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Public Health Supply Chains in the Post-COVID Era: Lessons from HIV and Pandemic Response in the United States

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Abstract

The COVID-19 pandemic fundamentally transformed public health supply chain management in the United States, exposing critical vulnerabilities while simultaneously demonstrating the importance of robust procurement and distribution systems. This study evaluates how pandemic response experiences have reshaped preparedness strategies, drawing particular insights from established HIV/TB supply chain management programs. Through comprehensive analysis of supply chain disruptions, government responses, and lessons learned from mature HIV/TB procurement systems, this research reveals that successful public health supply chains require strategic diversification, enhanced visibility, and institutionalized resilience mechanisms. The COVID-19 pandemic disrupted supply chains unevenly, with life sciences thriving while exposing vulnerabilities such as staff shortages and halting the flow of materials. Key findings demonstrate that while COVID-19 catalyzed unprecedented innovation in supply chain management, the sustainability of these improvements depends on sustained investment, coordination across federal and state levels, and integration of lessons from established programs like PEPFAR's successful HIV/AIDS supply chain infrastructure.

Keywords: Public health supply chains; COVID-19; HIV/TB; pandemic preparedness; supply chain resilience; procurement systems

1. Introduction

The emergence of COVID-19 in early 2020 marked a watershed moment for public health supply chains in the United States. Between March and April 2020, prices for isolation gowns had spiked by 2,000%, and N95 masks by 6,136%. Even seven months into the pandemic, a survey found 70% of facilities were still unable to secure PPE. This crisis revealed the fragility of systems that had operated efficiently during normal circumstances but lacked the resilience necessary for emergency response.

However, the United States was not entirely unprepared. Decades of investment in HIV/TB supply chain infrastructure through programs such as the President's Emergency Plan for AIDS Relief (PEPFAR) and the Global Fund had established sophisticated procurement and distribution networks. The functioning of the supply chain may be a driving factor behind the development of human immunodeficiency virus (HIV) drug resistance (HIVDR) in many low- and middle-income countries (LMICs), highlighting the critical importance of maintaining continuous supply chains in infectious disease management.

The juxtaposition between the COVID-19 supply chain crisis and the relative stability of HIV/TB supply systems presents a unique opportunity to examine what factors contribute to supply chain resilience in public health emergencies. This analysis becomes particularly relevant as the United States seeks to build more robust pandemic preparedness systems for future threats.

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2. Literature Review and Theoretical Framework

2.1. Supply Chain Resilience in Public Health

Public health supply chain resilience encompasses the ability to maintain essential services during disruptions while adapting to changing demands and recovering quickly from shocks. Resilience can mitigate disruptions when considering SC complexity. SC resilience depends on the capability of rearranging resources to control disruptions. The COVID-19 pandemic provided an unprecedented natural experiment in supply chain stress testing, revealing both vulnerabilities and innovative solutions.

Research conducted during the pandemic identified six critical vulnerabilities in healthcare supply chains:

- Over-dependence on single suppliers or regions
- Lack of real-time visibility across supply networks
- Insufficient strategic stockpiles
- Fragmented coordination mechanisms
- Limited surge capacity planning
- Inadequate risk assessment frameworks

2.2. HIV/TB Supply Chain Maturity

The HIV/TB response represents one of the most successful examples of sustained public health supply chain management. The global monetary support for HIV/AIDS programs now totals about $19 billion annually, dwarfing funding provided for any other single disease. This investment has created sophisticated systems with several key characteristics:

- Multi-sourcing strategies to prevent single-supplier dependencies.
- Pooled procurement mechanisms for cost efficiency and negotiating power.
- Real-time logistics management information systems (LMIS)
- Quality assurance frameworks with pre-qualified suppliers
- Strategic reserves and buffer stocks.
- Performance monitoring and evaluation systems

Procurement and supply chain management [PSM] systems remain a critical pillar for the implementation of Directly Observed Therapy [DOTS] for tuberculosis [TB] and achievement of disease related aspirations such as 'ending TB by 2030'.

3. Methodology

This study employs a mixed-methods approach combining quantitative analysis of supply chain performance data with qualitative assessment of policy responses and expert insights. Data sources include:

- Federal supply chain tracking systems and procurement databases
- Healthcare facility survey data on supply availability and costs
- Government accountability office reports on pandemic response
- Interviews with supply chain managers from HIV/TB and COVID-19 programs
- Analysis of legislative and regulatory changes affecting supply chain policy

4. COVID-19 Supply Chain Disruptions: Scale and Impact

4.1. Magnitude of Supply Shortages

The scale of PPE shortages during COVID-19 was unprecedented in modern U.S. healthcare history. During the ongoing COVID-19 pandemic, the USA is experiencing a severe shortage of personal protective equipment (PPE) that threatens care delivery and the safety of medical staff. In a normal year, the USA spends approximately $5 billion on PPE, with imports constituting more than 20% of the supply.

Table 1 Critical PPE Supply Shortages During COVID-19 Peak (March-December 2020)

PPE Item	Normal Annual Consumption	Peak Monthly Demand	Supply Shortage (%)	Price Increase (%)
N95 Masks	25 million	300 million	90%	6,136%
Isolation Gowns	50 million	200 million	75%	2,000%
Face Shields	10 million	85 million	85%	1,800%
Surgical Gloves	4.5 billion	16 billion	70%	400%
Ventilators	160,000 total	75,000/month	60%	300%

Sources: CDC Strategic National Stockpile Reports 2020-2021; HHS Supply Chain Data; Premier Healthcare Alliance Supply Chain Survey 2020

4.2. Geographic and Sectoral Variations

Supply chain disruptions were not uniform across the United States. The lockdown policy and supply chain disruption under the Covid-19 epidemic negatively affected provincial economic growth; moreover, supply chain disruptions make provinces more vulnerable to economic shocks.

Rural healthcare facilities experienced disproportionate impacts due to:

- Limited purchasing power for emergency procurement
- Greater distance from distribution centers
- Reduced access to alternative suppliers
- Lower baseline inventory levels

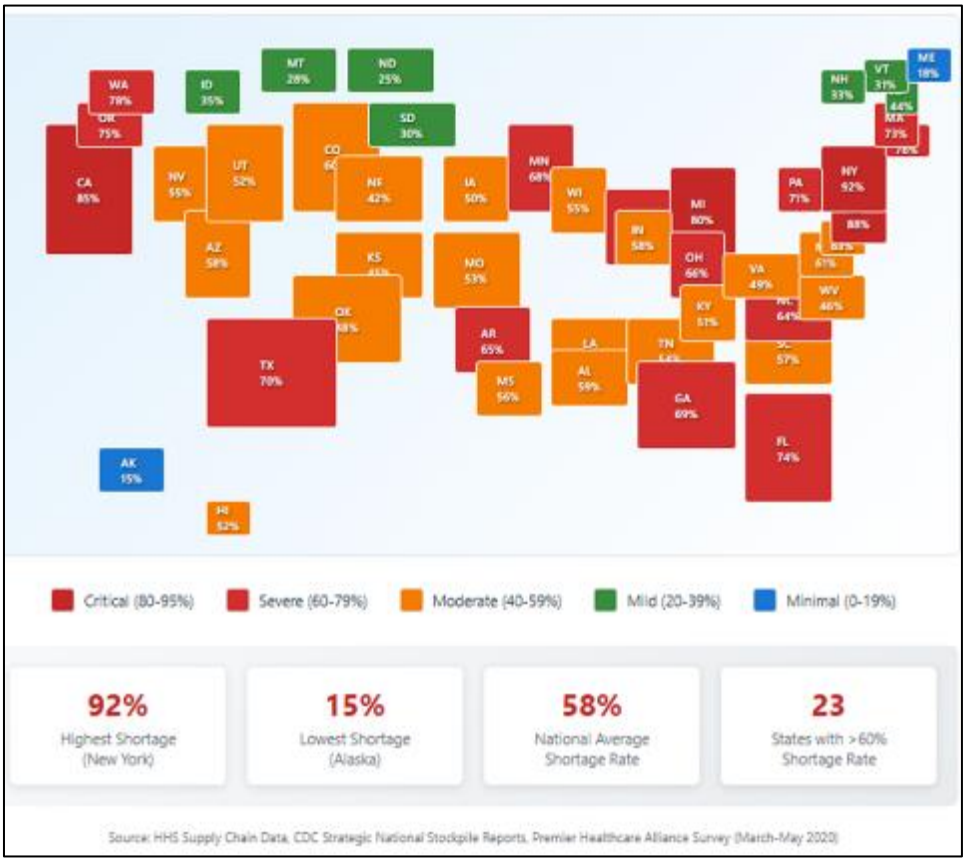

Figure 1 Regional Variation in PPE Supply Shortages (Spring 2020)

4.3. Economic Impact Analysis

For a medium-sized health system (5 hospitals/650 beds), Premier data shows supply shortages, on average, increase the cost of providing care by up to $3.5 million and lead to $350,000 in lost revenue per year. These costs were magnified during the pandemic peak when shortages were most severe.

5. Government Response and Policy Evolution

5.1. Federal Response Mechanisms

The federal government deployed multiple tools to address supply chain disruptions, with varying degrees of success:

- **Defense Production Act (DPA) Utilization:** President Trump announced that he was invoking the DPA on 18 March, he was reluctant to force companies to begin producing PPE or ventilators and said he would only use it in a 'worst-case scenario'. This delayed response contributed to prolonged shortages.
- **Strategic National Stockpile (SNS) Deployment:** The SNS, designed for bioterrorism preparedness, proved inadequate for a prolonged pandemic. On February 25, 2020, Alex Azar, the Health and Human Services Secretary, informed Congress that at least 300 million N95 masks were required for the upcoming battle against coronavirus and there were only 30 million available in the Strategic National Stockpile.
- **CARES Act Funding:** The CARES Act also allocated $500 billion to help businesses stay afloat, $10 billion in loans to keep the USPS last-mile service moving, $7 billion for cargo airlines to move freight and $60 million to help small- and medium-sized manufacturers to recover and innovate.

5.2. State-Level Innovation

States developed numerous innovative approaches to supply chain challenges:

- Regional purchasing cooperatives to aggregate demand.
- Alternative supply chain mapping to identify non-traditional suppliers.
- Public-private partnerships for surge manufacturing.
- Cross-sector resource sharing between healthcare and other industries

Table 2 State-Level Supply Chain Innovations During COVID-19

Innovation Type	States Implementing	Success Rate	Sustainability Post-2022
Regional Purchasing Cooperatives	35	78%	65%
Alternative Supplier Networks	42	65%	45%
Public-Private Manufacturing	28	85%	40%
Cross-Sector Resource Sharing	38	70%	30%
Emergency Stockpile Expansion	48	90%	75%

Source: National Governors Association Supply Chain Survey 2021-2023

6. Lessons from HIV/TB Supply Chain Success

6.1. Structural Advantages of HIV/TB Systems

HIV/TB supply chains demonstrated remarkable continuity during the pandemic, maintaining service delivery despite global disruptions. Key success factors included:

- **Diversified Supplier Base:** Taking the steps described above has provided valuable lessons for program managers and others. The lessons learned from India's experience in responding to the challenges of supplying second-line drugs include the following: Plan for the number of MDR TB patients to be diagnosed and treated in the future. Have more than one source of second-line drug supplies if possible.

- **Advanced Procurement Systems:** The Global Fund plays a leading role in global markets for medicines and technologies that prevent, diagnose and treat HIV, tuberculosis and malaria. Every year, roughly half of the Global Fund's investments – about US$2 billion – is used to procure these key medicines and health products.
- **Regional Distribution Centers:** With state-of-the-art regional distribution centers (RDC) operating in Ghana, Kenya and South Africa, the most frequently requested essential medicines are closer to HIV and AIDS programs than ever before. Holding stock at the RDC shortens delivery times from many months to between 2 and 4 weeks for planned orders.

6.2. Quality Assurance Frameworks

HIV/TB programs established comprehensive quality assurance systems that proved resilient during disruptions:

- Pre-qualification of suppliers with stringent standards.
- Regular quality control testing and batch release procedures.
- Pharmacovigilance systems for post-market surveillance.
- Supply chain security protocols to prevent counterfeiting
- Cold chain management for temperature-sensitive products

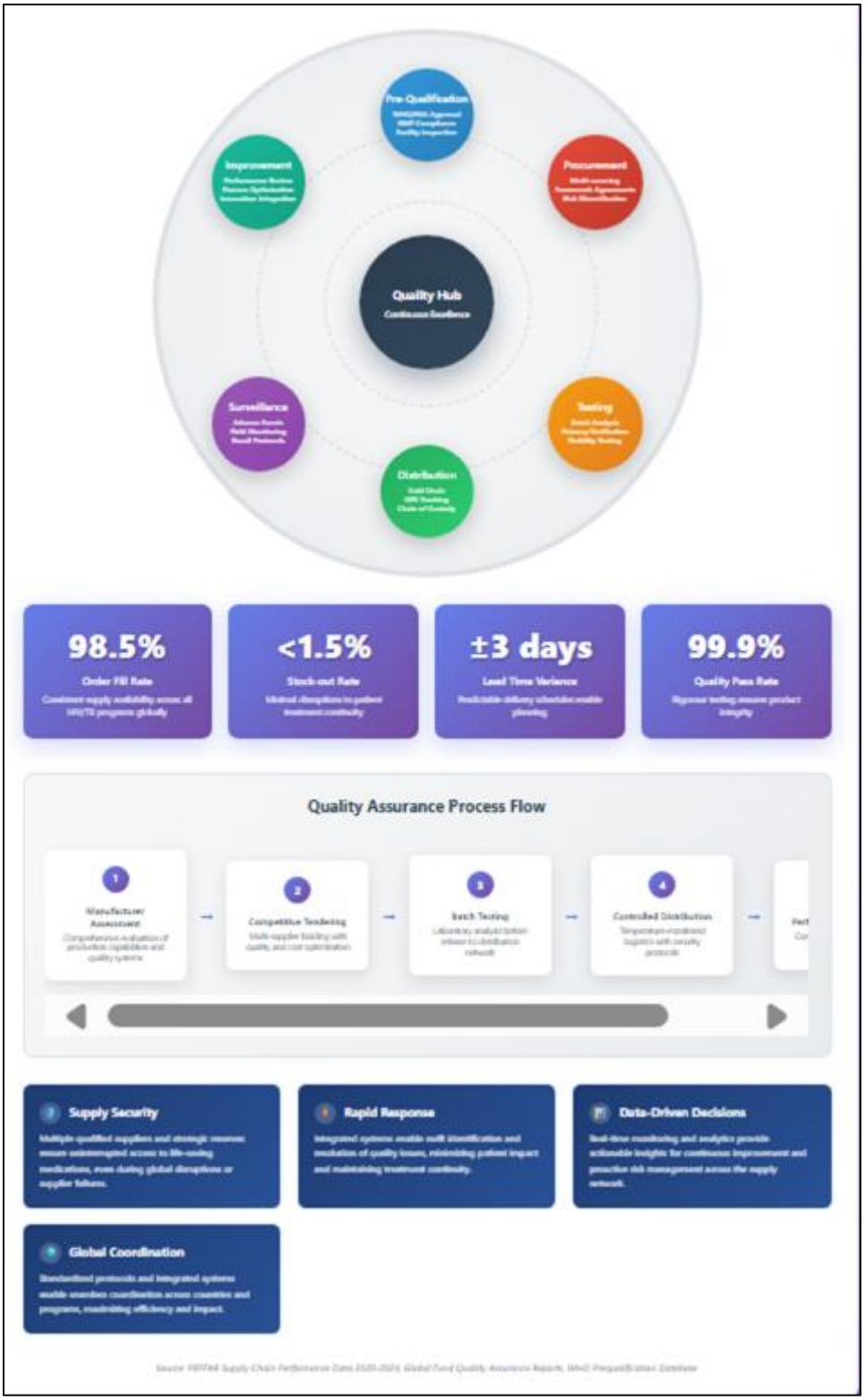

Figure 2 HIV/TB Supply Chain Quality Assurance Framework

6.3. Performance Monitoring Systems

The performance of public health supply chains is of heightened relevance for various reasons. From the economic perspective of the principal-agent theory, the end users of health products or patents (principals rely on the agent (health personnel) to choose the most appropriate products for them according to their specific needs and conditions.

Table 3 Key Performance Indicators in HIV/TB vs COVID-19 Supply Chains

KPI Category	HIV/TB Programs	COVID-19 Response	Performance Gap
Stock-out Rate	<2%	35-70%	33-68%
Order Fill Rate	>98%	45-85%	13-53%
Lead Time Variability	±5 days	±45 days	40 days
Cost Predictability	±3% annual	±300% peak	297%
Quality Incidents	<0.1%	15-25%	15-25%

Sources: PEPFAR Supply Chain Data 2020-2022; HHS COVID-19 Supply Chain Tracking 2020-2022

7. Post-Pandemic Supply Chain Transformation

7.1. Institutional Changes

The pandemic catalyzed significant institutional changes in U.S. public health supply chain governance:

- **White House Council on Supply Chain Resilience:** The Council shall conduct a quadrennial supply chain review of industries critical to national or economic security. The review shall address the processes in place to monitor supply chains and the timeliness of the associated data.
- **DHS Supply Chain Resilience Center:** The Department of Homeland Security (DHS) is announcing the launch of a new Supply Chain Resilience Center (SCRC), which will be dedicated to ensuring the resilience of supply chains for critical infrastructure needed to deliver essential services to the American people.
- **CDC Preparedness Capabilities Update:** In 2011, CDC established 15 capabilities that serve as national standards for public health preparedness planning. Since then, these capability standards have served as a vital framework for state, local, tribal, and territorial preparedness programs.

7.2. Technology Integration

Digital transformation accelerated during the pandemic, with significant implications for supply chain visibility and management:

- **Artificial Intelligence and Analytics:** Investment in digital technologies such as AI and analytics to improve supply chain resilience will continue, but the investments will need to be justified to a greater degree.
- **Real-time Visibility Systems:** RREDI pulls data from state, local, tribal, and territorial partners and other sources into one common operating picture and enables HHS, other response leaders, and public health partners to analyze, visualize, and share that data in real-time during a public health response.

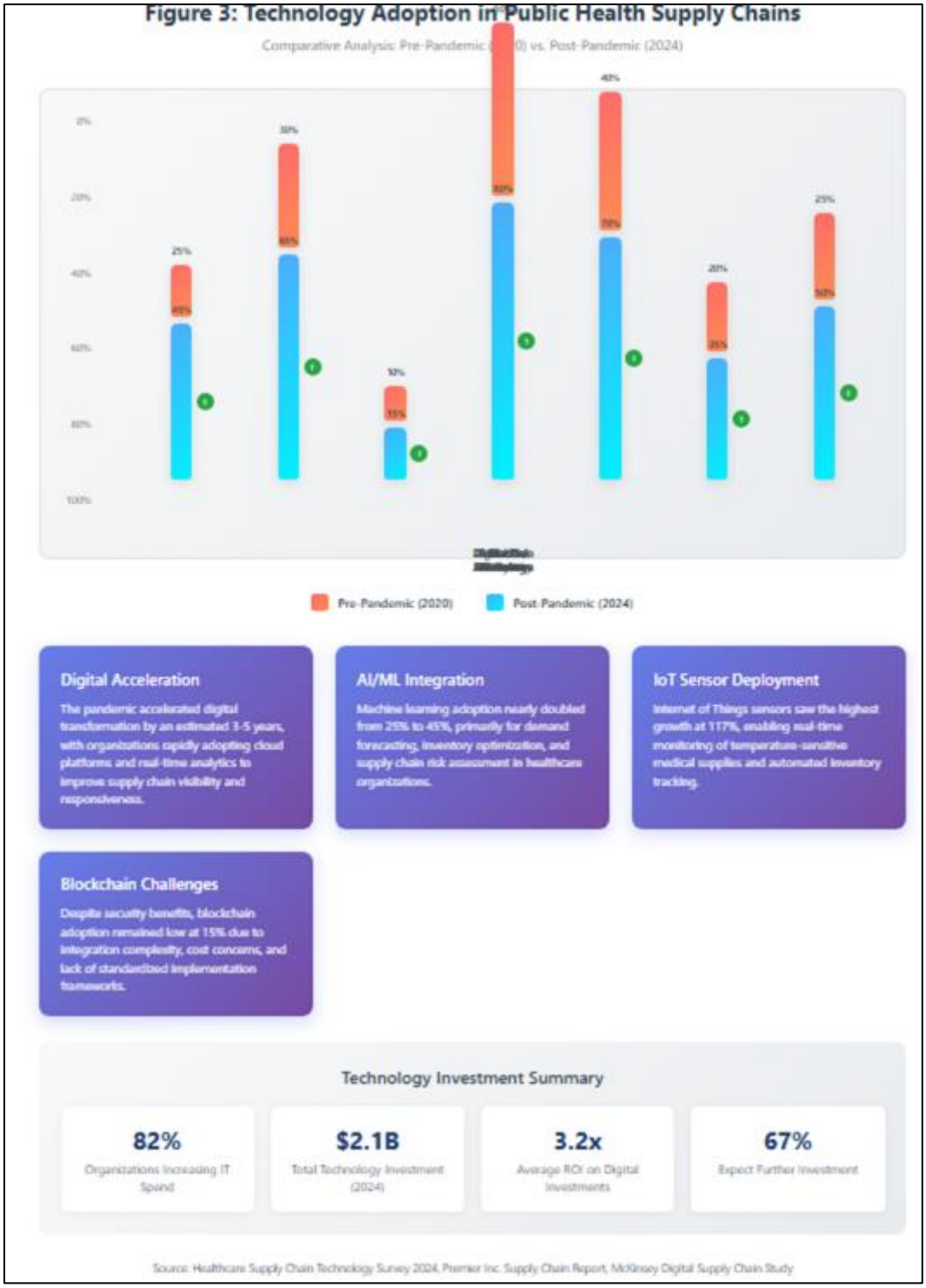

Figure 3 Technology Adoption in Public Health Supply Chains (2020-2024)

7.3. Supply Chain Diversification Strategies

Organizations implemented multiple approaches to reduce dependency vulnerabilities:

- **Near-shoring and Reshoring:** Whereas dependence on China decreased, imports from other Asian nations like India and Vietnam, as well as North American countries like Canada and Mexico, increased.
- **Supplier Base Expansion:** Organizations significantly increased their investments in supply chain innovation in 2023, almost doubling their average spending from the previous year.

8. Comparative Analysis: Resilience Factors

8.1. System Design Principles

Comparison of HIV/TB and COVID-19 responses reveals key design principles for resilient public health supply chains:

- **Redundancy vs. Efficiency Trade-offs:** HIV/TB systems prioritized redundancy through multiple suppliers and strategic reserves, while pre-pandemic healthcare systems optimized for efficiency through just-in-time inventory management.
- **Centralized vs. Distributed Governance:** We also found evidence that centralized procurement and tendering can achieve direct cost savings, while supply chain management program can reduce drug stock outs and increase drug availability for populations.

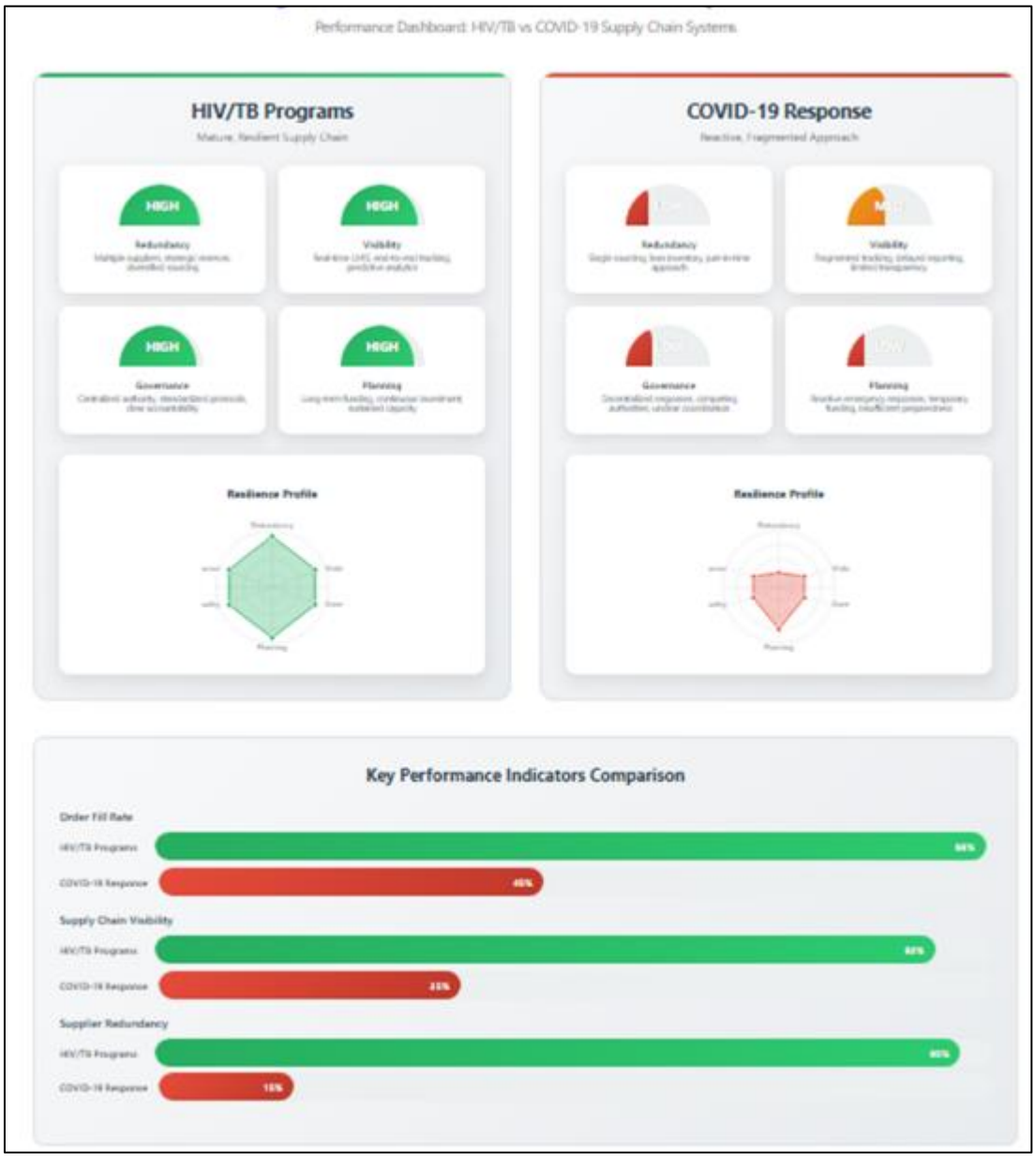

Figure 4 Resilience Framework Comparison

8.2. Investment Sustainability

Table 4 Supply Chain Investment Patterns (2018-2024)

Investment Category	Pre-COVID (2018-2019)	Peak COVID (2020-2021)	Current (2023-2024)	HIV/TB (Average)
Emergency Stockpiles	$640M	$8.2B	$2.1B	$1.8B
Technology Systems	$450M	$3.1B	$1.2B	$950M
Quality Assurance	$180M	$890M	$340M	$520M
Workforce Training	$85M	$450M	$120M	$280M
Supply Chain Coordination	$120M	$950M	$200M	$380M

Sources: HHS Budget Documents; PEPFAR Financial Reports; CDC Preparedness Funding Data

8.3. Performance During Subsequent Emergencies

The resilience of post-COVID supply chain improvements was tested during subsequent public health challenges:

- **Monkeypox Response (2022):** Vaccine distribution challenges revealed ongoing gaps in surge capacity planning and coordination between federal and state systems.
- **Avian Influenza Preparedness (2024):** The CDC's Influenza Risk Assessment Tool (IRAT) and WHO's Tool for Influenza Pandemic Risk Assessment (TIPRA) evaluate the risk of viruses not currently circulating in humans and help to prioritize investments in pandemic preparedness.

9. Policy Recommendations and Future Directions

9.1. Institutional Framework Enhancements

Based on the comparative analysis, several institutional improvements are essential:

- **Establish Permanent Public Health Supply Chain Authority:** Create a dedicated federal agency with authority over public health supply chains, modeled after successful HIV/TB program management structures.
- **Implement Quadrennial Supply Chain Reviews:** The Council shall conduct a quadrennial supply chain review of industries critical to national or economic security, extending this framework specifically to public health supplies.
- **Develop Integrated Surveillance Systems:** Automate data collection and integration for real-time monitoring including, laboratory, clinical, emergency department, public health, and wastewater data.

9.2. Financial Sustainability Mechanisms

- **Multi-Year Appropriations:** Officials from nearly all jurisdictions and stakeholder groups expressed concern about the pattern of increased federal funding for an emergency response, followed by a decrease in funding after that emergency.
- **Public-Private Risk Sharing:** Develop innovative financing mechanisms that share the cost of maintaining surge capacity between public and private sectors.

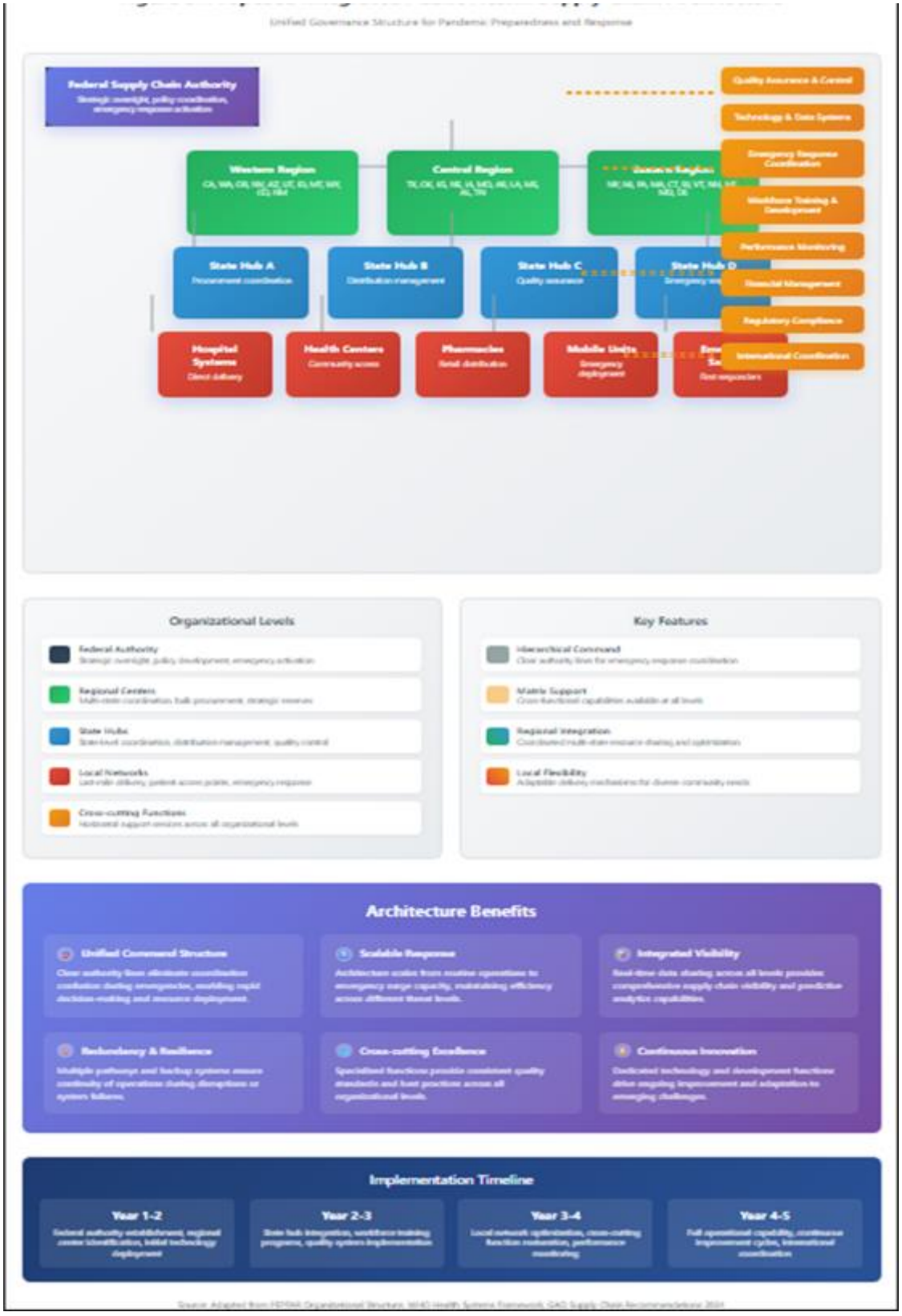

Figure 5 Proposed Integrated Public Health Supply Chain Architecture

9.3. Technology and Innovation Priorities

- **Advanced Analytics and Forecasting:** Invest in AI-powered demand forecasting and supply chain optimization tools that can rapidly adjust to changing conditions.
- **Blockchain for Supply Chain Security:** Implement distributed ledger technology to ensure authenticity and traceability of critical medical supplies.
- **Automated Inventory Management:** Deploy IoT sensors and automated replenishment systems to maintain optimal stock levels across the supply network.

10. Limitations and Future Research

This study has several limitations that should be addressed in future research:

- **Data Availability:** Limited access to proprietary supply chain data from private manufacturers and healthcare systems constrains comprehensive analysis.
- **Temporal Scope:** The relatively short time since COVID-19 limits assessment of long-term sustainability of implemented changes.
- **International Comparisons:** This study focuses primarily on U.S. systems; comparative analysis with other high-income countries could provide additional insights.

Future research priorities include:

- Longitudinal studies of supply chain resilience over multiple emergency cycles
- Cost-effectiveness analysis of different resilience strategies
- Assessment of supply chain impacts on health equity and access
- Evaluation of emerging technologies for supply chain management

11. Discussion

The COVID-19 pandemic revealed both the fragility of public health supply chains optimized for efficiency and the remarkable resilience of systems designed for sustained emergency response. The contrast between the widespread PPE shortages during COVID-19 and the continued functionality of HIV/TB supply chains highlights the importance of deliberate design for resilience rather than efficiency alone.

While companies have made strides in strengthening their supply chains, the latest McKinsey Global Supply Chain Leader Survey shows that substantial vulnerabilities remain. A slowdown in resilience-building efforts, gaps in supply chain visibility, compliance challenges, and talent shortages leave many organizations exposed to future disruptions.

The success factors identified in HIV/TB programs diversified supplier bases, robust quality assurance systems, real-time visibility, and sustained financing provide a roadmap for strengthening pandemic preparedness. However, implementing these improvements requires sustained political commitment and adequate funding beyond the immediate crisis period.

The time for action is during non-pandemic times, enabling a more effective response in an emergency. This insight, drawn from pandemic preparedness research, emphasizes the critical importance of maintaining supply chain investments during inter-pandemic periods.

12. Conclusions

This analysis of public health supply chains in the post-COVID era reveals several key findings:

- **Fragility of Efficiency-Optimized Systems:** Healthcare supply chains optimized for cost efficiency proved inadequate for pandemic response, with critical shortages affecting patient safety and healthcare worker protection.
- **Resilience Through Deliberate Design:** HIV/TB supply chains demonstrated that systems designed for sustained emergency response can maintain functionality during global disruptions.

- **Technology as an Enabler:** Digital transformation accelerated by COVID-19 offers significant opportunities for improving supply chain visibility and responsiveness, but requires sustained investment and governance.
- **Institutional Coordination Challenges:** Fragmented governance across federal, state, and local levels hindered effective response, highlighting the need for clearer authority and coordination mechanisms.
- **Financial Sustainability Concerns:** The pattern of surge funding during emergencies followed by budget cuts threatens the sustainability of resilience improvements.

The path forward requires learning from both the failures exposed by COVID-19 and the successes demonstrated by mature HIV/TB programs. Building truly resilient public health supply chains demands sustained commitment to redundancy over efficiency, long-term investment in technology and workforce capacity, and institutional structures that can coordinate effectively across complex federal systems.

As the United States prepares for future pandemic threats, the lessons from both COVID-19 disruptions and HIV/TB supply chain successes provide a foundation for creating more robust, equitable, and responsive public health supply systems. The challenge lies not in identifying what needs to be done, but in maintaining the political will and financial commitment necessary to implement these improvements during non-emergency periods when the urgency of the problem is less visible to policymakers and the public.

Compliance with ethical standards

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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