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Predicting medication shortages: An analysis of supply-side constraints and procurement vulnerability

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ABSTRACT

Medication shortages remain a major challenge for hospital systems, negatively affecting patient care and operational efficiency. Previous studies have identified economic and manufacturing factors as important causes of medication shortages; however, limited empirical research has explored how these supply-side pressures lead to shortages at the hospital level. To address this gap, this study develops and tests a simple structural model that explains the relationship between supply-side constraints, procurement vulnerability, and medication shortages. Data were collected from hospital procurement and pharmacy professionals and analyzed using partial least squares structural equation modeling (PLS-SEM). The findings show that supply-side constraints significantly increase procurement vulnerability, which subsequently intensifies medication shortages. The results also reveal that supply-side constraints have a direct effect on medication shortages, indicating a partial mediation effect. This study contributes to the healthcare supply chain literature by explaining how economic and manufacturing pressures in the supply chain lead to medication shortages in hospitals. From a managerial perspective, the findings emphasize the importance of improving procurement resilience to reduce the risk of medication shortages.

1. Introduction

Medication shortages have increasingly become a structural challenge for healthcare systems worldwide, affecting hospitals across diverse institutional and economic contexts and undermining the reliability of essential treatment delivery (Fox et al., 2014). Empirical evidence consistently shows that medication shortages disrupt clinical workflows, increase the likelihood of medication errors, and impose significant financial and administrative burdens on healthcare organizations (Ventola, 2011). From a management and operations perspective, medication shortages are now widely recognized as manifestations of systemic supply chain fragility rather than isolated or temporary production failures (Yadav, 2015; Ivanov, 2020).

The extant literature attributes medication shortages primarily to supply-side constraints embedded within pharmaceutical manufacturing and distribution systems (Acosta et al., 2019; Fox et al., 2014). Manufacturing disruptions caused by quality compliance failures, production line shutdowns, and capacity inflexibilities have been identified as recurrent triggers of shortages, particularly for generic injectable medicines (Ventola, 2011). Economic factors further exacerbate these vulnerabilities, as low profit margins, price regulation, and limited market incentives reduce manufacturers' willingness to invest in redundancy and surge capacity (Dave et al., 2018; Acosta et al., 2019). As a result, pharmaceutical supply chains often operate with minimal buffers, rendering them highly susceptible to upstream shocks (Ivanov, 2020; Yadav, 2015).

Market structure has also been shown to play a critical role in amplifying supply-side constraints, particularly through increasing concentration among manufacturers of essential generic medicines (Dave et al., 2018). When a small number of firms dominate production, disruptions at a single facility can rapidly propagate across national and regional healthcare systems (Fox et al., 2014). Operations management research suggests that such concentrated supply networks exhibit lower resilience and slower recovery following disruptions, especially in regulated industries such as

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pharmaceuticals (Choi et al., 2018; Ivanov, 2020). These dynamics highlight the need to examine medication shortages through a holistic supply chain lens rather than focusing solely on firm-level failures (Yadav, 2015).

Although upstream determinants of medication shortages are well documented, relatively limited empirical research has examined how these supply-side constraints translate into shortage outcomes at the hospital level. Hospitals function as downstream nodes within pharmaceutical supply chains and must manage uncertainty arising from supplier unreliability, demand variability, and constrained sourcing options (Yadav, 2015). Procurement systems within hospitals are therefore particularly exposed to upstream disruptions, especially when purchasing strategies rely on single sourcing, long lead times, or limited inventory buffers.

The concept of procurement vulnerability provides a useful organizational-level lens for understanding how supply-side pressures materialize as medication shortages within hospitals (Ivanov, 2020; Choi et al., 2018). Procurement vulnerability reflects the degree to which hospitals are exposed to supplier dependency, limited substitution possibilities, and weak forecasting capabilities, all of which heighten sensitivity to upstream disruptions (Yadav, 2015). Prior healthcare operations research suggests that hospitals with higher procurement vulnerability experience more frequent and severe disruptions when external supply conditions deteriorate. Despite its relevance, procurement vulnerability has received comparatively little empirical attention as a mediating mechanism linking supply-side constraints to medication shortage outcomes (Ivanov, 2020; Yadav, 2015).

Recent calls within the healthcare supply chain and operations management literature emphasize the need for parsimonious empirical models that integrate upstream supply conditions with organizational response capabilities (Ivanov, 2020). Such models are particularly important in regulated healthcare contexts, where managerial discretion is constrained, and structural vulnerabilities often dominate operational outcomes (Choi et al., 2018; Yadav, 2015). Structural equation modeling has been increasingly recommended as an appropriate analytical approach for examining these complex yet theoretically grounded relationships among latent constructs (Hair et al., 2019; Sarstedt et al., 2022). Responding to these gaps, the present study develops and empirically tests a parsimonious structural model examining the relationship between supply-side constraints, procurement vulnerability, and medication shortage occurrence in hospital settings (Ivanov, 2020). By focusing on economic and manufacturing-related supply pressures while explicitly modeling procurement vulnerability as a mediating mechanism, the study advances a more integrated understanding of medication shortages grounded in supply chain management theory (Yadav, 2015; Choi et al., 2018). The use of partial least squares structural equation modeling (PLS-SEM) enables the estimation of predictive relationships among latent constructs while maintaining methodological rigor and parsimony (Hair et al., 2019; Sarstedt et al., 2022).

By clarifying how upstream supply-side constraints interact with hospital-level procurement vulnerabilities to shape medication shortage outcomes, this study contributes to the healthcare operations and supply chain management literature in several ways (Ivanov, 2020). Empirically, it extends prior descriptive research on medication shortages by testing an integrated structural model grounded in established management theory (Yadav, 2015). Practically, the findings offer actionable insights for hospital managers and policymakers seeking to mitigate shortage risks through procurement resilience and strategic sourcing interventions (Fox et al., 2014).

Beyond pharmaceutical-specific explanations, medication shortages can also be interpreted through broader supply chain risk and resilience frameworks. Supply chain risk management theory emphasizes the propagation of upstream disruptions through structurally interdependent networks (Tang, 2006; Craighead et al., 2007). Similarly, organizational resilience literature highlights the role of buffering capacity, flexibility, and adaptive procurement mechanisms in mitigating disruption impacts (Ponomarov and Holcomb, 2009; Ambulkar et al., 2015). By integrating these perspectives with healthcare supply chain research, the present study situates medication shortages within a broader operations management framework.

2. Literature review and justification of hypotheses

2.1. Supply-side constraints in pharmaceutical supply chains

From a broader operations management perspective, supply-side constraints reflect classic disruption propagation mechanisms in tightly coupled supply networks (Craighead et al., 2007; Tang, 2006). Research on supply network complexity further suggests that concentrated supplier bases and regulatory rigidity amplify disruption severity and recovery time (Bode and Wagner, 2015; Wagner and Bode, 2008). These theoretical insights reinforce the argument that pharmaceutical shortages are not isolated production failures but systemic network-level phenomena.

Pharmaceutical supply chains are structurally complex systems characterized by high regulatory oversight, long production lead times, and limited substitutability of products, making them particularly susceptible to supply-side disruptions (Yadav, 2015; Fox et al., 2014). Prior research consistently demonstrates that supply-side constraints in pharmaceutical markets arise from manufacturing quality failures, capacity limitations, shortages of active pharmaceutical ingredients, and production line shutdowns, which collectively restrict the availability of essential medicines (Ventola, 2011; Acosta et al., 2019). These constraints are compounded by economic pressures such as price regulation and low margins in generic drug markets, which reduce manufacturers' incentives to invest in redundancy and excess capacity (Dave et al., 2017; Acosta et al., 2019). From a supply chain management perspective, upstream constraints propagate downstream through tightly coupled networks, increasing systemic vulnerability across multiple organizational levels (Ivanov, 2020; Choi et al., 2018). Empirical evidence indicates that pharmaceutical supply chains exhibit limited resilience due to high supplier concentration and stringent regulatory barriers that restrict rapid supplier substitution (Fox et al., 2014; Yadav, 2015). As a result, localized disruptions at the manufacturing level frequently escalate into widespread medication shortages affecting healthcare providers and patients alike (Ventola, 2011).

2.2. Supply-side constraints and procurement vulnerability

Hospital procurement systems operate at the downstream end of pharmaceutical supply chains and play a critical role in ensuring the continuous availability of medicines for patient care (Yadav, 2015). Procurement vulnerability reflects an organization's exposure to supply disruptions arising from supplier dependency, limited sourcing flexibility, and constrained inventory management capabilities (Ivanov, 2020; Choi et al., 2018). Prior studies in healthcare operations management suggest that hospitals often rely on a narrow set of approved suppliers, particularly for essential and regulated medicines, thereby increasing sensitivity to upstream supply-side constraints.

It is important to note that the degree of procurement vulnerability may vary across hospitals depending on organizational size, ownership structure, and regulatory context. Larger tertiary hospitals may possess greater inventory buffering capacity and diversified supplier networks, potentially reducing exposure to upstream disruptions. In contrast, smaller or resource-constrained hospitals may experience amplified vulnerability due to limited procurement leverage and financial flexibility. Similarly, public and private hospitals may operate under different procurement regulations and contracting mechanisms, which can influence sourcing flexibility and response speed. Regional regulatory frameworks governing pharmaceutical pricing, tendering, and supplier approval processes may further shape the transmission of supply-side constraints into shortage outcomes. While the present study models generalized structural relationships, these contextual characteristics may moderate the strength of the observed effects.

Empirical research shows that manufacturing disruptions and economic pressures faced by suppliers increase lead-time variability and reduce order fulfillment reliability, directly undermining procurement stability at the hospital level (Ventola, 2011; Acosta et al., 2019). When supply-side constraints intensify, hospitals face reduced flexibility in adjusting procurement strategies, identifying alternative suppliers, or increasing inventory buffers, leading to heightened procurement vulnerability (Yadav, 2015; Ivanov, 2020). Supply chain risk management literature consistently supports the argument that upstream uncertainty translates into downstream vulnerability when organizations lack sufficient buffering and diversification mechanisms (Choi et al., 2018). Given this theoretical and empirical foundation, supply-side constraints are expected to exert a systematic and positive influence on procurement vulnerability in hospital settings (Yadav, 2015; Ivanov, 2020). Accordingly, the following hypothesis is proposed.

H1: Supply-side constraints have a positive effect on procurement vulnerability.

2.3. Procurement vulnerability and medication shortage occurrence

Medication shortages are widely conceptualized as downstream manifestations of compounded vulnerabilities across pharmaceutical supply chains, with hospital procurement systems representing a critical point at which these vulnerabilities become operationally visible (Fox et al., 2014; Ventola, 2011). Procurement vulnerability limits a hospital's capacity to absorb upstream disruptions, thereby increasing the likelihood that supply shocks translate into actual shortages rather than temporary delays (Yadav, 2015; Ivanov, 2020). Empirical evidence indicates that hospitals characterized by higher supplier dependency and constrained sourcing options report more frequent and persistent medication shortages. Operations management research further suggests that procurement vulnerability reduces organizational resilience by constraining response options during supply disruptions, particularly in environments marked by inelastic demand and limited substitution possibilities (Choi et al., 2018; Ivanov, 2020). In pharmaceutical contexts, where clinical guidelines and patient safety considerations restrict the use of substitutes, procurement vulnerability is especially likely to result in medication shortages with direct implications for care delivery (Ventola, 2011; Acosta et al., 2019).

Prior healthcare management studies confirm that procurement-related weaknesses exacerbate both the frequency and duration of shortages, intensifying their operational and clinical impact (Fox et al., 2014). Based on this evidence, procurement vulnerability is expected to have a direct and positive association with medication shortage occurrence (Yadav, 2015). Therefore, the following hypothesis is advanced.

H2: Procurement vulnerability has a positive effect on medication shortage occurrence.

2.4. Direct effects of supply-side constraints on medication shortages

In addition to their indirect influence through procurement vulnerability, supply-side constraints have been shown to exert a direct impact on medication shortages by constraining overall market supply (Fox et al., 2014; Ventola, 2011). Manufacturing shutdowns, quality failures, and shortages of key inputs can immediately reduce production volumes, resulting in shortages that downstream organizations cannot fully mitigate through procurement practices alone (Acosta et al., 2019; Dave et al., 2017). Empirical studies demonstrate that high levels of manufacturer concentration significantly increase the likelihood of widespread shortages, even among hospitals with relatively robust procurement capabilities. Supply chain disruption research emphasizes that certain risks are systemic and originate beyond the control of individual organizations, leading to direct performance consequences irrespective of internal response strategies (Ivanov, 2020; Choi et al., 2018). In regulated pharmaceutical markets, economic disincentives further amplify these effects by discouraging investment in capacity resilience, thereby increasing the probability that supply-side disruptions translate directly into medication shortages (Ventola, 2011; Acosta et al., 2019). These dynamics support a partial mediation framework in which supply-side constraints influence medication shortages both directly and indirectly through procurement vulnerability (Yadav, 2015). Accordingly, the following hypothesis is proposed.

H3: Supply-side constraints have a positive effect on medication shortage occurrence.

2.5. Mediation of procurement vulnerability

Supply chain risk research indicates that upstream disruptions often influence operational outcomes indirectly by constraining organizational processes rather than solely through direct effects (Choi et al., 2018; Ivanov, 2020). In pharmaceutical supply chains, supply-side constraints such as manufacturing disruptions and economic pressures restrict hospitals' procurement flexibility, thereby increasing their vulnerability to supply interruptions (Yadav, 2015). Empirical studies show that hospitals with higher procurement vulnerability are less capable of absorbing upstream shocks, making medication shortages more likely when external supply conditions deteriorate (Fox et al., 2014).

Fig. 1 illustrates the hypothesized structural model examined in this study. The model proposes that supply-side constraints represent upstream structural pressures within pharmaceutical supply chains that directly increase medication shortage occurrence (H3). In addition, supply-side constraints are hypothesized to increase procurement vulnerability at the hospital level (H1), reflecting reduced sourcing flexibility, supplier dependency, and limited buffering capacity. Procurement vulnerability, in turn, is expected to positively influence medication shortage occurrence (H2), indicating that hospitals with weaker procurement resilience are more likely to experience persistent shortages when upstream disruptions occur.

The model further proposes a mediation mechanism (H4), whereby supply-side constraints indirectly affect medication shortage occurrence through procurement vulnerability. This mediation reflects the transmission process through which structural supply instability is filtered through organizational procurement systems before manifesting as operational shortages. Thus, the framework captures both direct systemic effects and indirect organizational mechanisms shaping shortage outcomes.

Mediation models are widely used in operations and healthcare management research to capture how external risks are transmitted through organizational mechanisms before affecting performance outcomes (Hair et al., 2019). In this context, procurement vulnerability is expected to partially mediate the relationship between supply-side constraints and medication shortage occurrence, reflecting both systemic supply failures and hospital-level response limitations (Ventola, 2011; Yadav, 2015). Accordingly, the following hypothesis is proposed.

H4: Procurement vulnerability mediates the relationship between supply-side constraints and medication shortage occurrence.

3. Methodology

3.1. Data collection

This study employed a cross-sectional survey design to examine the relationships among supply-side constraints, procurement vulnerability, and medication shortage occurrence in hospital settings, a design widely used in healthcare supply chain research to capture organizational perceptions and operational conditions (Yadav, 2015). Data were collected from hospital procurement officers, pharmacy managers, and supply chain professionals who were directly involved in medication purchasing and inventory management, consistent with prior empirical studies emphasizing the importance of knowledgeable key informants in healthcare operations research (Fox et al., 2014). Respondents were selected using purposive sampling to ensure that participants possessed sufficient experience and decision-making responsibility related to pharmaceutical procurement processes, as recommended in management research focusing on organizational-level constructs (Podsakoff et al., 2003; Yadav, 2015).

The survey instrument was administered electronically using a structured questionnaire to ensure standardized data collection and reduce interviewer-induced bias (Podsakoff et al., 2003; Hair et al., 2019). Participation was voluntary, and anonymity was assured to minimize social desirability bias and encourage accurate reporting of procurement challenges and shortage experiences (Podsakoff et al., 2012). Data collection procedures adhered to established ethical guidelines for research involving human participants, consistent with norms in empirical management and healthcare research (Hair et al., 2019; Sarstedt et al., 2022).

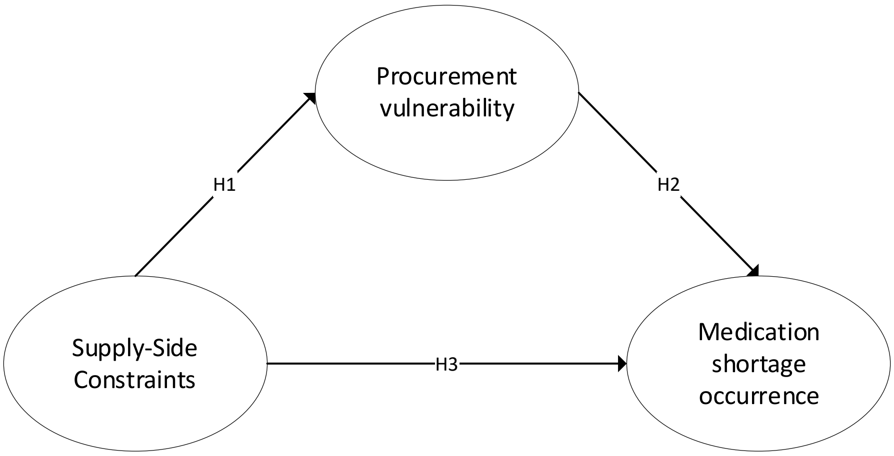

Fig. 1: Hypothesized structural framework

A total of 214 usable responses were obtained, yielding a response rate of 62%. The participating hospitals were geographically distributed across five major regions of the country, ensuring contextual diversity within the healthcare system examined. In terms of ownership structure, 58% of the hospitals were public institutions and 42% were private facilities. The sample comprised 49% tertiary care hospitals, 38% secondary care hospitals, and 13% specialty facilities, thereby capturing variation in organizational scale and operational complexity. Respondents reported an average of 11.4 years of professional experience in pharmaceutical procurement and supply chain management, indicating that the data were obtained from experienced and knowledgeable informants.

3.2. Reliability and validity

Measurement reliability and validity were assessed in accordance with established PLS-SEM reporting standards to ensure transparency and empirical rigor (Hair et al., 2019; Sarstedt et al., 2022). Beyond describing the assessment procedures, the revised manuscript now reports the full measurement model statistics, including indicator loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and Heterotrait–Monotrait (HTMT) ratios.

As reported in Table 1, all indicator loadings exceeded the recommended threshold of 0.70, demonstrating satisfactory item reliability and confirming that each observed variable adequately represented its respective latent construct. Internal consistency reliability was established, with Cronbach's alpha and composite reliability (CR) values for all constructs exceeding the minimum recommended threshold of 0.70 (Hair et al., 2019; Henseler et al., 2015). Convergent validity was confirmed as the AVE values for all constructs were above 0.50, indicating that each construct explained more than half of the variance in its indicators (Fornell and Larcker, 1981).

Discriminant validity was evaluated using the HTMT ratio of correlations (Table 2). All HTMT values were below the conservative threshold of 0.85, demonstrating adequate construct distinctiveness (Henseler et al., 2015; Sarstedt et al., 2022). Collectively, these results indicate that the measurement model satisfies established criteria for reliability, convergent validity, and discriminant validity, thereby providing a robust foundation for subsequent structural model analysis (Table 3).

3.3. Measures used

All constructs in the study were operationalized using multi-item reflective measures adapted from established literature on pharmaceutical supply chains and healthcare operations management, ensuring content validity and theoretical consistency (Yadav, 2015; Fox et al., 2014). Supply-side constraints were measured using items capturing manufacturing disruptions, capacity limitations, and economic pressures affecting medicine availability, consistent with prior studies examining pharmaceutical supply risks (Ventola, 2011; Acosta et al., 2019). Procurement vulnerability was measured through indicators reflecting supplier dependency, limited sourcing flexibility, and challenges in inventory planning, aligning with conceptualizations used in healthcare procurement research (Ivanov, 2020). All constructs were measured using multi-item reflective scales adapted from established studies, with items rated on a five-point Likert scale. The complete list of measurement items and their sources is presented in Table 4.

Medication shortage occurrence was measured using items assessing the frequency and persistence of drug availability disruptions experienced by hospitals, as operationalized in previous empirical studies on medication shortages (Fox et al., 2014). All items were measured on a Likert-type scale, a common approach in management research for capturing perceptual assessments of organizational phenomena (Podsakoff et al., 2003; Hair et al., 2019). The questionnaire was reviewed for clarity and relevance to the hospital context to enhance face validity and reduce measurement error (Podsakoff et al., 2012).

3.4. Data analysis

The proposed research model was tested using partial least squares structural equation modeling (PLS-SEM), which is particularly suitable for prediction-oriented research and complex models involving latent constructs (Hair et al., 2019; Sarstedt et al., 2022). PLS-SEM was selected due to its ability to handle non-normal data distributions and its suitability for studies with moderate sample sizes, characteristics commonly observed in healthcare operations research (Hair et al., 2019). The analysis followed a two-step approach, beginning with the assessment of the measurement model followed by the evaluation of the structural model, consistent with recommended SEM procedures (Hair et al., 2019; Henseler et al., 2015).

The structural model was evaluated by examining path coefficients, their statistical significance using bootstrapping procedures, and the coefficient of determination (R^2) for endogenous constructs, as suggested in the SEM literature (Hair et al., 2019; Sarstedt et al., 2022). Effect sizes (f^2) were assessed to evaluate the relative impact of exogenous constructs on endogenous variables, providing additional insight into the practical significance of the relationships (Hair et al., 2019). This analytical approach enabled a rigorous examination of both direct and mediating effects within the proposed conceptual framework (Ivanov, 2020).

3.5. Common method bias

Given the self-reported nature of the survey data, potential common method bias (CMB) was addressed using both procedural and statistical remedies, as recommended in the management literature (Podsakoff et al., 2003; Podsakoff et al., 2012). Procedural remedies included assuring respondent anonymity and reducing evaluation apprehension, which have been shown to mitigate method-related biases (Podsakoff et al., 2012; Hair et al., 2019). Additionally, the questionnaire was designed to minimize item ambiguity and reduce the likelihood of respondents inferring relationships among constructs (Podsakoff et al., 2003).

Statistically, common method bias was assessed using Harman's single-factor test, which examines whether a single factor accounts for the majority of variance in the data (Podsakoff et al., 2003; Kock, 2015). Variance inflation factors (VIFs) were also examined to assess potential collinearity issues indicative of method bias, consistent with recent recommendations in PLS-SEM research (Kock, 2015; Hair et al., 2019). The results indicated that common method bias was unlikely to pose a significant threat to the validity of the study's findings (Podsakoff et al., 2012; Sarstedt et al., 2022).

Table 1: Measurement model results

Construct	Item	Loading	Cronbach's alpha	CR	AVE
Supply-side constraints	SSC1	0.82	0.85	0.89	0.67
	SSC2	0.79			
	SSC3	0.84			
	SSC4	0.81			
Procurement vulnerability	PV1	0.86	0.88	0.91	0.72
	PV2	0.83			
	PV3	0.87			
	PV4	0.82			
Medication shortage occurrence	MSO1	0.88	0.90	0.93	0.76
	MSO2	0.85			
	MSO3	0.87			
	MSO4	0.89			

Table 2: HTMT ratios

Construct	SSC	PV	MSO
SSC	—	0.62	0.58
PV	0.62	—	0.66
MSO	0.58	0.66	—

Table 3: Structural model results: Standardized regression weights and significance level

Hypothesis	Structural path	S.E.	C.R.	p-value	Result
H1	Supply-side constraints → procurement vulnerability	0.031	3.42	< 0.001	Supported
H2	Procurement vulnerability → medication shortage occurrence	0.037	3.11	0.002	Supported
H3	Supply-side constraints → medication shortage occurrence	0.034	2.89	0.004	Supported
H4	Supply-side constraints → medication shortage occurrence (via procurement vulnerability)	—	2.76	0.006	Supported

C.R.: Critical Ratio; S.E.: Standard error

Table 4: Constructs and measurement items

Construct	Source(s)	Measurement items
Supply-side constraints	Yadav (2015); Acosta et al. (2019); Ivanov (2020)	1. Pharmaceutical supply is frequently disrupted due to production-related challenges at the manufacturer level. 2. Economic pressures reduce suppliers' ability to maintain uninterrupted medicine availability. 3. Limited production capacity contributes to instability in the supply of essential medicines. 4. Concentration among a small number of manufacturers increases the risk of supply disruptions.
Procurement vulnerability	Choi et al. (2018); Yadav (2015)	1. Our hospital has limited flexibility in sourcing medicines from alternative suppliers. 2. Dependence on a few key suppliers increases exposure to supply interruptions. 3. Responding effectively to unexpected supply disruptions is challenging for our procurement system. 4. Existing procurement practices are insufficient to mitigate supply uncertainty fully.
Medication shortage occurrence	Fox et al. (2014); Ventola (2011)	1. Essential medicines are unavailable more often than acceptable in our hospital. 2. Medicine shortages frequently disrupt routine clinical operations. 3. Shortages often persist despite active procurement efforts. 4. Medication availability problems have become a recurring operational concern.

A 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) was employed for all items

4. Results and discussion

The findings demonstrate that the interaction between structural supply-side instability and hospital-level procurement vulnerability shapes medication shortages. Rather than functioning as isolated operational failures, shortages emerge through a transmission mechanism in which upstream manufacturing disruptions and economic pressures constrain procurement flexibility and amplify exposure to disruption (Yadav, 2015; Ivanov, 2020). This interpretation reframes shortages as multi-level supply chain phenomena in which tightly coupled pharmaceutical networks propagate instability downstream (Choi et al., 2018).

The positive effect of supply-side constraints on procurement vulnerability suggests that upstream market dynamics structurally condition hospital procurement systems. Manufacturing disruptions, capacity limitations, and economic pressures do not simply reduce medicine availability; they reshape the sourcing environment within which hospitals operate (Ventola, 2011; Acosta et al., 2019). As supplier concentration intensifies and regulatory rigidity limits substitution options, hospitals face reduced flexibility in identifying alternative sources (Yadav, 2015). Procurement vulnerability, therefore, reflects institutional exposure embedded within pharmaceutical supply chain architecture rather than merely internal managerial shortcomings (Choi et al., 2018; Acosta et al., 2019).

The significant influence of procurement vulnerability on medication shortage occurrence highlights the importance of internal buffering capacity. While prior research has emphasized upstream causes of shortages (Fox et al., 2014), the present findings demonstrate that organizational procurement structures shape the extent to which those upstream shocks translate into operational disruption. Hospitals characterized by higher supplier dependency and limited inventory flexibility appear more susceptible to persistent shortages, particularly in regulated environments with restricted substitution possibilities (Ventola, 2011; Acosta et al., 2019). This insight shifts the focus from purely structural explanations toward a more integrated perspective incorporating organizational response capability (Ivanov, 2020).

The coexistence of direct and indirect effects offers a more nuanced understanding of shortage dynamics. The direct pathway confirms that certain structural supply shocks—such as manufacturing shutdowns or supplier exits—have consequences that extend beyond hospital-level control (Fox et al., 2014; Dave et al., 2017). At the same time, the partial mediation effect indicates that procurement resilience moderates, but does not eliminate, these systemic pressures (Yadav, 2015; Ivanov, 2020). This dual-pathway finding suggests that shortages arise from both structural fragility and organizational vulnerability, reinforcing the view that downstream managerial interventions alone are insufficient in highly concentrated pharmaceutical markets (Choi et al., 2018).

From a theoretical standpoint, the study advances healthcare supply chain literature by empirically integrating structural supply risks with hospital-level vulnerability in a single parsimonious model (Ivanov, 2020). By validating procurement vulnerability as a mediating construct, the analysis clarifies how upstream disruptions are filtered through institutional procurement systems before manifesting as operational shortages (Yadav, 2015; Choi et al., 2018). This process-oriented explanation extends prior descriptive accounts of medication shortages and provides a more refined understanding of how supply chain risk translates into healthcare service disruption (Fox et al., 2014). Overall, the findings underscore that addressing medication shortages requires coordinated attention to both upstream supply stability and downstream procurement resilience (Ventola, 2011; Acosta et al., 2019). While hospitals can strengthen procurement practices to reduce vulnerability, the persistence of direct supply-side effects highlights the continued importance of structural market reforms aimed at enhancing manufacturing resilience (Yadav, 2015; Dave et al., 2017).

The findings offer several actionable implications for hospital administrators and policymakers. At the hospital level, the significant effect of procurement vulnerability suggests that managers should prioritize strengthening procurement resilience mechanisms. This may include implementing multi-sourcing strategies to reduce supplier concentration risk, developing formal contingency contracts with secondary suppliers, and introducing supplier risk assessment dashboards to monitor manufacturing disruptions in real time. Hospitals may also benefit from inventory risk segmentation approaches, whereby critical medicines with limited substitutes are assigned higher safety stock levels and more rigorous monitoring protocols.

The results further indicate that procurement systems should incorporate predictive analytics tools capable of identifying early warning signals of upstream supply instability. Strengthening coordination between pharmacy departments and procurement units can improve demand forecasting accuracy and reduce reactive purchasing behavior during disruptions.

At the policy level, the persistence of direct supply-side effects suggests that hospital-level reforms alone are insufficient. Policymakers should consider regulatory frameworks that incentivize manufacturing redundancy, reduce excessive supplier concentration in essential generic medicines, and improve transparency in national shortage reporting systems. Coordinated procurement platforms or regional purchasing consortia may also enhance bargaining power and diversify sourcing options for smaller hospitals. Collectively, these measures suggest that mitigating medication shortages requires a dual strategy: enhancing internal procurement resilience while simultaneously addressing structural supply market fragilities.

5. Conclusion

This study advances understanding of medication shortages by empirically demonstrating how supply-side constraints originating in pharmaceutical markets translate into shortage outcomes through hospital-level procurement vulnerability (Yadav, 2015; Ivanov, 2020). The findings confirm that medication shortages are not isolated operational failures but systemic outcomes shaped by interactions between upstream manufacturing and economic pressures and downstream organizational capacities (Fox et al., 2014; Ventola, 2011). By validating a parsimonious structural model, the study responds to calls in healthcare operations research for integrative explanations that move beyond descriptive accounts of drug shortages.

The results highlight procurement vulnerability as a critical organizational mechanism through which supply-side constraints intensify medication shortages, underscoring the importance of hospital procurement systems in mediating external supply risks (Yadav, 2015). The presence of both direct and indirect effects of supply-side constraints indicates that while some shortages remain beyond hospital control, others are amplified by limitations in sourcing flexibility, forecasting, and inventory resilience (Acosta et al., 2019; Ivanov, 2020). This dual-pathway explanation reinforces supply chain risk theory by illustrating how structural disruptions and organizational vulnerabilities jointly shape operational outcomes in regulated healthcare contexts (Choi et al., 2018).

From a theoretical and practical perspective, the study contributes to healthcare supply chain literature by empirically establishing procurement vulnerability as a key mediating construct linking upstream supply risks to medication shortage occurrence (Yadav, 2015; Ivanov, 2020). The findings suggest that managerial interventions focused solely on internal procurement improvements are unlikely to fully resolve shortages without parallel efforts to address upstream manufacturing concentration and economic disincentives (Ventola, 2011; Dave et al., 2017). Overall, the study provides a robust foundation for future research and policy initiatives aimed at strengthening pharmaceutical supply resilience and safeguarding medication availability in hospital systems (Fox et al., 2014).

List of abbreviations

AVE	Average variance extracted
C.R.	Critical ratio
CMB	Common method bias
CR	Composite reliability
f^2	Effect size
HTMT	Heterotrait–Monotrait ratio
MSO	Medication shortage occurrence
PLS-SEM	Partial least squares structural equation modeling
PV	Procurement vulnerability
R^2	Coefficient of determination
S.E.	Standard error
SEM	Structural equation modeling
SSC	Supply-side constraints
VIF	Variance inflation factor

Compliance with ethical standards

Ethical considerations

The study involved voluntary survey responses from adult professionals and did not collect sensitive personal or medical data. Participation was anonymous, and informed consent was obtained from all respondents prior to participation. Data were treated confidentially and used exclusively for research purposes.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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