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Drug inventory optimization using integrated ABC–VED–FSN matrix analysis in a tertiary care hospital

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Abstract:
Drug stock-outs in tertiary care hospitals interrupt pharmacotherapy, yet inventory analyses rarely link drug categories to supply failure. Therefore, it is of interest to evaluate 564 drug formulations of a 1000-bed tertiary care hospital using an integrated ABC-VED-FSN matrix. Procurement and consumption records from April 2024 to March 2025 were analysed retrospectively for stock-out events and therapeutic substitution. Annual expenditure was ₹9.90 crore, Category A consumed 69.98% of spend from 9.21% of items and 62.1% of 264 stock-outs fell in AVF, AEF and BVF drugs, 61% with substitution. Thus, data shows that integrated ABC-VED-FSN matrix identifies predictable, preventable stock-outs and guides procurement to protect uninterrupted pharmacotherapy.

Keywords: Drug utilization review, drug shortages, pharmacotherapy, hospital pharmacy, inventory control, cost analysis

Background:
Access to medicines underpins almost every clinical decision a hospital makes. In tertiary care, the sheer diversity, volume and cost of the pharmacy make inventory management a determinant of care rather than a back-office chore **[1]**. When inventory control falters, the consequences are tangible: essential drugs run out, slow-moving items overstock and expire, working capital is locked away and patients ultimately bear the cost through delayed or substituted treatment **[2]**. The problem, therefore, is not merely one of stock records but of therapeutic continuity, since every stock-out translates into a clinical decision taken under constraint rather than by choice. Inventory systems that rank medicines by consumption or expenditure alone capture only part of the picture because they say nothing about how clinically indispensable a drug is, potentially resulting in inadequate prioritization of medicines that are critical for patient care **[3]**. Drug availability is not simply a logistics problem; it shapes therapeutic continuity and in time-sensitive conditions, a short delay or an unplanned substitution can alter the clinical course. To move beyond single-dimension control, hospital pharmacies have long drawn on three complementary tools **[4]**. ABC (Always Better Control) analysis, grounded in the Pareto principle, isolates the small set of high-cost items that warrant tight financial oversight **[3]**. In most hospital formularies, a handful of Category A drugs consume the bulk of the budget while a long tail of Category B and C items accounts for the remainder **[5]**. Useful as it is, ABC classification is blind to clinical criticality, ranking solely by cost and thereby neglecting cheap but life-saving medicines **[4]**. VED (Vital, Essential, Desirable) analysis addresses that blind spot by grading drugs on therapeutic importance: vital (V) agents must never be unavailable, essential (E) agents treat common conditions but can tolerate brief shortages and desirable (D) agents can be absent without materially harming care **[4, 6]**. FSN (Fast-moving, Slow-moving, Non-moving analysis adds a third axis, sorting drugs by movement from the store into fast- (F), slow- (S) and non-moving (N) categories and thereby flagging items prone to stagnation or expiry and informing reorder levels and disposal decisions **[6]**. Each method, applied on its own, leaves gaps. Combining them into an integrated ABC-VED-FSN matrix allows cost, criticality and consumption behaviour to be weighed simultaneously, producing a far more actionable map of where managerial attention should be directed **[6]**. This matters most in tertiary centres running complex specialities such as oncology and cardiology, where high-cost therapeutics, emergency drugs and supportive medications must all remain available under tight budgets, conditions that magnify the risk of stock-outs, expiries and financial waste. Yet most published inventory analyses stop at description. They report the distribution of drugs across categories but rarely link those categories to stock-out dynamics or to how pharmacotherapy is affected when supply fails, which limits the extent to which their findings translate into clinical practice **[7]**. As a result, inventory management is too often treated as an administrative function rather than as a lever for therapeutic continuity, even though stock-outs of critical medicines can interrupt treatment pathways, force suboptimal substitutions and delay essential interventions **[7]**. Therefore, it is of interest to apply an integrated ABC-VED-FSN framework to the drug inventory of a tertiary care hospital, with the explicit aim of identifying priority categories to guide procurement planning, optimise resource use and protect continuity of pharmacotherapy.

Materials and Methods:
Study design and setting:
This was a retrospective, record-based observational study conducted in the pharmacy department of a 1000-bed tertiary care hospital whose central pharmacy serves both inpatient and outpatient services. A census approach was used: all eligible drugs during the study period were included and no sampling was performed.

Study period and data source:
Procurement and consumption data were extracted from pharmacy records covering the period April 2024 to March 2025.

Inclusion and exclusion criteria:
All medicines with complete procurement and consumption records during the study period were included. Non-drug items, surgical disposables, intravenous fluids, vaccines and blood products were excluded, as these are managed through independent procurement and inventory systems; records with incomplete data were likewise excluded. Each unique formulation, defined by molecule, strength and dosage form, was treated as a single analytical unit. Stock-out analysis was confined to drugs falling in the very-high- and high-priority categories of the integrated matrix (AEF, AVF, AVN, AVS, BEF, BVF, BVS).

Study tools and variables:
Data were drawn from the pharmacy procurement and issue registers. Variables comprised drug name, unit cost, annual consumption, annual drug expenditure, therapeutic criticality

and movement from the store. Annual drug expenditure was calculated as unit cost multiplied by annual consumption. A stock-out was defined as complete unavailability of a drug for ≥1 day, a threshold chosen to capture clinically meaningful interruptions in availability. Substitution was defined as a ≥30% increase in consumption of a pharmacologically similar drug during a stock-out period, taken as evidence of a significant compensatory shift in prescribing or dispensing.

ABC analysis:

Drugs were ranked in descending order of annual expenditure and assigned to classes A, B and C based on cumulative expenditure, using the conventional cut-offs shown in (**Table 1)**.

Table 1: Conventional cut-offs used for ABC (Always Better Control) classification

Class	Drugs (%)	Cumulative cost (%, approx.)
A	10–15	70
B	20–25	20
C	65–70	10

Table 2: Consolidation of the 27 ABC-VED-FSN combinations into four priority groups

Priority level	Combinations	Control strategy
Very high	AVF, AVS, AVN, AEF, BVF	Strict monitoring, continuous availability
High	AES, ADF, BVS, BEF	Periodic review
Moderate	AEN, ADS, BVN, BES, BDF, CVF, CVS, CEF	Routine supervision
Low	ADN, BEN, BDS, BDN, CVN, CES, CEN, CDF, CDS, CDN	Minimal control

A/B/C: Always Better Control classes; V/E/D: vital/essential/desirable; F/S/N: fast/slow/non-moving

Table 3: ABC analysis of inventory drugs

Parameter	A	B	C	Total
Annual expenditure (₹)	6,92,78,652	1,97,44,589	99,76,995	9,90,00,237
Expenditure (%)	69.98	20.02	10.00	100
Number of drugs	52	102	410	564
Drugs (%)	9.21	18.10	72.69	100

ABC: Always Better Control; ₹: Indian Rupees.

Table 4: VED classification of inventory drugs

Parameter	Vital (V)	Essential (E)	Desirable (D)	Total
Number of drugs	368	179	17	564
Percentage	65.25	31.74	3.01	100

VED: Vital, Essential, Desirable.

Table 5: ABC-VED cross-classification of drugs by number and annual expenditure

VED	Measure	A	B	C	Total
V	No. of drugs (%)	51 (9.05)	78 (13.82)	239 (42.38)	368 (65.25)
	Annual expenditure (%)	6,60,80,952 (66.74)	1,58,85,937 (16.05)	71,15,763 (7.19)	8,90,82,652 (89.98)
E	No. of drugs (%)	1 (0.18)	21 (3.73)	157 (27.83)	179 (31.74)
	Annual expenditure (%)	31,97,700 (3.23)	33,84,421 (3.42)	27,00,934 (2.73)	92,83,056 (9.38)
D	No. of drugs (%)	0	3 (0.53)	14 (2.48)	17 (3.01)
	Annual expenditure (%)	0	4,74,231 (0.48)	1,60,298 (0.16)	6,34,529 (0.64)
Total	No. of drugs (%)	52 (9.23)	102 (18.08)	410 (72.69)	564 (100)
	Annual expenditure (%)	6,92,78,652 (69.97)	1,97,44,589 (19.95)	99,76,995 (10.08)	9,90,00,237 (100)

ABC: Always Better Control; V/E/D: vital/essential/desirable; ₹: Indian Rupees. Percentages are of grand totals.

Table 6: Consolidated ABC-VED priority categories

Measure	Category I (AV+AE+AD+BV+CV)	Category II (BE+BD+CE)	Category III (CD)
No. of drugs (%)	369 (65.43)	181 (32.09)	14 (2.48)
Annual expenditure (%)	9,22,80,352 (93.21)	65,59,586 (6.63)	1,60,298 (0.16)

Total: 564 drugs; ₹9,90,00,237. ABC: Always Better Control; V/E/D: vital/essential/desirable.

Table 7: FSN analysis of inventory drugs

Parameter	Fast-moving (F)	Slow-moving (S)	Non-moving (N)
Number of items	363	107	94
Percentage	64.36	18.97	16.67

FSN: Fast-, Slow- and Non-moving. Total = 564 drugs (100%).

Table 8: Integrated ABC-VED-FSN classification of drugs by number and share of annual expenditure (AE)

ABC-VED	F: n	F: AE%	S: n	S: AE%	N: n	N: AE%	Total (AE%)
AV	45	56.73	4	3.22	2	6.78	51 (66.73)
AE	1	3.22	0	0	0	0	1 (3.22)
AD	0	0	0	0	0	0	0
BV	59	12.48	11	2.20	8	1.40	78 (16.08)
BE	15	2.49	3	0.46	3	0.47	21 (3.42)
BD	2	0.32	1	0.16	0	0	3 (0.48)
CE	95	1.96	25	0.47	37	0.28	157 (2.71)
CV	138	5.15	61	1.32	40	0.72	239 (7.19)
CD	8	0.15	2	0.02	4	0	14 (0.17)
Total	**363**	**82.50**	**107**	**7.85**	**94**	**9.65**	**564 (100)**

I Very high	105	72.43	4	3.22	2	6.78	111 (82.43)
II High	15	2.49	11	2.20	0	0	26 (4.69)
III Moderate	235	7.43	64	1.78	8	1.40	307 (10.61)
IV Low	8	0.15	28	0.65	84	1.47	120 (2.27)

AE: annual expenditure; A/B/C: Always Better Control classes; V/E/D: vital/essential/desirable; F/S/N: fast/slow/non-moving; n: number of drugs. Priority groups I-IV are the consolidated very high, high, moderate and low categories.

Table 9: Stock-out burden and its distribution across priority groups

Parameter	Value
Total drugs analysed	564
Drugs with ≥1 stock-out	88
Total stock-out events	264
Very-high- and high-priority drugs (AEF, AVF, AVN, AVS, BEF, BVF, BVS)	138
Very-high-/high-priority drugs that stocked out	89
Stock-out events in very-high-/high-priority drugs	164
Share of events in very-high-/high-priority group (%)	62.1
Share of very-high-/high-priority drugs that stocked out (89/138, %)	64.5

AEF, AVF, AVN, AVS, BEF, BVF, BVS: integrated ABC-VED-FSN category codes.

Table 10: Substitution patterns observed during drug stock-out events

Parameter	Value
Total stock-out events analysed	264
Events with substitution (≥30% rise)	161
Strong substitution (>50% rise)	92
No substitution	103
Substitution detected (%)	61

Table 11: Representative substitution patterns during stock-out events

Index drug	Category	Substitute drug	Class	% change	Type
Amoxicillin + clavulanate	AVF	Other β-lactams	Antibiotic	+52 to +68	Strong
Acenocoumarol	BVF	Other strengths	Anticoagulant	+35 to +60	Dose
Adrenaline	AVF	Noradrenaline	Vasopressor	+45 to +62	Functional
Apixaban	AVF	Warfarin, heparin	Anticoagulant	+20 to +38	Weak
Abiraterone	AVN	None	Oncology	~0	None

AVF, BVF, AVN: integrated ABC-VED-FSN category codes.

VED analysis:
Drugs were classified as vital (V), essential (E) or desirable (D) according to therapeutic criticality and importance to patient care. Classification was performed through expert consensus among clinicians and pharmacists, using predefined criteria based on clinical necessity and the likely consequences of unavailability; disagreements were resolved through discussion within the panel.

ABC–VED matrix:
Drugs were then grouped into three managerial priority categories. Category I (AV, AE, AD, BV, CV) covered vital and/or high-cost drugs requiring strict control; Category II (BE, BD, CE) required moderate control; and Category III (CD) comprised low-priority drugs needing only minimal control.

FSN analysis:
FSN classification was based on movement from the store, using time since last issue as the indicator. Drugs issued within the preceding 30 days were classed as fast-moving, those issued between 30 and 90 days as slow-moving and those not issued for more than 90 days as non-moving **[6-8].**

ABC–VED–FSN matrix:
Combining all three dimensions produced 27 theoretical categories, which were consolidated into four priority groups with corresponding control strategies, as set out in (**Table 2)**.

Statistical analysis:
Data were entered and analysed in Microsoft Excel (Microsoft Corporation, USA). Descriptive statistics and comparative temporal analysis were used to characterise inventory patterns and to assess changes in utilisation during stock-out periods. A ≥30% rise in consumption of a similar agent was taken to indicate substitution. Given the descriptive nature of the study, no inferential statistical tests were applied.

Risk of bias:
As a retrospective, record-based analysis, the study is susceptible to information bias arising from inaccuracies or gaps in pharmacy records and to selection bias from excluding drugs with incomplete data. VED categorisation, resting on expert consensus, may carry misclassification bias. Stock-out events and substitution were inferred from inventory data and may not fully reflect real-time clinical decisions or external procurement.

Impact on patient care:
The results make plain that structured inventory management feeds directly into clinical outcomes. Keeping high-priority drugs continuously available sustains critical care, reduces reliance on suboptimal alternatives, limits preventable morbidity and complications and improves overall therapeutic outcomes; fewer stock-outs may also lower out-of-pocket spending and improve adherence.

Ethical considerations:
The study was approved by the Institutional Ethics Committee of SVIMS-SPMCW (Approval No. 1864) before data collection. No patient identifiers were used and the requirement for informed consent was waived.

Results:
A total of 564 drugs met the inclusion criteria, representing an annual drug expenditure of ₹9,90,00,237 (approximately ₹9.90 crore). Expenditure was heavily concentrated in a minority of items. Category A drugs made up just 9.21% of the inventory yet accounted for almost 70% of annual spend, while Category C drugs, nearly three-quarters of all items, contributed only a tenth. This skew confirms the case for focused financial and managerial control of Category A items (**Table 3**). Vital drugs dominated the formulary, comprising nearly two-thirds of all items. This distribution mirrors the critical-care burden of a tertiary hospital, where life-saving medicines must remain continuously available (**Table 4**). Cross-tabulating cost against criticality placed the great majority of drugs in Category I, which absorbed a disproportionate 93.21% of expenditure (**Tables 5 and 6**). In other words, most of the formulary, by both count and value, requires strict managerial control due to cost, criticality, or both. Fast-moving drugs predominated, making up just under two-thirds of items, a signal of high, sustained demand that calls for frequent replenishment. The slow and non-moving fractions, together accounting for around a third of items, indicate where stock can stagnate and where turnover could be improved (**Table 7**). Layering all three dimensions distributed the formulary across four priority groups (**Table 8**). The very-high- and high-priority groups gathered the drugs that are at once costly, clinically critical and rapidly consumed, precisely the items most exposed to stock-outs and where any supply disruption carries the greatest clinical weight. Across the year, 264 stock-out events were recorded. Of the 138 drugs in the very-high and high-priority groups, 89 (64.5%) ran out at least once, together generating 164 events, 62.1% of all stock-outs. The concentration of failures in exactly the categories that matter most clinically points to gaps in demand forecasting and procurement alignment rather than to random chance (**Table 9**). Temporal analysis linked 161 of the 264 events (61%) to a ≥30% rise in pharmacologically similar agents, the marker of substitution; 92 events showed strong substitution (>50% rise) and 103 showed no meaningful compensatory change. Substitution was most evident where therapeutic alternatives existed, while a sizeable share of events left no detectable replacement (**Table 10**). Representative cases showed intra-class antibiotic substitution, dose adjustment for anticoagulants and functional substitution among emergency drugs, reflecting how readily different classes can be interchanged. Non-substitutable agents, notably in oncology, showed no compensatory use at all (**Table 11**).

Discussion:
Drug expenditure in this tertiary hospital followed a clear Pareto distribution, with a small fraction of medicines absorbing most of the budget, a pattern that recurs across the inventory literature and reinforces the case for targeted financial control of high-cost items **[3-5]**. The more important message of this study, however, is that stock-outs were not random but concentrated in the very drug categories that are clinically and economically most critical, making them largely predictable and, by extension, preventable. The predominance of vital drugs is itself telling, reflecting the heavy critical-care commitment of a tertiary centre and the need to always keep life-saving medicines on hand. Comparable distributions have been reported by Devnani *et al.* Mahatme *et al.* Joosse *et al.* and Jobira *et al.* where vital drugs likewise accounted for the largest share of the inventory because emergency and critical-care needs demanded it **[5-8]**; Manivel and Ranganathan, applying a prioritised ABC-FSN matrix, similarly narrowed managerial attention to a small band of fast-moving, high-value items **[9]**. On the ABC-VED matrix, Category I drugs, those that are high-value, therapeutically critical, or both, emerged as the segment requiring the tightest control, echoing earlier hospital analyses in which a modest number of Category I items accounted for the lion's share of annual spend. Such medicines warrant close monitoring, frequent stock checks and priority procurement and integrated ABC–VED analysis is widely endorsed to pinpoint them **[4-6, 10]**. FSN analysis sharpened the picture further by highlighting the dominance of fast-moving drugs, consistent with high patient turnover and continuous demand; identifying the slow- and non-moving fractions, in turn, points to where wastage and locked capital can be trimmed, again in line with prior pharmacy studies **[6, 10 and 11]**. Bringing the three dimensions together identified AVF, AEF and BVF drugs as the categories most in need of assured availability and it was precisely here that stock outs clustered. That concentration exposes systemic weaknesses in demand forecasting, procurement planning, lead-time management and supply-chain responsiveness. Clinically, these failures translate into delayed treatment initiation, interrupted therapy, reliance on suboptimal alternatives and higher out-of-pocket costs, risks that are amplified in acute and chronic conditions where continuity is essential. These observations sit comfortably within the global evidence. Fox *et al.* documented that drug shortages disrupt care and raise the risk of medication errors **[12]**; Acosta *et al.* linked shortages of high-priority medicines to greater morbidity through delays and substitutions **[13]**; and recent evidence suggests that supply chain disruptions, manufacturing constraints, procurement inefficiencies and inadequate demand forecasting remain major contributors to medicine shortages across healthcare systems **[13, 14]**. The substitution analysis adds a clinically grounded layer to these findings. That a compensatory rise in similar agents accompanied 61% of events suggests clinicians actively adapt to shortages by reaching for available alternatives. This was most pronounced in classes with many therapeutic equivalents, antibiotics, where intra-class substitution (for instance, alternative β-lactams replacing amoxicillin-clavulanate) preserved antimicrobial continuity **[15]**. Anticoagulant substitution was more restrained, confined largely to dose or formulation changes, reflecting narrow therapeutic indices and

monitoring demands **[16]**. Emergency drugs showed functional substitution. Agents with overlapping physiological effects stood in for one another, though not always with equal efficacy; the use of methylprednisolone in place of hydrocortisone, for example, exploits corticosteroid interchangeability while differing in potency, duration, receptor selectivity and mineralocorticoid activity. At the other extreme, oncology drugs such as abiraterone showed essentially no substitution, underscoring the absence of viable alternatives and marking these as a critical vulnerability. When they run out, treatment is delayed or interrupted outright **[17]**. Even where substitution cushions the immediate impact, it can mean suboptimal therapy, a higher risk of adverse reactions and more variable outcomes. And in roughly 39% of events with no substitution, patients likely experienced therapy interruption or had to source medicines externally, with knock-on effects on costs and adherence. Embedding ABC-VED-FSN classification within real-time stock was monitoring and demand forecasting and holding buffer stock for non-substitutable agents such as oncology drugs, offers a practical route to averting these disruptions **[18]**. These findings also sit alongside the most recent ABC-VED literature. Jain and Makkar, analysing 4,581 items in a tertiary care teaching hospital, reported Category A drugs accounting for 70% of annual drug expenditure and Category I items absorbing 78.91% of spend, a concentration closely mirroring the 69.98% and 93.21% observed here **[19]**. Ilango *et al.* described an almost identical Pareto split across 1,402 drugs, with Category A at 9.62% of items and 70.11% of expenditure and Category I at 32.66% of items and 78.49% of expenditure, confirming that the cost-criticality gradient reproduces across settings **[20]**. Sinha and Singh by contrast, found a very different profile in a resource-constrained tertiary hospital, where desirable items consumed 80.13% of expenditure and reactive procurement with weak stock tracking were the dominant failure modes **[21]**. The divergence is instructive: expenditure concentration alone does not predict where care will break down and the present study extends these ABC-VED analyses by adding the FSN axis and, more importantly, by tying category membership to observed stock-out and substitution events rather than stopping at classification. A particular strength of this work is its use of temporal consumption data to infer substitution objectively, in the absence of patient-level prescribing records; pairing stock-out data with consumption trends lends the findings additional reliability. Translating them into practice points to a shift from reactive to proactive, data-driven inventory management: priority-based procurement of high-criticality, fast-moving drugs (AVF, AEF, BVF); lead-time-adjusted safety stock that accounts for demand variability and supply delays; and real-time monitoring with automated reorder triggers for high-risk categories. Strengthening forecasting through FSN-based consumption trends, diversifying vendors and using rate contracts to build supply-chain resilience and periodically rationalising low-priority and non-moving stock would together optimise resource use. Collectively, these measures support a systems-level reframing in which inventory classification is woven into pharmacotherapy planning rather than treated as a purely administrative exercise, keeping drug availability aligned with clinical priority.

Conclusion:

Stock-outs in this hospital were not random events but clustered predictably, with 62.1% falling in the clinically critical AVF, AEF and BVF categories. The integrated ABC-VED-FSN matrix therefore converts routine inventory data into a clinical risk map that names the drugs most likely to fail patients. Embedding this matrix in procurement shifts hospital pharmacy from reactive replenishment to the proactive protection of uninterrupted pharmacotherapy.

Limitations:

Several limitations temper these findings. The study was conducted at a single tertiary centre, which constrains generalisability and its retrospective design relies on existing records, exposing it to information bias and limiting its ability to capture real-time variability. Advanced quantitative inventory models and lead-time data were not incorporated, limiting precision in defining optimal stock levels; neither root-cause analysis of stock-outs nor supplier-side factors were examined, restricting causal inference; and the cost-effectiveness of the proposed interventions was likewise not assessed. VED classification rested on expert consensus and is therefore open to variability. Temporal shifts in disease pattern and demand were not modelled and patient-level prescribing and outcome data were unavailable to validate substitution or to gauge clinical impact directly. Finally, the absence of integration with digital inventory systems limited any assessment of real-time monitoring, automated forecasting and predictive capability.

Future directions:

Multicentre studies that link inventory classification to patient-level prescribing and outcome data would strengthen external validity and enable the clinical validation of substitution patterns. Prospective designs incorporating lead-time-adjusted quantitative models, root-cause analysis of stock-outs and cost-effectiveness analysis of priority-based procurement are warranted, as is the integration of ABC-VED-FSN classification with digital inventory platforms to enable real-time monitoring, automated reordering and predictive forecasting.

Authors' contributions:

The first author contributed to the study conception, data collection and drafting of the manuscript. The second author provided methodological guidance, supervision and critical revision. The third author contributed to the study design, data analysis and drafting. The fourth author provided study oversight and final approval. All authors approved the final version for publication and agree to be accountable for all aspects of the work, ensuring its accuracy and integrity.

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