resilience scores in the quantitative analysis than secondary hospitals.

3.7.3. Coordination and Communication

Qualitative findings revealed that weak communication between ZAMMSA and facilities affected planning and expectation management. Participants explained that this breakdown in coordination created a reactive environment in which facility staff felt that they were working in the dark because of deficiencies in

accessing real-time visibility of the status of their orders and sudden changes in delivery schedules. Qualitative data highlighted that communication was often inefficient and unidirectional. Facilities were frequently unaware of stock shortages at the central warehouse until they physically sent staff to follow up on-site.

“If they can take regular feedback on the submitted orders, there should be continuous communication and no breakdown in communication between ZAMMSA and the hospital. There should not be a breakdown in communication between ZAMMSA and the hospital.” (KII, First Level Hospital)

“Yes, we do have challenges. Sometimes, we are unaware of the changes in the delivery schedules or the quantities that are available at the warehouse. So, it is sometimes like we are working in the dark.” (Facility Manager, First Level Hospital)

“The communication is not very efficient. We only get to know when we sent our staff to follow up on the commodities. That’s when we are told that, no, this is not available, or it’s out of stock.” (Facility Manager, Tertiary Hospital)

The participants’ narratives highlight that while commodity security policies provide a strategic framework for availability, insufficient funding, weak coordination, and implementation gaps limit their influence on the resilience of surgical supply chains. These coordination gaps reinforce the quantitative evidence that responsiveness and system visibility remain critical weaknesses in the operating theatre supply chain.

The qualitative findings highlight that although commodity security policies are well-articulated, funding constraints, staffing shortages, and coordination gaps limit their effective implementation. These structural challenges weaken the policy’s influence on supply chain resilience, despite the generally positive stakeholder awareness.

3.8. Joint Display of Quantitative and Qualitative Findings

The joint display highlights the fact that while some factors, such as lead time management, showed convergence between quantitative and qualitative findings, others, such as forecasting and LMIS utilisation, demonstrated partial divergence (**Table 5**). This observation suggested gaps between statistical significance and operational realities.

Table 5. Joint display of quantitative and qualitative findings.

Variable	Quantitative Finding	Qualitative Theme	Interpretation
LMIS Adoption	High access (86.4%) but not linked to decision-making	Delayed data entry, limited skills	Partial convergence —system exists but is not fully utilised
Forecasting Accuracy	Strong predictor (AOR $\approx$ 22)	Over-reliance on historical data; poor adaptability	Partial divergence —statistically strong but operationally weak

Continued

Inventory Management	Not statistically significant	Issues with stock monitoring and redistribution	Divergence —practice challenges but no strong statistical effect
Lead Time Management	Strong predictor (AOR = 12.82)	Procurement delays, supplier inefficiencies	Convergence —both data sources agree
Stakeholder Factors	Moderate influence	Staff shortages, limited capacity	Convergence —both show capacity challenges

4. Discussion

This study assessed the determinants of supply chain resilience for operating theatre supplies in Lusaka District, Zambia. The study found that demand forecasting capacity and lead-time management were the strongest factors independently associated with surgical supply chain resilience, whereas commodity security policies and inventory management were not statistically significant after adjustment. These findings suggest that operational efficiency may play a more direct role in maintaining resilience than policy awareness alone.

These findings are consistent with previous studies that highlighted demand forecasting and timely replenishment as critical determinants of resilient health supply chains. For example, Olaniran et al. reported that accurate forecasting based on historical consumption and real-time demand data significantly improved commodity availability and reduced stockouts (Olaniran et al., 2022). Similarly, Mekonen et al. emphasised that resilient health commodity supply chains in low- and middle-income countries depend on strong forecasting systems and effective lead-time management (Mekonen et al., 2024). In this study, this suggests that the resilience of operating theatre supplies is more strongly linked to operational efficiency and anticipatory planning than to policy frameworks.

4.1. Effect of LMIS Adoption on the Supply Chain Resilience of Operating Theatre Supplies

The findings show that although LMIS infrastructure is available across most study facilities, its contribution to supply chain resilience remains limited by persistent challenges in data quality, delayed reporting, and underutilisation for operational decision-making. While quantitative findings showed moderately positive perceptions of eLMIS functionality, this did not translate into an independent statistical association with resilience after adjustment. This may suggest that system availability alone is insufficient to improve supply chain outcomes. Similar findings have been reported in healthcare logistics literature. These findings conclude that digital systems improve resilience only when supported by data quality controls and routine use in decision-making (Tiye & Gudeta, 2018).

However, qualitative findings provide a critical explanation for this weak association. Participants consistently reported delayed data entry, inaccurate report-

ing, and limited confidence in system outputs. Such weaknesses undermine the ability of eLMIS to support accurate quantification, procurement planning and timely replenishment. Therefore, although the system exists structurally, its functional effectiveness appears constrained by implementation gaps.

4.2. Influence of Demand Forecasting Accuracy and Inventory Management Practices on the Supply Chain Resilience of Operating Theatre Supplies

Demand forecasting emerged as the strongest independent predictor of supply chain resilience in this study. Facilities that reported strong forecasting capacity had significantly higher odds of reporting high resilience. This finding strongly suggests that anticipatory planning plays a more central role in resilience than downstream stock control measures. This is supported by healthcare supply chain literature, which emphasises predictive demand planning as a key resilience capability, particularly in environments with fluctuating clinical demand (Subramanian, 2021).

However, the wide confidence interval observed in the adjusted model indicates substantial imprecision and should be interpreted cautiously. A plausible explanation is the relatively small number of low-resilience events, which may have reduced estimate precision and contributed to model instability.

Qualitative findings deepen this interpretation. Although forecasting systems were present, participants reported heavy reliance on historical consumption data that relies on average monthly consumption. Average monthly consumption models are reactive and may fail to capture sudden increases in surgical demand, particularly emergency workload spikes, which is a recognised limitation of simple moving average approaches in volatile demand environments (Tetteh, 2021a). Similar concerns have been raised in health supply chain studies, where reliance on past consumption alone increases the risk of stockouts during demand surges (Tetteh, 2021b).

Although inventory management showed a strong crude association with resilience, it lost statistical significance after adjustment for multiple comparisons. One plausible explanation is confounding and overlap with stronger upstream operational variables, particularly forecasting and lead-time management. This suggests that inventory performance at the facility level may partly reflect the quality of upstream planning and replenishment systems rather than functioning as an independent predictor of resilience. This finding is supported by existing health supply chain literature, which suggests that inventory performance is often downstream of stronger upstream operational functions, such as forecasting accuracy and procurement responsiveness (Subramanian, 2021; Yadav, 2015). Studies have shown that effective inventory control depends heavily on timely replenishment cycles and accurate demand estimation, and when these upstream processes are accounted for, the independent contribution of inventory management may appear attenuated (Subramanian, 2021; Yadav, 2015). In the present study, this may explain why the strong crude association observed for inventory management was

no longer statistically significant after adjustment.

4.3. Effect of Lead Time Management on the Availability and Resilience of Operating Theatre Supplies

Lead-time management remained independently associated with resilience after adjustment, highlighting its critical role in maintaining continuity of theatre supplies. This finding is particularly important because it identifies procurement responsiveness as a major structural determinant of supply chain resilience. Existing literature consistently shows that lead-time predictability is central to resilient healthcare supply systems because delays directly translate into stock interruptions and service disruption (Yadav, 2015).

However, qualitative findings revealed that lead-time performance remained constrained by procurement delays, missed delivery schedules and lengthy regulatory approval processes. Although emergency procurement pathways exist, these mechanisms remain bound by legal and administrative procedures that may delay urgent replenishment.

Nevertheless, this may explain why lead-time management remained significant despite other variables losing significance after adjustment. The ability to replenish supplies in a timely manner appears to directly influence the continuity of surgical services.

4.4. Stakeholder Perspectives on the Implementation of Commodity Security Policies and Their Influence on Supply Chain Resilience

The findings on stakeholder perspectives highlight that the effectiveness of commodity security policies in strengthening supply chain resilience depends largely on how well these policies are operationalised across different actors in the supply chain. While respondents generally demonstrated positive awareness of the policies, qualitative findings revealed a clear policy-practice gap, with facilities reporting inconsistent implementation, weak communication, and delayed feedback from ZAMMSA. This suggests that awareness alone is insufficient to strengthen resilience unless it is accompanied by strong coordination, accountability, and operational follow-through. These findings are consistent with previous studies, which have shown that effective collaboration between central medical stores, procurement agencies and facility-level staff is essential for resilient health supply chains, particularly in resource-constrained settings (Tetteh, 2021a; Yadav, 2015).

A particularly important finding is the role of funding constraints as a major upstream barrier to surgical supply chain resilience. Participants consistently reported that although facilities were able to quantify their needs, actual procurement was often restricted by limited budget allocations. This resulted in partial procurement, stockouts, and reduced preparedness for emergencies. This finding aligns with the broader health supply chain literature, which identifies inadequate and unpredictable financing as a critical determinant of commodity availability

and supply continuity in low- and middle-income countries (Tetteh, 2021a; Yadav, 2015). In this study, the gap between the quantified need and actual procurement strongly suggests that financial limitations weaken resilience when forecasting systems are functional.

Weak communication and coordination between facilities and the ZAMMSA emerged as key structural challenges. Participants described limited visibility of order status, poor communication on delivery schedule changes and delayed feedback on stock availability. Such coordination gaps may reduce responsiveness and system visibility, both of which are recognised as essential resilience capabilities within supply chain systems. These findings suggest that strengthening stakeholder engagement mechanisms, communication pathways, and financing arrangements may be as important as forecasting and inventory systems in improving the resilience of operating theatre supply chains.

4.5. Mixed-Method Tension: Perception versus Operational Reality

While 86.7% of staff perceived high surgical supply chain resilience, qualitative interviews revealed persistent stockouts, funding gaps, and missed delivery schedules. This apparent contradiction suggests a mixed-method tension, where the quantitative findings indicate a high perceived level of resilience, yet the qualitative narratives expose substantial operational weaknesses.

This discrepancy was probably due to a high degree of informal coping and adaptive workarounds within facilities. In the face of operational failures, facilities frequently borrowed surgical supplies from neighbouring hospitals, rationed available stock, and postponed elective procedures. Although these practices enabled continuity of emergency surgical services, they may have masked deeper system failures within the central medical stores and procurement system.

A consistent secondary supply pathway through inter-facility borrowing may have made staff more comfortable in their perception of resilience because their immediate focus was commodity availability at the point of care rather than the performance of the upstream supply chain. Consequently, resilience may have been perceived based on the ability to continue service delivery despite disruptions, rather than on the absence of supply chain disruptions.

This can be attributed to what mixed-methods literature describes as meta-inference tension, where findings from the quantitative and qualitative strands appear divergent but, when integrated, provide a more nuanced understanding of the phenomenon. Mixed-methods theory suggests that such divergence does not represent inconsistency, but rather reflects the complexity of the underlying system and the different dimensions captured by each method. Quantitative data often captures perceived outcomes, whereas qualitative findings illuminate the mechanisms and lived operational realities behind those outcomes (Yadav, 2015).

As noted in the broader supply chain resilience literature, resilience is not solely defined by uninterrupted performance, but also by the system's adaptive capacity to absorb, respond to, and recover from disruptions (Yadav, 2015). In this study,

the high perception of resilience is likely driven by strong adaptive resilience at the facility level, where staff-created workarounds compensated for weaknesses in forecasting, procurement, and financing systems.

However, the findings of this study should be interpreted cautiously. While borrowing and redistribution of surgical supplies demonstrate short-term absorptive and adaptive capacity, they may also indicate that the system is functioning in a reactive rather than structurally resilient manner. In resilience theory, true structural resilience requires robust forecasting systems, predictable lead times, adequate financing, and strong coordination mechanisms (Ojo, 2024; Yadav, 2015).

Therefore, the apparent high resilience reported by staff may not necessarily reflect optimal system performance but rather the ability of frontline personnel to sustain service delivery through informal coping strategies. This distinction is critical because it highlights that perceived resilience may coexist with systemic fragility, thereby reinforcing the importance of integrating qualitative insights within mixed-methods studies.

4.6. Policy and Practice Implications and Recommendations

The findings of this study have important implications for strengthening the resilience of operating theatre supply chains in Zambia. Demand forecasting capacity and lead-time management emerged as the strongest determinants of resilience, while qualitative findings highlighted challenges related to data quality, procurement delays, emergency demand fluctuations, coordination gaps, and financing constraints. These findings suggest that strengthening operational supply chain functions, improving data-driven decision-making, enhancing emergency preparedness, and streamlining procurement processes are essential for ensuring uninterrupted availability of operating theatre commodities and improving surgical service delivery. The policy and practice implications arising from these findings are summarised in Table 6.

Table 6. Policy and practice implications and recommendations for strengthening supply chain resilience of operating theatre supplies in Zambia.

Domain	Key Issue/Evidence	Policy and Practice Implications	Recommendations
Demand Forecasting Capacity	Demand forecasting was the strongest predictor of supply chain resilience (AOR = 22.03; $p = 0.023$). Facilities largely relied on historical consumption data and average monthly consumption.	Forecasting systems based solely on historical consumption are insufficient for highly dynamic surgical environments.	Integrate surgical workload data, emergency surgery trends, seasonal variations, and service statistics into forecasting models. Adopt advanced forecasting approaches integrated into eLMIS.
Lead-Time Management	Effective lead-time management was independently associated with resilience (AOR = 12.82; $p = 0.015$). Delayed deliveries and procurement bottlenecks disrupted theatre services.	Reducing procurement and distribution delays is critical for ensuring uninterrupted surgical care.	Establish procurement turnaround benchmarks, strengthen supplier performance monitoring, implement real-time order tracking, and automate alerts for delayed deliveries.

Continued

LMIS and Data Quality	Qualitative findings revealed inaccurate reporting, delayed data entry, and low confidence in eLMIS-generated data.	Poor-quality data undermine forecasting accuracy, quantification, and procurement decisions.	Strengthen data quality audits, routine data validation, staff training, and accountability mechanisms for eLMIS reporting.
Emergency Preparedness and Demand Surges	Emergency surgeries and fluctuating workloads disrupted forecasting assumptions and supply plans.	Surgical supply chains require mechanisms to accommodate unpredictable demand.	Establish emergency buffer stocks, contingency procurement plans, and rapid response supply mechanisms for high-priority theatre commodities.
Inventory Management	Inventory management showed a strong crude association but was not independently significant after adjustment. Stockouts and expiries were reported.	Inventory systems remain important but should be linked to forecasting and lead-time performance.	Strengthen stock monitoring, safety stock policies, redistribution systems, and First-Expiry-First-Out (FEFO) practices.
Procurement and Regulatory Processes	Long procurement approval processes and administrative requirements contributed to delayed deliveries.	Bureaucratic procurement procedures reduce responsiveness during emergencies.	Streamline procurement approvals, strengthen framework contracts, and establish expedited procurement pathways for critical surgical commodities.
Coordination Across Supply Chain Actors	Weak coordination between facilities and ZAMMSA affected order fulfilment and supply continuity.	Strong coordination is essential for resilient and responsive supply systems.	Establish regular forecasting and review meetings between facilities, provincial health offices, and ZAMMSA.
Commodity Security Policy Implementation	Commodity security policies were not independently associated with resilience after adjustment, partly due to implementation gaps.	Policy effectiveness depends on operational execution rather than policy existence alone.	Strengthen monitoring, supervision, financing, and accountability mechanisms for policy implementation.
Human Resource Capacity	Staff reported challenges in forecasting, data analysis, and supply chain decision-making.	Supply chain resilience requires skilled personnel capable of using data for decision-making.	Provide continuous professional development in forecasting, quantification, inventory management, and supply chain analytics.
Health System Resilience	Stockouts, delayed deliveries, and procurement inefficiencies resulted in postponement of elective surgeries and increased referrals.	Reliable theatre supply chains are essential for patient safety and continuity of surgical services.	Integrate supply chain resilience indicators into national surgical care and health system performance frameworks.
Financing for Surgical Commodities	Quantification often exceeded available budgets, leading to procurement gaps and reduced supply fulfilment.	Sustainable financing is necessary to ensure implementation of quantification plans.	Increase budget allocation for surgical commodities and align procurement plans with forecasted needs and service demand.
Research and Innovation	Limited evidence exists on resilience of specialised surgical supply chains in Zambia.	Evidence-based interventions are needed to improve supply chain performance.	Conduct multi-site studies, evaluate forecasting innovations, and explore predictive analytics and artificial intelligence tools for supply chain management.

4.7. Limitations and Strengths of the Study

This study had several limitations. First, the relatively small number of low-resilience cases may have contributed to the wide confidence intervals and reduced precision of the adjusted estimates. Second, several measures were based on self-reported perceptions and may therefore be subject to response bias. Third, the cross-sectional design limits causal inference, and the associations should be interpreted cautiously. However, the mixed-methods design strengthened the interpretation through the triangulation of quantitative and qualitative findings. This study recognised the potential pitfalls that may affect the quality and reliability of the findings. These were reliance on perception-based responses and possible respondent or interviewer bias.

5. Conclusion

This study demonstrates that supply chain resilience for operating theatre supplies in Lusaka District is more strongly associated with operational performance factors than with the presence of commodity security policies. In particular, demand forecasting capacity and lead-time management emerged as key drivers of resilience, highlighting the importance of efficient planning and timely procurement. Although inventory management practices and policy frameworks contribute to the overall system performance, they were not independently associated with resilience after adjustment, suggesting that their effectiveness depends on integration with broader supply chain functions. Qualitative findings further revealed gaps in LMIS utilisation, data-driven decision-making and coordination across stakeholders. Strengthening these critical care areas, such as surgical commodities supply alongside targeted capacity building and improved system integration, is essential to enhance supply chain resilience and ensure the consistent availability of operating theatre supplies for safe surgical care.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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