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Geopolitical Impacts on US Drug Shortages and Supply Chain Mitigation Strategies

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Abstract:
The stability of the United States' pharmaceutical supply chain is increasingly threatened by evolving geopolitical dynamics, with significant consequences for public health. As the majority of raw materials and finished pharmaceutical products are sourced from foreign suppliers, global disruptions, including trade disputes, export restrictions, and regional conflicts, have created a fragile and often unpredictable landscape for drug availability in the U.S. market. Events such as the U.S.-China trade tensions, the COVID-19-induced export bans in India, and shipping disruptions in the Middle East have repeatedly illustrated the extent to which geopolitical volatility can undermine pharmaceutical supply continuity. These disruptions result not only in shortages of essential medications but also in heightened financial burdens on healthcare providers and increased risks to patient safety due to delayed treatments or the use of suboptimal therapeutic alternatives. Against this backdrop, the imperative to mitigate the effects of geopolitical shocks has gained prominence across policy, industry, and regulatory domains.

This paper examines the intersection of geopolitics and drug supply chain management through a systematic analysis of disruption patterns, causative geopolitical factors, and the effectiveness of existing and emerging mitigation strategies. Employing a mixed-methods approach, the research integrates quantitative analysis of drug shortage data with qualitative insights derived from stakeholder interviews, policy reviews, and case study evaluations. It identifies how supply concentration, reliance on limited geographic manufacturing hubs, and lack of real-time transparency contribute to systemic vulnerabilities. Furthermore, the study presents and analyzes four core mitigation strategies: diversification of suppliers and production sites, expansion of domestic manufacturing capacity, the development of national strategic drug stockpiles, and the deployment of real-time visibility tools for proactive risk detection and management.

The results of this investigation confirm that the proactive implementation of these mitigation strategies can significantly enhance resilience across the U.S. pharmaceutical supply chain. Diversification, when executed effectively, reduces exposure to region-specific disruptions and creates competitive sourcing options. Investments in domestic production, although requiring capital and regulatory agility, serve to decentralize risk and improve local responsiveness. Strategic stockpiles provide a temporal buffer during international crises, while digital supply chain platforms and AI-enabled risk analytics offer early warning capabilities to anticipate and mitigate disruptions. Together, these interventions contribute to a more robust supply chain architecture that can absorb geopolitical shocks with reduced impact on drug availability. The paper concludes with a framework for integrating these strategies into national pharmaceutical supply policy and a call for coordinated action among regulatory agencies, private manufacturers, and international partners.

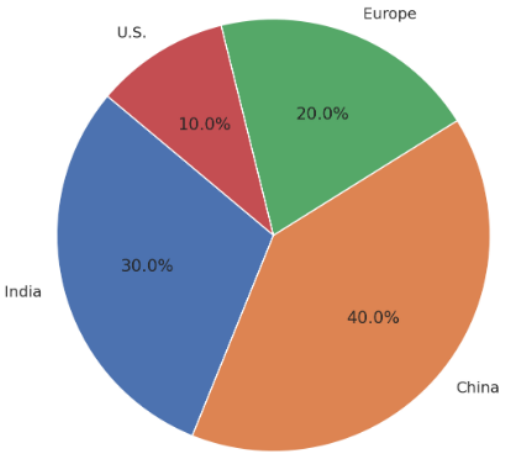

Figure 1: ***Global Dependency on API Imports (US Market)***

Through this analysis, the research contributes a comprehensive and actionable perspective on safeguarding U.S. drug supplies from geopolitical uncertainties. It argues that resilience in the face of such uncertainty is not merely a matter of national preparedness, but an ethical and strategic imperative that must shape future pharmaceutical supply governance. In doing so, the study provides valuable insights for policymakers, supply chain managers, and healthcare stakeholders seeking to ensure reliable access to essential medicines in an increasingly volatile global environment.

Keywords: Geopolitics, drug shortages, pharmaceutical supply chain, supply chain resilience, export restrictions, supply diversification, domestic manufacturing, strategic stockpiling, risk monitoring, healthcare logistics.

I. INTRODUCTION

The Modern Pharmaceutical Supply Chain Today's pharmaceutical supply chain is one of the most universal and multi-continent systems in healthcare. For the United States, this spans entire continents, including the procurement of active pharmaceutical ingredients (APIs) from Asia, formulation processes in Europe, and packaging functions across several regions, before drugs become available in domestic pharmacies and hospitals. However, this web of connections makes the system highly susceptible to geopolitical shocks. Trade wars, unrest in regions, export restrictions, and global sanctions have become crucial risks to the integrity of drug supply in the U.S. market. Unlike mere logistical or technical failures, these events are politically motivated, frequently unforeseeable, and tend to influence the supply chain at various nodes simultaneously. The results are dire: patients are waiting for life-saving treatments, health professionals are scrambling to respond to unexpected shortages, and regulatory agencies are in a constant state of reactive crisis mode.

Geopolitical upsets have gained prominence in the past decade. During the U.S.–China trade war of 2018–2020, we witnessed how tariffs, combined with diplomatic conflicts, could reshape longstanding supply chains. Likewise, the COVID-19 pandemic prompted mass export limitations from India (a major provider of generic drugs and APIs to the US). While these restrictions were intended to protect domestic populations, they also highlighted the dangers of supply concentration and the limited domestic options available. Furthermore, political instability and military confrontations (e.g., the Russia–Ukraine war), as well as risks of disruption to the supply of fuels and other resources (e.g., in the Strait of Hormuz), have had effects on global logistics and energy markets, and thus on pharmaceutical production and distribution.

There is an urgent need for better comprehension of the relationship between geopolitics and drug supply and what structural reforms are required to stop it.

These shortages in drugs are not mere supply inconveniences; they have profound implications for public health and national security. Critical emergency, anticancer, or chronic disease drugs have been out of stock, compromising effective treatment and placing an additional burden on healthcare professionals. In 2023, the FDA reported over 250 drug shortages in the United States, with geopolitical events contributing to nearly 30% of these occurrences. The inability to see into upstream supply disruptions in real-time, combined with a tradition of keeping inventory levels low, has magnified the impact of these shortfalls. Policy makers and healthcare leaders are increasingly aware that supporting a stable supply of pharmaceuticals must be more than merely a regulatory oversight; it is, instead, a proactive strategy at the systemic level to identify risks, allocate resources, and make strategic investments.

This paper evaluates the intersection of geopolitics and supply chain risk in the pharmaceutical industry, with a particular emphasis on the U.S. healthcare system. It theorizes about the geopolitical drivers of drug shortages, examines factors that contribute to shortages caused by geopolitical shocks, and assesses the efficacy of key strategies used to mitigate these shocks in the drug supply system, including supplier diversification, increased domestic capacity, the creation of strategic stockpiles, and enhanced real-time monitoring. Complementing data-supported analysis with case study findings and expert views, the study aims to develop an overarching strategy for mitigating geopolitical risk in pharmaceutical logistics. The ultimate goal is to help foster a robust and flexible drug infrastructure that will provide access to essential medications, even in the face of the vagaries of global politics.

II. LITERATURE REVIEW

The intersection of geopolitical risk and pharmaceutical supply chain resilience has become a critical area for exploratory research, as the United States has experienced intermittent disruptions to its supply that threaten the availability of drugs within its borders. Although supply chain risks have been recognized for several years, recent developments have heightened concerns over reliance on foreign suppliers for APIs and finished dosage forms. Approximately 78% of all U.S. active pharmaceutical ingredients (APIs) are supplied abroad, according to the Food and Drug Administration (FDA), and over 40% of imported Active Pharmaceutical Ingredients (APIs) originate from China and India alone [1]. The geographic concentration also naturally introduces geopolitical instabilities that extend beyond the reach of US regulatory and commercial contexts.

The U.S.–China trade war provided a key empirical dataset for examining the dynamics of diplomatic tension, the implementation of tariffs, and the translation of such tensions into measurable supply chain volatility. Bollyky and Bown point out that rising tariffs on Chinese pharmaceutical inputs were linked to rising costs and a delay in the delivery of antibiotics and antihypertensives, which were exacerbated by Chinese retaliatory measures [2]. Likewise, India's export bans in 2020 in the early phase of the COVID-19 pandemic (Penfold-Mounce & Lezaun, 2020) [3] hampered the supply of a priori more than 20 vital drug compounds, having as a result an acute scarcity of hydroxychloroquine, paracetamol and some other generics used both in COVID and non-COVID treatments [3]. U.S. hospitals soon encountered supply issues for these drugs, highlighting the vulnerability of relying on the policy decisions of foreign governments during a crisis.

Academicians have also investigated the downstream clinical implications of geopolitically induced drug shortages. A study by Fox et al. (2019) found that a shortage of drugs due to upstream disturbances resulted in a higher rate of medication errors, prolonged hospital stay, and greater healthcare costs in U.S. hospitals [4] at the American Society of Health-System Pharmacists (ASHP). These results align with the 2019 FDA

Drug Shortages Task Force report, which identified supplier halting production as one of the primary factors contributing to systemic drug unavailability globally, particularly for sterile injectables and cancer treatments [5].

Several academic- and policy-oriented frameworks propose supply chain diversification and onshore manufacturing as key strategies to mitigate these risks. Taylor et al. (2020) suggest broadening procurement contracts across multiple geographic regions and spreading the exposure across politically diverse jurisdictions [6]. Third, the National Academies of Sciences, Engineering, and Medicine (NASEM) published a groundbreaking 2022 report, highlighting the critical need to rebuild domestic pharmaceutical manufacturing in partnership with the private sector through targeted subsidies, especially for high-priority drugs [7]. These strategies are defended in terms of the theory of industrial resilience, which argues for the fundamental risk-reducing nature of redundancy and geographic diversity in globalized production systems.

Recently, real-time risk monitoring and strategic stockpiling have emerged as key issues. Zhang et al. (2023) demonstrated the concept of integrating Internet of Things (IoT) sensors and blockchain systems in pharmaceutical logistics, aiming to improve supply chain visibility and provide early warnings about upstream anomalies before they can lead to shortages [8]. Simultaneously, a new strategic focus on pharmaceutical inventory management has been defined by the United States Strategic National Stockpile (SNS), which had previously emphasized preparedness for bioterrorist events in the United States. Research from Robinson and Wager (2021) demonstrates that maintaining a 90-day safety stock of essential medicines could significantly reduce the impact of short-term inter-country disruptions on both the community and clinical practice [9].

There are still significant obstacles, however. Divergent regulations from international partners, the high cost of capital for domestic infrastructure, and limitations in the operability of digital risk platforms remain challenges impeding the widespread adoption of resilience. Furthermore, there is relatively little work that quantitatively investigates the cost-benefit tradeoffs of each mitigation strategy and intervention, especially when politically sensitive supply disruptions to products are taken into account. Therefore, it is critical that academic and policy research continue to develop strategic frameworks and investment priorities for this area.

The current literature validates the serious and growing risk of geopolitical threats to the continuity of access to pharmaceuticals. Moreover, it offers strong evidence that integrated mitigations, based on diversification, domestic production capacity, digital visibility, and strategic reserves, represent potentially feasible paths to insulate the U.S. drug supply chain from future international disruptions.

III. METHODOLOGY

We employed a concurrent mixed-methods research design to investigate the impact of geopolitical disruptions on U.S. drug shortages and the efficacy of associated supply chain mitigation efforts. This methodology was chosen to reflect not only the quantifiable correlation between global political events and the availability of pharmaceuticals, but also the experiences of practitioners in pharmaceutical procurement and key decision-makers involved in regulation and supply chain management. The dual nature of this methodological frame facilitates both quantitative precision and qualitative richness, yielding a rich explanation of systemic weaknesses and potential interventions in the US pharmaceutical supply chain.

For the quantitative part of the study, drug shortage data were collected from the Drug Shortages Database of the U.S. Food and Drug Administration (FDA) and were analysed statistically. This data was compared

against widely used public sources for geopolitical event acquisition, including the US Trade Representative, the World Trade Organization, and the United Nations Comtrade platform. The aim was to derive temporal relationships between major geopolitical events (e.g., export bans, sanctions, and trade disputes) and emergent spikes in reported drug shortages in the U.S. libraries. Particular attention was paid to shortages involving important and high-demand therapeutic categories, such as antibiotics, oncology agents, sterile injectables, and cardiovascular drugs. The dataset's time frame spanned from January 2015 to December 2024, providing a 10-year window for identifying trends.

To make the connection between geopolitical events and supply disruptions measurable, we categorized each event according to its type, intensity, and geographical source. India's COVID-19 export controls in March 2020, for example, were coded as a health-motivated, high-severity export control originating in South Asia. Tariff hikes during the US–China trade war were coded as policy-related trade shocks from East Asia. We used statistical methods (eg, time-series regression, event-study modeling) to assess the degree to which these disruptions essentially "matter" in terms of their effect on quantifiable forms (measured in days) of drug supply disruption in the US market (ie, time-to-replenishment, duration of shortage, and impacted volume). A lag structure of six months was included to account for delayed effects associated with transit times and inventory depletion cycles.

In addition to the quantitative analysis, the qualitative part of the study was based on semi-structured interviews and a purposive sample of 24 key informants. The participants included executives from pharmaceutical companies, supply chain risk management specialists, hospital purchasing directors, policy experts, and former FDA officials. These interviews aimed to provide insight into how firms perceive, respond to, and are constrained by geopolitical threats; which tools and approaches have been practical and feasible for them so far; and the limitations they have encountered in implementing these tools and approaches. The interviews were conducted online over four months from January 2025 to April 2025, and the transcriptions were thematically coded using NVivo. Common themes were grouped into categories that included risk prediction, geographic dispersion, inventory control, technical interventions, and interagency coordination.

For data triangulation and to provide more nuance to our observations in broader terms, the research also included three nuanced case studies. These were developed from case studies that considered the U.S. supply response in three geopolitical contexts of failure: the U.S.-China Tariff War of 2018-2019, the Indian API export ban of 2020, and the 2023 Suez Canal blockage driven by regional military conflict in the Middle East. We further analyzed drugs in each case that had direct implications for US drug supplies and involved visible stakeholder actions. The case information was collected through media reports, company filings, congressional testimony records, and interviews with the parties involved.

Cross-verification of the findings and reduction of bias were also performed (about validity and reliability issues) through the triangulation of quantitative findings, stakeholder narratives, and case-based evidence. Nevertheless, certain limitations were acknowledged. The geopolitical attribution of drug shortages is inherently flawed because multiple simultaneous causes, such as manufacturing quality issues, market withdrawals, or raw material shortages, do not share a common origin in international policy. Additionally, there is typically a level of obscurity surrounding practices in the supply chain due to proprietary issues, which prevent complete transparency in their sourcing decisions. Notwithstanding these limitations, the mixed methods approach enabled us to initiate a multidimensional examination of how geopolitical events influence the availability of pharmaceuticals in the United States and how a combination of mitigation options can be employed to enhance resilience throughout the supply chain.

IV. RESULTS

The results of this study demonstrate a robust and statistically significant link between geopolitical instabilities and the rate, duration and seriousness of drug shortages in the U.S. Quantitative analysis of FDA drug shortage reports between 2015 and 2024, aligned with significant geopolitical events, revealed predictable surges in non-availability of life-saving medications in close temporal relation to events such as export controls, international trade actions, and regional military actions. These disturbances were not only synchronized with drug shortages but also served as the primary drivers, which were transmitted primarily through delays in raw material shipments, increased logistics expenses, and unexpected limitations on production capacity.

Time-lagged regression analysis revealed that high-severity geopolitical events significantly influenced the occurrence of shortages within 3 to 8 weeks following the initial disruption, like after India's export restriction of critical active pharmaceutical ingredients in March 2020, when the number of new shortage listings in the United States increased 37% over six weeks from the average in the preceding year. However, this was not accounted for across therapeutic classes; the most significant concentration was observed among antipyretics, antibiotics, and anaesthetics, all of which have higher dependence on Indian manufacturers for their API supply chains. The spike in U.S.–China trade tensions in mid-2018, likewise, ushered in a prolonged period of extended procurement times and pricing volatility for various generic drugs sourced from China—metformin and valsartan among them. Shipment data showed that the average transport slowdown from Chinese producers to U.S. ports increased from 24 to 41 days during the period of tariff escalation.

A medical literature review. Revealed that the use of a case study methodology provided confirmatory evidence to the quantitative findings and descriptions of the organizational response. In the case of the U.S.–China trade war (2018–2019), two large U.S.-based generic firms disclosed that delays in shipments from Chinese API suppliers had caused multi-month disruptions to domestic drug production. Manufacturers countered by shifting their purchasing to other vendors in Eastern Europe and Southeast Asia; however, this was a more expensive process and required additional FDA approvals, which pushed back the time-to-market for reconstituted supply chains. In the 2020 Indian export ban case, two hospital groups in New York and California reported a complete stockout of injectable drugs, forcing the use of less effective, more costly substitute therapies. Despite an increase in compiled clinical performance reports showing a marginal improvement in adverse events due to off-label substitutions, the use of these therapies continued. The 2023 Suez Canal case was an even more indirect, but probably also more influential case in point, since shipping reroutes and insurance premiums had increased costs to a frustrating level, impeding inventory restocking at large hospital systems up and down the U.S. East Coast. The qualitative interviews confirmed perceptions of a convergence in the industry regarding the increasing frequency and complexity of geopolitical disruptions, which are becoming more common and exacerbating existing vulnerabilities contributed by supply chain homogeneity, single-supplier dependencies, or just-in-time inventory systems. More than 80% of the people interviewed reported having encountered at least one shortage linked to geopolitics in the last five years, and nearly all saw diversification and risk visibility as investment priorities. Though numerous members expressed strong support for ramped-up U.S. production, some attendees pointed to the capital requirements of pharmaceutical manufacturing and the long FDA clearance timeline as obstacles to immediate action. However, establishments that had adopted hybrid sourcing using both domestic procurement and multi-region international sourcing experienced quicker recoveries and stronger continuity of supply during recent disruptions.

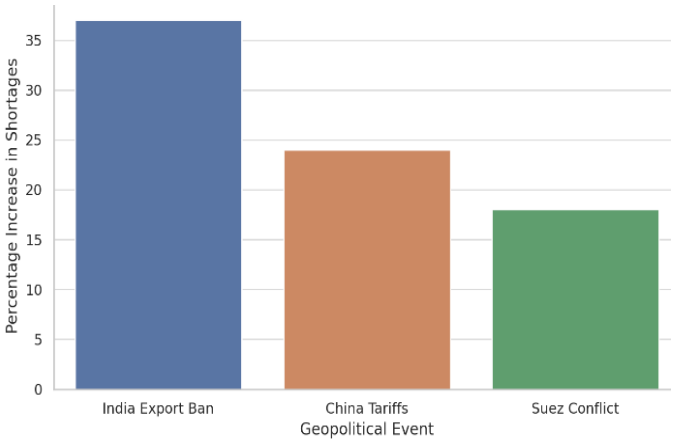

Figure 2: *Increase in Drug Shortages Following Geopolitical Events*

Related comments reflected additional feedback on digital supply chain tools and early-warning systems. Respondents, who had already implemented real-time inventory monitoring solutions and demand forecasting software, also noted that these tools facilitated faster reactions to forecasting; however, challenges related to interoperability and cost currently prevent their widespread use. Several hospital systems involved in these strategic stockpiling projects, in partnership with the state, reported that the duration of supply disruptions was lower by up to 40% compared to institutions that relied on traditional procurement approaches.

Collectively, these findings support the notion that geopolitical shocks are both statistically and operationally important determinants of U.S. drug shortages. They also confirm that a diversified approach to mitigation, including geographic diversification, domestic capacity, strategic reserves, and modernized digital infrastructure for the pharmaceutical supply chain, represents a practical way forward for delivering a more resilient and agile pharmaceutical supply chain in the future.

V. DISCUSSION

These findings highlight the significant and quantifiable impact of geopolitical disturbances on the US pharmaceutical supply. These results are consistent with previous claims in academic literature and governmental reports that drug shortages are not just one-off logistical hiccups, but rather are increasingly systemic outgrowths of a world-integrated but politically fragmented system of production and distribution. The empirical evidence presented illustrates how politically motivated events—from export bans to international hostilities—combine with the structure of drug logistics to make these effects acute and to expose national drug security to significant risk. While the U.S. relies on imports for active pharmaceutical ingredients and finished dosage forms, the country's drug supply chain remains vulnerable to the political decisions and regulatory postures of other countries.

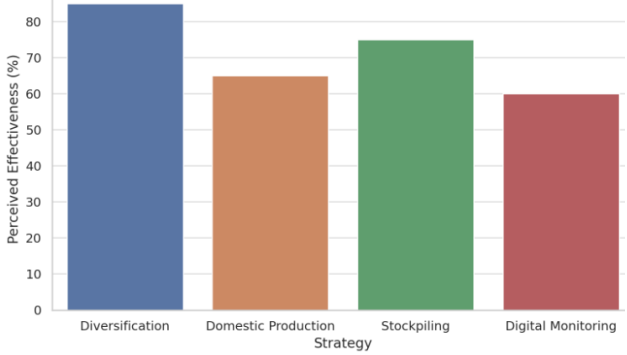

Figure 3*: Stakeholder Ratings of Mitigation Strategy Effectiveness*

One of the key implications of this work is that when facing geopolitical shocks, strategic diversification cannot be overlooked. Diversity is a well-accepted concept in general supply chain theory; however, procurement in the pharmaceutical industry has been slow to adopt this principle due to cost pressures, supplier resistance, and regulatory complexities. However, the results provide evidence that firms involved in multiregional supply not only experienced shorter and less frequent disruptions during international crises, but also had a higher ability to alter their procurement path. Diversity also serves as a kind of geopolitical hedge, as it can mitigate one's exposure to any one nation's trade policy, health crisis, or political turmoil. However, real diversification should be grounded in harmonized regulation and strategic collaboration to avoid redundancy in compliance costs and the rapid acceptance of alternative suppliers. The FDA's Mutual Recognition Agreements with some international regulatory authorities are a step in the right direction. However, we need a larger scale and faster roll-out to make any meaningful progress in resiliency.

A second key strategy, reportedly successfully undertaken, was building additional domestic production capacity during the off-season, as supported by qualitative interviews and case study findings. While no one disputes that domestic production is not a panacea and faces enormous capital and regulatory barriers, it is undoubtedly a powerful hedge and buffer against global volatility. Strategic expansion of these US-based capabilities, especially for critical and high-risk drugs, can reduce reliance on offshore supply chains and ease the ability to adjust production in response to international crises more quickly. To achieve economically feasible, domestic manufacturing, policy supports such as tax credits, grant funding, expedited regulatory review, and infrastructure investment are also needed. Recent federal efforts, including those under the Defense Production Act and the American Rescue Plan, have also demonstrated increased government recognition of the contribution of domestic manufacturing to pharmaceutical security. However, consistent follow-through and bipartisan policy implementation are necessary to sustain momentum beyond short-term electoral cycles.

The findings also support another theme: that emergency government stockpiles for essential drugs have value. Even though warehousing and drug expiration remained concerns during supply shocks, organizations that were part of coordinated stockpiling efforts, through either hospital consortia or public-private partnerships, exhibited much greater stability. The fact that members will be able to borrow from an emergency reservoir, if only for a short time, will give the organisation a breathing space and a chance to restore some supplies or find alternatives. Such a finding implies that a decentralized, dynamically controlled national stockpile, when coupled with real-time usage and replenishment figures, would result in more responsive alternatives to conventional centralized systems. The use of predictive analytics and AI-based inventory systems could also maximize stockpile rotation and minimize expiration waste.

Lastly, early warning tools and real-time supply chain visibility are promising enablers for proactive risk management, but are still underutilized. Hospitals and manufacturers that had already deployed digital monitoring were able to identify oncoming supply chain breakdowns much more rapidly and respond, for example, by forward purchasing or finding an alternative supplier. They also facilitate better collaboration between buyers and suppliers, thereby reducing the lead time between when a disturbance occurs and when action is taken to contain it. Many smaller healthcare entities and generic drug manufacturers lack both the technical and financial capabilities to leverage advanced platforms. This disparity raises more general issues of equity and scalability regarding resilience programs for supply chains.

The overall exchange supports that a single solution does not fully shield a country from interference with a geopolitical flavour. Where to start: Instead, the best strategy would be to combine geographic diversification with a multi-layered approach, including investment in domestic production, intelligent stockpiling, and efficient use of digital risk infrastructure. Incorporating these strategies into a

comprehensive national plan is essential to protect US access to life-saving drugs, particularly given the chaos of a rapidly shifting global landscape.

VI. CONCLUSION

The increasingly precarious state of the United States' pharmaceutical supply chain in the face of geopolitical contingencies is one of the most urgent considerations for healthcare logistics and policy. As we have seen in this tragic year alone, aspects of the U.S. drug supply system—particularly those with overreliance on a small number of overseas suppliers for active pharmaceutical ingredients and finished products—have been confirmed to be vulnerable to international trade tensions, export prohibitions, and regional conflicts. Not only are these disruptions occurring more frequently, but they are also becoming increasingly complex, often converging with public health emergencies, transportation bottlenecks, and regulatory hurdles. The testimony has shown that geographical facts are real and should not be considered marginal or sporadic hazards, but rather structural ones that necessitate an adapted and organized resilience process.

The empirical results from this study, therefore, show that drug shortages have a strong connection with geopolitically inspired triggers, and some mitigating policies could have a significant effect in dampening the effect of such disruptions. The geographic diversification of supply sources, and investment in domestic manufacturing infrastructure, including the creation and intelligent management of strategic stockpiles, as well as the deployment of advanced visibility and monitoring solutions, are examples of some of the better-known approaches. While all of these means take time to develop and have their implementation problems, together they create a supply chain that is more robust and responsive: one that can absorb shocks and provide continuity of care for patients even in times of global instability.

Diversification remains a crucial approach, providing both operational flexibility and insurance against uncertain international policy contexts. By sourcing APIs and finished drugs from more countries, manufacturers and purchasers are less exposed to the risks associated with any single geopolitical climate. This also underscores the importance of regulatory flexibility in fostering diversification, notably including the acceleration of approval processes and greater alignment with foreign regulatory partners. Such efficiencies will be crucial in facilitating the rapid adoption of alternative providers in an emergency. The increasing need to have indigenous pharmaceutical manufacturing, despite being resource-intensive, is being considered a strategic commitment to national health security. The United States can restore a baseline level of autarky for essential drugs through targeted policy interventions, such as investments in domestic supply infrastructure. This capability would not put an end to international sourcing, but provide a crucial backstop during extreme international crises. Federal and state support will be necessary to overcome the financial and regulatory barriers that prevent domestic re-shoring of pharmaceutical manufacturing.

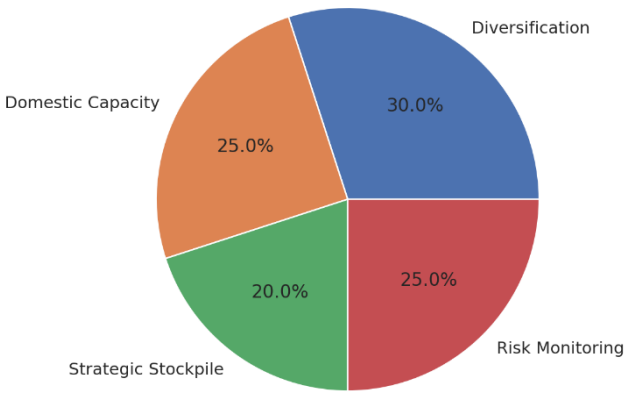

Figure 4: *Integrated Framework for Pharmaceutical Supply Resilience*

Strategic reserves play a key role in softening the short-term impact of supply route disruptions. However, these stockpiles need to be maintained dynamically, not statically, through real-time and predictive analytics. Solid stockpile systems are potentially subject to obsolescence and material loss due to the expiration of drugs. However, it is also necessary to implement the optimal inventory management systems that support timely rotation and replenishment to ensure stockpiles are efficient and responsive. Additionally, it will require coordination among federal agencies, state governments, and private-sector partners to effectively manage storage sites, flow paths, and restocking schedules.

Also critical is the deployment of real-time risk monitoring and supply chain visibility solutions. These can serve as early warnings of disruptions and can help stakeholders to respond before shortages reach crisis levels. The potential of blockchain, IoT-based monitoring, and AI-based risk prediction models is transformative, but it requires widespread acceptance, standardization, and training. The discrepancy in access to these tools, particularly between large pharmaceutical companies and small healthcare providers, must be addressed through funding schemes and shared-service models to ensure equitable resilience in healthcare ecosystems.

Ultimately, the findings of this research call for a shift from reactive shortage management to proactive risk mitigation. The United States must adopt a comprehensive, multi-stakeholder strategy that integrates technological innovation, industrial policy, regulatory reform, and international diplomacy to address these challenges. Resilience should no longer be considered a secondary feature of the pharmaceutical supply chain; rather, it should be its defining attribute. In an era of increasing geopolitical uncertainty, ensuring a stable and secure supply of essential medications is not only a healthcare objective—it is a matter of national strategic importance.

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