NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s1-008

Research Article

Open Access

Exploration of Pharmaceutical Supply Chain for the Factors of Medicinal Drugs Shortages

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Received: November 24, 2022
Accepted: March 10, 2023
Published: March 12, 2023

Citation: Sharma J, Tyagi M, Gupta A, Kharayat TS. 2023. Exploration of Pharmaceutical Supply Chain for the Factors of Medicinal Drugs Shortages. *NanoWorld J* 9(S1): S34-S40.

Published by United Scientific Group

Abstract

Nowadays, pharmaceutical supply chains (PSCs) are getting attention. Gaps between the supply and demand of the various lifesaving drugs needs to be relooked to improve the supply chain's efficiency. Hence, factors that cause the shortage and unavailability of the drugs to the consumers need to be identified. The presented work aims to identify those factors and contemplates them for quantifying the mutual interdependencies. For the same, fuzzy set theory is incorporated with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique. The results of the presented study outrank the factors behind the shortage of drugs within the scope of pharmaceutical supply chain dynamics. Presented work finds it implication in decision-making procedures and governs various strategic and tactical planning frameworks.

Keywords

Pharmaceutical supply chain, DEMATEL, Drugs shortage

Introduction

Supply chain management is the integration of important business processes across the supply chain to generate value for customers and investors. Supply chain management blends demand and supply within corporations and with each other in an efficient business model [1]. Supply chains are getting their identity from the nature of a product flowing through its channels. Among them, pharmaceutical supply chains are ones, which are dedicated towards the delivery of various lifesaving drugs.

The PSCs delivers medications in the proper amount with the right consistency, the right destination with the right consumers, at the right time and at the best price to meet the health care system's priorities and make money for its shareholders. The supply chain consists of processes, data, and the resources that transport and distribute the raw materials and components to customers to the final products or services. It includes manufacturers, brokers, third-party service providers and buyers. This also applies to all logistical operations, promotions, product design, distribution, manufacturing operations, funding and information technology operations, and all marketing activities [2]. Supply chain management in the healthcare industry will modernize the firm to allow better use of resources and assets, generate profits, improve shareholder value, and respond positively to user demand. Efficient supply chain management can efficiently impact and grow all corporate processes, such as the procurement of supplies, data quality, reduction of operational complexity, storing and distribution.

PSCs are uniquely characterized by the prompt response to consumer demands (patient), which infers a short lead time [3]. To manage the same, drugs should be readily available, and inventory should be managed for assuring transparent operations within the periphery of PSC. It shows the need for accurate forecasting procedures, shorter scheduling times and low suppliers' count.

Radically, new sets of targets, drivers, and restrictions become prevalent when a drug is implemented. A variety of government departments, hospitals, health clinics, medical producers, pharmacy stores, drug dealers, sellers, research administrations, and the Food and Drug Administration are important players in the supply chain [4]. The supply network is responsible for delivering prescript drugs, over-the-counter medications (OTCs), generics, and biologics with varying storage requirements and organizational priorities to compound matters further [5]. Due to very different commercial priorities, organizations make managing the supply chain network harder. In addition, due to the industry's supervisory existence and many mergers/ acquisitions, several pharmaceutical supply networks have evolved unregulated rather than designed for optimum performance [6].

A strong supply network is needed for goods flow, money, and information across the right routes to meet client needs [7]. Drugs are manufactured, distributed, and consumed in the pharmaceutical sector. Because of its importance, storage, transit, and laws, it must be treated differently than other physical product supply chains [8]. While attempting to be lucrative, the pharmaceutical industry's fundamental purpose is to provide necessary healthcare support systems by supplying vital drugs at the right moment and the right patients [9].

The healthcare business is quickly expanding research and development in the field; nevertheless, appropriate supply network activities in this field sector produce massive, environmentally harmful pharmaceutical waste directly impacting human health [10]. People's perceptions of the environment have improved significantly in recent decades, and regulatory organizations have begun to pay attention to global ecological issues such as the scarcity of resources, climate change, carbon emissions [11]. Managers and practitioners propose green supply chain principles to help businesses (Xie and Breen). The healthcare value chain is responsible for advanced drugs and requires greater venture in investigation and development [11]. Increased internal and global constraints on ecological protection, economics, and security considerations [12] are driving the healthcare industry to handle green supply chain activities in its sector. Green supply chain initiatives contribute to the healthcare industry's economic and environmental benefits by reprocessing unused/unwanted medications and setting of commodities in an environmentally responsible manner.

Research Literature

Pharmaceutical companies all over the world are dealing with issues such as world quality standards, healthcare reform, patent expiry, and enhanced service requirements. Pharmaceutical companies must reduce prices, upgrade agility, and boost the pace to the market to address these challenges. Strategic preparation is critical for growth in a global and unstable market. Perez-Escobedo et al. emphasized the development of strategies felicitating decision-making to reduce hazard while achieving an organizational goal such as enlargement of expected net present worth, minimizing the time to market, etc. [13]. Wan et al. explored the uncertainty allied with the time-sensitive policy decisions such as capability expansion/narrowing necessitate [14]. Jain and Grossmann created an organizational decision support framework focused solely on quantitative data [15]. Ageron et al. concentrated on the various practices and problems of cooperation between suppliers and consumers to improve the supply chain's competitiveness [16].

Governmental and privately owned organizations must become more engaged about rising healthcare medication costs. According to Shah, stringent steps should be taken to control the prices of new products, and the use of generic substitutions should be encouraged [17]. Strategic problems have been grouped into three major categories for this study's systematic literature review: processes, resources, and performance. Thakur and Sharma focused on their system's properties, processes, and efficiency to assess supply network keenness [18]. Sharma et al. reviewed the various endorsers of e-business practices in the supply chain network [19].

Kumar et al. investigated a cost-cutting technique for medical supplies by considering a case study of a Singapore-based firm [20]. The study concluded that some Just-in-Time Flow Reduction (JIT), outsourcing and reengineering applications could be cost-effective. When it comes to locating suppliers, information technology can help save money [21]. Kumar et al. looked for the scope of radio frequency identification devices (RFID) that can enhance the cost-effectiveness and efficiency of the Medicare supply network [22]. Attaran highlighted the critical factors and recent challenges in adopting RFID systems for managing the pharmaceutical supply network and the financial and process benefits and downsides of using RFID systems in supply chains [23, 24]. Sharma et al. reviewed the impacts of COVID-19-based disruption on the supply chain dynamics [25]. Sinha and Kohnke recognized a gap in the medical business between rising demand and new greater supply, as well as cost and time effectiveness, as an issue [26]. For bridging the same proposed model comprised of three A's: affordability, awareness, and access to notify Medicare supply network managers and to incorporate unceasing improvements as a meaning of technology and quality enhancements.

Kogan et al. investigated the impact of working together among Medicare supply network participants on provider relationships in the healthcare industry [27]. Imran et al. attempted to construct a multi-period model of the healthcare supply network based on the assumption that the number of drugs delivered by providers is uncertain [28]. Syahrir et al. created a study to conduct an investigation and observe the topics of supply network management in Medicare and catastrophe management, taking into account service quality, managing inventory, research-related operations in the health sector, and information technology [29]. Rossetti et al. looked for the elements that affect healthcare supply chain logistic management [30]. Moons et al. explored research literature to assess the performance of healthcare supply chain logistics based on the most recent studies [31]. Chen et al. employed an experimental test to assess the performance of hospitals' supply chains [32]. Bishara identified the critical components of pharmaceutical supply chain management [33]. Bagchi et al. investigated the impact of procurement capacity on foreign straight investment by evaluating the supply, infrastructure, and capacity environments; investments can be made utilizing Boolean-based logical analysis [34].

Mustaffa and Potter assessed the portfolios of inventory management in Malaysia's private healthcare industry, with a specific focus on drug distribution from wholesalers to clinics [35]. Bhakoo et al. investigated the nature and significance of the arrangements used by the Australian hospital supply chain to manage its inventory [36]. Meijboom et al. revealed the issues allied with the dynamics of PSCs [37]. Aronsson et al wrote this study to better understand the most critical variables to adopt lean and agility notions within PSCs [38]. Kritchanchai examines Thailand's healthcare supply chain management advancement [39].

Research motivation

In today's world, supply chain management in the health industry is a major challenge. The different aspects that influence the pharmaceutical supply chain must be evaluated dynamically. Patient safety necessitates effective healthcare supply chain management. As a result, having a proper, efficient, and productive healthcare supply chain is critical [8]. Cost effectiveness, right quantity, standard quality, on-time delivery, correct installation and training, proper maintenance, and transparent and trustworthy service are all required for a successful supply chain. Some of the main obstacles emerging countries face are poor infrastructure, political instability, and a lack of competent and trained staff. Stock-outs are possible due to these supply-chain constraints, resulting in waste and unmet needs [25]. The current and desired state of health must be assessed, demand forecasted, and supply must satisfy the demand. This situation necessitates sound decision-making. The supply chain process does not end when the final product is delivered to the client; it must be evaluated on an ongoing basis to ensure its success [1].

Hence, the need arises to identify and assess the various factors behind the shortage of drugs. The PSCs need to be relooked for the various loopholes, which must be addressed to ensure the right product availability at the right time. Although many academics have identified answers to some difficulties in healthcare supply chains, there is still many studies in this sector. In the future, it will be crucial to look into the impact of demand uncertainty on workloads. More attention needs to be paid to factors such as the number of personnel required to deal with excessive workload resulting from inventory management issues. Further research into outsourced vs. in-house distribution network models is also possible. It is possible to assess a compromise between the indicated level of service around a whole system and the predetermined level of service at the operational levels.

Model development

A reliable supply chain is necessary for the transportation of commodities, data, and money in order for appropriate networks to meet the needs of consumers [40]. In the Medicare sector, pharmaceuticals are developed, distributed, and consumed. It also needs to be differentiated from many other supply chains for physical products. Transportation and legislation are all important because of their value [9]. The pharmaceutical industry's principal aim is to expand the industry while attempting to profit. The availability of key pharmaceutical items at the right place and at the correct time is necessary help for healthcare services [24]. The pharmaceutical sector is continually evolving in terms of research and development; nevertheless, in this market, good supply chain implementation produces massive healthcare waste that is environmentally harmful and has a significant impact on human health [41]. Hence, based upon the identified factors leading to the shortage in PSCs are listed in table 1.

Table 1: Factors responsible for shortage of drugs.

Sl. No.	Abbreviation used	Factors	References
1	U1	Market Withdrawals	[42]
2	U2	Export Demand	[42]
3	U3	Manufacturing and Quality Problems	[43]
4	U4	Shortage of Raw Material	[25]
5	U5	Managing Regulatory Expectations	[44]
6	U6	Supply Chain Design	[45]
7	U7	Purchaser–Manufacturer Incentives	[46]
8	U8	Lack of Advanced Learning System	[47]

Research Methodology

For the assessment of the identified factors, the methodology of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) is implied. It incorporates the fundamentals of fuzzy set theory, enriching its implication by capturing uncertainties and assessing the mutual interdependencies. Its association with the structural modelling approach effectively studies the cause-and-effect links in the system dynamics [24]. Crisp values in the original DEMATEL are used to analyze the interactions between decision factors to build a structural model. In so many practical applications, human judgments are frequently unclear, and precise numerical values are insufficient to assess the fuzzy interdependent relationships between criteria. As a result, many researchers have applied the concept of fuzzy sets to the DEMATEL method [48].

DEMATEL finds the leading edge over the existing methodologies of the Multi-Criteria Decision-Making Techniques, in terms of its ability to handle the mutual interrelationships between the decisional attributes. DEMATEL classifies the factors distinctly into a cause-and-effect group which helps to understand the contextual relationships. Hence, this study identified the methodology of DEMATEL analyses causes of the drug shortage. This methodology seeds the input of the field experts, which is contemplated to secure the priorities. This study gathers rating-based assessments from thirty-five industrial and five academic experts. These inputs result in the development of the pairwise decision matrix. In this study, fundamentals of the fuzzy set theory are integrated with DEMATEL to handle the uncertainties in decision-making process.

The proposed methodology of the fuzzy DEMATEL seeds the pairwise comparison of the factors, which yields the development of decision matrix. To generate the initial fuzzy direct relationship matrix *A*, evaluators insert fuzzy impact links between the two components into a matrix *m * m*, where '*h*' is the number of assessment providers. As an outcome, the direct-relation matrix is A = $[A_{ij_n}]$, where *A* is a *n*n* non-negative matrix, a_{ij} signifies the direct effect of component '*i*' on factor '*j*', and b_{ij} = 0 when *i*=*j*. Mathematically, it can be understood from equation 1.

$$A_{ij}^n = (a_{ij}^n, b_{ij}^n, c_{ij}^n);\ A^n = \begin{bmatrix} 0 & A_{12}^n & A_{13}^n \cdots A_{1m}^n \\ A_{21}^n & 0 & A_{23}^n \cdots A_{2m}^n \\ \vdots & \vdots & \vdots \\ A_{m1}^n & A_{m2}^n & A_{m3}^n \cdots \ 0 \end{bmatrix} n = 1,2,3,h \quad (1)$$

For the development of the same ratings are provided on the basis of triangular fuzzy numbers-based linguistics as detailed in table 2. Here triangular fuzzy number-based linguistic ratings are defined on the five-rating scale (0- No effect and 4- Very high effect). Relative to each rating, an abbreviation of NO, VL, L, H and VL is provided for ease of understanding. Gathered assessment needs to be defuzzified for the further evaluation of mutual interdependencies. For the same, mathematical formulation structured in the equation, 2 is utilized, based upon the principles of CFCS method.

$$xc_{ij}^n = \frac{c_{ij}^n - min a_{ij}^n}{\Delta_{min}^{max}};\ xb_{ij}^n = \frac{b_{ij}^n - min a_{ij}^n}{\Delta_{min}^{max}};\ xa_{ij}^n = \frac{a_{ij}^n - min a_{ij}^n}{\Delta_{min}^{max}}$$

Where, $\Delta_{min}^{max} = \max(xc_{ij}^n) - \min(xa_{ij}^n)$ (2)

Initially, assessments are normalized for removing the extremities within the rating values, done by implying formulation mentioned in equation 2. Based upon the implication of the formulation mentioned in the equation 2, normalized defuzzified values are shown in table 3.

Normalized fuzzy values are utilized to evaluate normalized crisp values by implying the mathematical equations 3 and 4.

$$x_{ij}^n = \frac{[xas_{ij}^n(1 - xas_{ij}^n) + xcs_{ij}^n x xcs_{ij}^n]}{[1 - xas_{ij}^n + xcs_{ij}^n]} \quad (3)$$

Table 2: The Fuzzy Linguistic Scale [48].

Linguistic variable	Influence score	Abbreviation used	Triangular Fuzzy numbers (TFN's)
No effect	0	NO	(0, 0.1, 0.3)
Very low effect	1	VL	(0.1, 0.3, 0.5)
Low effect	2	L	(0.3, 0.5, 0.7)
High effect	3	H	(0.5, 0.7, 0.9)
Very high effect	4	VH	(0.7, 0.9, 1.0)

$$k_{ij}^n = \min xa_{ij}^n + x_{ij}^n \text{ x } \Delta_{min}^{max} \quad (4)$$

Furthermore, obtained crisp values are integrated as shown in equation 5. Based upon which average direct relation matrix (K) is developed.

$$k = \frac{1}{h}(k_{ij}^1 + k_{ij}^2 + \cdots + k_{ij}^h) \quad (5)$$

Average direct relation matrix K = $[k_{ij}]$ (6)

Normalised direct relation matrix is developed to determine the causal and effect group. It implies the formulation in equation 7.

$Y = \lambda.K$

Where, $\lambda = \left[\frac{1}{\max_{1 \le i \le m} \sum_{j=1}^{m} |k_{ij}|}, \frac{1}{\max_{1 \le i \le m} \sum_{j=1}^{m} |k_{ij}|}\right]$ *i,j* = *1,2,…, m* (7)

The Sum of the rows and columns of the total relation matrix helps to evaluate prominence and relation value (Refer to equation 8). The totality of rows (J) and totality of columns (K) from the complete association matrix (T) (Refer to equation 9). So, J and K can be determined as:

Total-relationship matrix (T) = Y. $(I - Y)^{-1}$ (8)

Where, I = identity matrix

J = $[\sum_{j=1}^{m} t_{ij}]_{m \times 1}$ = $[t_i]_{m \times 1}$ and K = $[\sum_{j=1}^{m} t_{ij}]_{1 \times m}$ = $[t_j]_{m \times 1}$ (9)

Based upon the inferences drawn from the equations above, total relation matrix is evaluated, and its obtained values are tabulated in table 4.

Results and Discussion

The outcomes of the proposed methodology resulted in evaluating the prominence and relation values based upon the addition and subtraction of the *J* and *K* values, respectively. By implying the formulation mentioned in equation 9, evaluated values are shown in table 5. Positive values of prominence depict the factors which belong to the 'causal group' whereas negative values of the same pose as the 'effect group' value. For the same, a causal digraph is developed in figure 1, easing the visualisation. The causal graph is constructed using the horizontal axis *(J+K)* and the vertical axis *(J-K)*. The horizontal axis "*Prominence*" indicates how important the factor is, while the vertical axis "*Relationship*" indicates the extent of the influence. The factor is within the *cause* group if the value *(J - K)* is *positive*. If the *(J-K)* is *negative*, the factor is within the effect group. Causal charts can help solve problems by converting complex component interactions into a structural paradigm that is easy to understand.

The factors "supply chain design" (U6), "export demand" (U2), "Lack of advanced learning system" (U8), "man-

Table 3: Defuzzified Direct Relation Matrix.

	U1	U2	U3	U4	U5	U6	U7	U8
U1	0.000	0.3679	0.1586	0.3765	0.3968	0.3331	0.6845	0.5894
U2	0.3256	0.000	0.7845	0.5641	0.4562	0.3218	0.8965	0.8756
U3	0.2336	0.6812	0.000	0.5498	0.3912	0.7896	0.7202	0.4521
U4	0.5635	0.3491	0.5978	0.000	0.5857	0.4287	0.2964	0.4978
U5	0.3256	0.5968	0.4156	0.7481	0.000	0.7846	0.1027	0.7202
U6	0.7356	0.7874	0.9785	0.7984	0.5846	0.000	0.4096	0.7946
U7	0.308	0.4562	0.2015	0.321	0.1452	0.2884	0.000	0.51
U8	0.6894	0.5122	0.393	0.5714	0.6134	0.9685	0.7812	0.000

Table 4: Total Relation Matrix.

	U1	U2	U3	U4	U5	U6	U7	U8
U1	0.1811	0.2710	0.2246	0.2810	0.2485	0.2754	0.3345	0.3426
U2	0.3142	0.2915	0.4100	0.4011	0.3321	0.3694	0.4621	0.4853
U3	0.2859	0.3953	0.2683	0.3843	0.3079	0.4202	0.4117	0.4018
U4	0.3095	0.3051	0.3334	0.2511	0.3122	0.3319	0.3048	0.3669
U5	0.3095	0.3845	0.3505	0.4244	0.2469	0.4303	0.3125	0.4496
U6	0.4374	0.4908	0.5070	0.5077	0.4123	0.3744	0.4497	0.5479
U7	0.2043	0.2469	0.1980	0.2313	0.1739	0.2269	0.1779	0.2844
U8	0.4004	0.4091	0.3762	0.4319	0.3814	0.4925	0.4619	0.3696

aging regulatory expectations" (U5) and manufacturing quality problems" (U3) all have "positive" (J- K) values and are classified as part of the triggered community or cause group. Others, such as "market withdrawal" (U1), "shortage of raw material" (U4), and "purchaser manufacturing incentive" (U7) factors in the market fall into the effect group since their (J - K) value is negative. Factors in the "cause" community affect factors in the "effect" group, as seen in the causal diagram. After looking at table 5 and the sketch, it appears that U6 is more important because it has the highest (J+ K) and (J - K) values, i.e., 6.6482 and 0.8062, respectively, making it a precise influence.

Furthermore, an interrelationship matrix is developed to understand the mutual interdependencies better. This is developed by comparing the values of the total relation matrix with the threshold value 'β'. A threshold value is evaluated by implying the formulation mentioned in equation 10.

$$\beta = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m}[t_{ij}]}{N} \qquad (10)$$

Where, N = Total number of components in the total relation matrix (T)

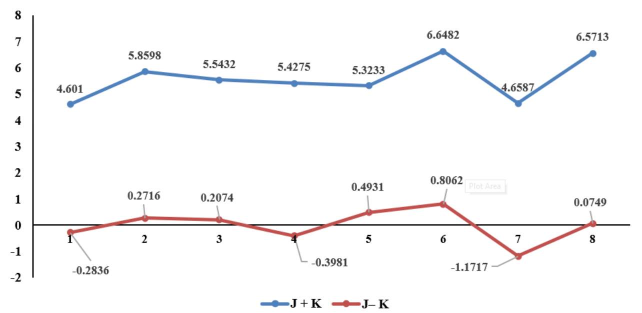

Figure 1: Data plot of prominence and relation values of identified factors.

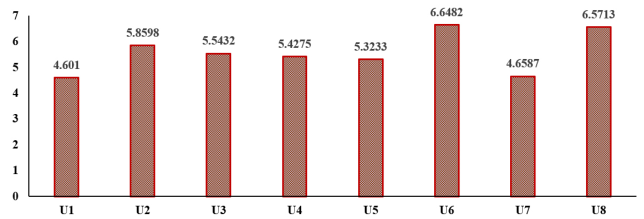

Figure 2: Causal factors plot.

The total interrelationship value-based matrix is developed by comparing the total relation matrix elements with the threshold value individually. This is evaluated in table 6, where values having higher values than the threshold are indicated by the "*" for ease of convenience.

Conclusion

To meet the objective of the study, a collection of eight critical factors was recognized and evaluated using DEMATEL's fuzzy tactic. The planned method is the expansion of the DEMATEL technique, which uses language words and a vague aggregation method to avoid ambiguities and imprecise judgements. Conversion Fuzzy Data into Crisp Scores (CFCS) was used in this work to aggregate fuzzy data. To cut the sophistication of the problem and make reliable decisions, Fuzzy DEMATEL brings together a set of factors in groups of cause and effect. According to the research, the cause group factors (U6, U5, U8, U2 and U3) have a more important impact on the stated objective due to their high degree of interaction. As a result, they are tough to move and necessitate more attention. "SUPPLY CHAIN DESIGN" (U6) is a major stumbling factor, according to research

Table 5: Evaluated prominence and relation values.

	Factors	J	K	J + K *Prominence*	J – K *Relation*
U1	Market Withdrawals	2.1587	2.4423	4.6010	-0.2836
U2	Export Demand	3.0657	2.7941	5.8598	0.2716
U3	Manufacturing and Quality Problems	2.8753	2.6679	5.5432	0.2074
U4	Shortage of Raw Material	2.5147	2.9128	5.4275	-0.3981
U5	Managing Regulatory Expectations	2.9082	2.4151	5.3233	0.4931
U6	Supply Chain Design	3.7272	2.921	6.6482	0.8062
U7	Purchaser–Manufacturer Incentives	1.7435	2.9152	4.6587	-1.1717
U8	Lack of Advanced Learning System	3.3231	3.2482	6.5713	0.0749

Table 6: Inter-relation matrix for identified factors (β = 0.3487).

	U1	U2	U3	U4	U5	U6	U7	U8
U1	0.1811	0.2710	0.2246	0.2810	0.2485	0.2754	0.3345	0.3426
U2	0.3142	0.2915	0.4100*	0.4011*	0.3321	0.3694*	0.4621*	0.4853*
U3	0.2859	0.3953*	0.2683	0.3843*	0.3079	0.4202*	0.4117*	0.4018*
U4	0.3095	0.3051	0.3334	0.2511	0.3122	0.3319	0.3048	0.3669*
U5	0.3095	0.3845*	0.3505*	0.4244*	0.2469	0.4303*	0.3125	0.4496*
U6	0.4374*	0.4908*	0.5070*	0.5077*	0.4123*	0.3744*	0.4497*	0.5479*
U7	0.2043	0.2469	0.1980	0.2313	0.1739	0.2269	0.1779	0.2844
U8	0.4004*	0.4091*	0.3762*	0.4319*	0.3814*	0.4925*	0.4619*	0.3696*

findings. A firm must commit to designing an effective supply chain to reduce the drug shortage to achieve this (U6). On the other hand, the factors of the effective group (U4, U7 and U1) are easily influenced by the factors of the cause group and may be displaced, so they need to be improved. As a result, it is concluded that an organization should place a greater emphasis on maintaining irregular infrastructure and supply chain support, support systems, as well as a higher degree of integration in their engineering preparation and process maturity, in order to reduce the shortage of drugs in the Indian pharmaceutical and medical supply chain system. This study provides an empirical review of the study factors, outlining their classification into cause-and-effect groups and the degree of interaction. This research work's findings may help managers adopt an effective and adaptable supply chain system in the Indian pharmaceutical and health care sectors, therefore improving the drug shortage problem.

Acknoweldgements

None

Conflict of Interest

None

Credit Author Statement

Janpriy Sharma: Conceptualization, Data analysis, Methodology, Writing - original draft preparation, Writing - review and editing; Mohit Tyagi: Conceptualization, Investigation, Methodology, Writing - original draft preparation, Writing - review and editing; Ajay Gupta: Investigation, Writing - review and editing; Thakur Singh Kharavat: Conceptualization, Data analysis, Methodology, Writing - original draft preparation. All the authors read and approved the manuscript.

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