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Adopting Blockchain Technology to Improve the Pharmaceutical Supply Chain in Bangladesh: Vision, Barriers and Roadmap

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Abstract

The proliferation of counterfeit and substandard pharmaceuticals has become a ticklish global issue, particularly in developing nations (like Bangladesh) where supply chain vulnerabilities are more spoken. The complicacy of the pharmaceutical supply chain involves diverse mediators such as manufacturers, wholesalers, pharmacies also distributors. It makes blind spots in drug traceability and transparency. This lack of visibility not only facilitates the percolation of counterfeit drugs but also averts effective recalls, regulatory pitfalls and post-market surveillance. Blockchain technology grants promising authorization to these challenges by proposing a safe, decentralized and transparent platform for governing pharmaceutical supply chains. This paper, we try to enquire into the installation of permissioned networks of blockchain technology in tracking the movement, production and use of pharmaceutical products from the point of manufacture to end users. By allowing authorized stakeholders to input and access real-time data, blockchain confirms the authenticity of medicines, secures regulatory compliance and improves patient safety.

Concentrating on the context of Bangladesh and illustrates comparisons with global practices, this study examines the probability and implementation mechanisms of blockchain in the pharmaceutical sector. We highlight how blockchain can secure data integrity, digital traceability, and accountability in every state of supply chain. Moreover, to enhance reliability of supply chain, the proposed model embodies post-consumption feedback, allowing for data collection on drug effectiveness and patient outcomes availing to future research and health analytics.

By placing blockchain technology into pharmaceutical operations, the industry can take a necessary step forward in combating counterfeit drug circulation, developing public health outcomes and building a more zesty and transparent medicine distribution system.

Keywords: Proliferation, counterfeit, pharmaceuticals, vulnerabilities, drug traceability, surveillance, blockchain technology, stakeholders, digital traceability

Objective of This Research

The objective of this study is to emphasize the urgent need for adopting blockchain as a transformative tool for securing the pharmaceutical supply chain and assuring that patients receive safe, genuine, and traceable medications.

CHAPTER 1: INTRODUCTION

1.1 Background and Global Perspective

The outcome of counterfeit and substandard pharmaceuticals is one of the most pressing objections facing the global healthcare industry today. The WHO (World Health Organization) catalogues that 1-2 in 10 medical products in middle- and low-income countries is mispresented or low-grade, with an especially high outbreaks in regions like sub-Saharan Africa and Southeast Asia [1]. These drugs not only fail to serve the illnesses they are intended for but may also cause severe sullen effects, contributing to antimicrobial resistance, raised disease burden and in some cases death. In response to this thriving crisis, governments and health agencies worldwide have begun pursuing advanced technologies to secure pharmaceutical supply chains.

Pharmaceuticals are distributed through a multi-layered supply chain connecting manufacturers, wholesalers, distributors and retailers before reaching the end-user—the patient. While each stage plays an essential role in assuring medicine availability, fragmented also non-transparent nature of this supply chain makes it highly capable of fraud, theft, diversion and falsification. Regulatory bodies mostly lack access to real-time data, making it extremely tough to verify the authenticity of products or track their journey from production to consumption [2].

1.2 The Crisis in Bangladesh

Bangladesh has appeared as a major player in the global generic drug industry, exporting medicines to over 150 countries. However, counterfeit drugs stay as a significant threat to the industry's reputation, public trust and more significantly patient safety. According to data from Supply Chain Insider (2022), 20% of medicines sold in Bangladesh are either substandard or counterfeit, amounting to a financial fall of over Tk 1,500 crore per year [3]. A total of 370 incidents of counterfeit drug activities were officially filed in just the first half of 2019 [4].

Some well-known pharmaceutical companies have faced legal action or license repeals in recent years due to involvement in illegal manufacturing or distribution of fake drugs. The challenge is exacerbated by the high number of unlicensed pharmacies, lack of mandatory digital prescriptions and weak enactment of drug regulation laws. These gaps allow criminal networks to pervade even the most established distribution channels including those used by public hospitals and licensed retailers [5].

This alarming situation not only touches domestic health outcomes but also threatens Bangladesh's goal to capture 10% of the global generic pharmaceutical market in the coming years. Without a safe, transparent, and trusted supply chain system, this vision remains hard to achieve.

1.3 Limitations of this Existing Supply Chain

The conventional pharmaceutical supply chain in Bangladesh, like in many developing countries undergoes from several critical limitations:

- Lack of real-time prospect: Stakeholders don't have synchronized access to drug movement data.

- Manual record-keeping system: Apt to human error and data tampering.
- Limited recall capability: Difficulty in recognizing and retrieving harmful batches quickly.
- Unverified prescription habits: Prescription-only drugs are often enacted without proper documentation.
- Poor regulatory monitoring: Authorities lack the tools to monitor the full period of pharmaceutical products.

These lacks allow counterfeit drugs to blend seamlessly with authentic products, making detection extremely difficult. Moreover, manufacturers can't track adverse reactions to specific batches and regulators can't perform timely interventions.

1.4 The Promise of Blockchain Technology

Blockchain, a localized, distributed and cryptographically secured digital register, has emerged as a powerful tool for overcoming these challenges. Every transaction recorded on a blockchain is immutable, time-stamped and shown to all authorized parties. This ensures end-to-end traceability, trace the origin to enabling stakeholders, movement and status of pharmaceutical outcomes at every stage of the supply chain [6].

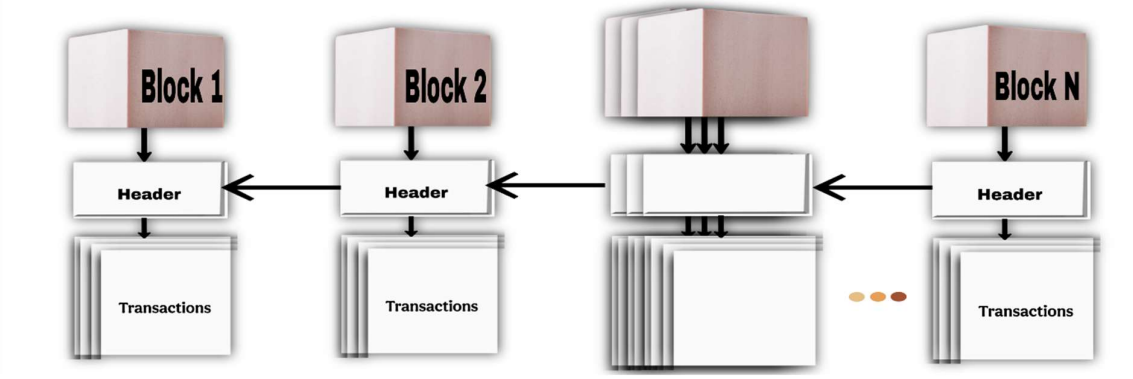


Figure 1: Blockchain systems chain structure

Within a permissioned blockchain network, only trusted entities such as manufacturers, regulators and certified distributors are allowed to attend and input data. Once data is added it can't be deleted without consonance from the network, drastically reducing the potential for fraud. Blockchain can be mobilized with IoT sensors, QR codes, barcodes, RFID tags and mobile applications to ensure authenticity and transparency for both providers and consumers [7].

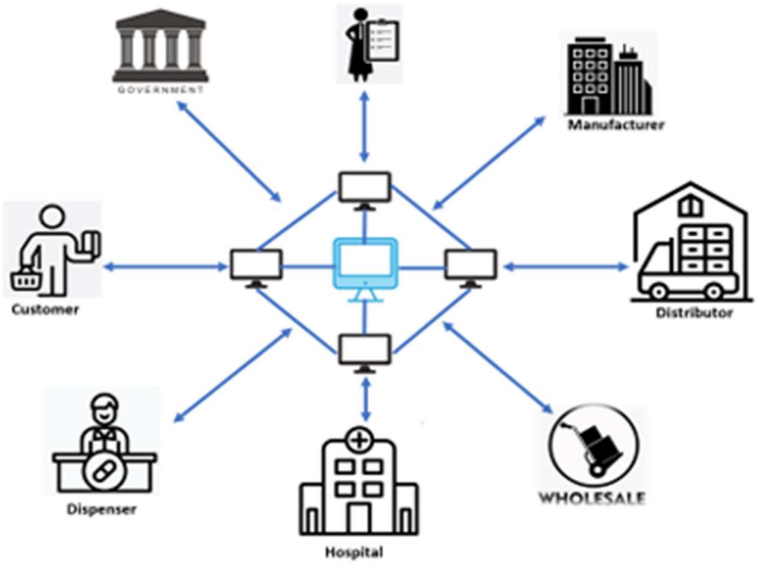


Figure 2: Enabled network of blockchain technology

1.5 Relevance and Opportunity for Bangladesh

For Bangladesh, applying blockchain in the pharmaceutical supply chain is not just an option. It's a strategic necessity. With its spreading pharmaceutical exports and domestic market, Bangladesh can no longer grant the consequences of counterfeit drugs on public health and international credibility. If properly implemented, blockchain could help to achieve:

- Authentication of all the pharmaceutical products in the market
- Digitized tracing from production to patient delivery
- Real-time regulatory access also enforcement
- Increased consumer trust through clearness
- Reduction in fraud, theft and diversion of drugs

Moreover, patient-level data (such as unfavorable drug reactions or treatment effectiveness) can also be stored in an anonymized format for research and public health planning.

Though its potential, Bangladesh faces several obstacles to full-scale blockchain adoption including infrastructure gaps, cost concerns, lack of awareness, policy limitations and resistance to change among industry stakeholders. A structured, phased roadmap is essential to outcome these challenges.

1.6 Aim and Scope of the Study

This aims to give a comprehensive evaluation that how blockchain technology can emphasize pharmaceutical supply chain in Bangladesh. Specifically, it can:

- Examine the present weaknesses of our pharmaceutical supply chain.
- Identifying technical potential also use cases of blockchain in pharmacology.
- Analyze current global models for inspiration.
- Identify barriers to adoption in Bangladeshi context.
- Bring forward a roadmap and strategic vision for national implementation.

By doing so, this research hopes to offer a practical, forward-looking framework for policymakers, pharmaceutical firms and technology developers to collaborate on building a safer, smarter and more transparent supply chain for Bangladesh's healthcare future.

CHAPTER 2: LITERATURE REVIEW

2.1 Current Situation of the Pharmaceutical Supply Chain in Bangladesh

Bangladesh's pharmaceutical industry is an important contributor to the national economy, supplying 97% of the domestic demand and exporting to more than 150 countries [8]. However, the industry suffers from steady issues in supply chain integrity including medicine counterfeiting, lack of proper storage and weak tracking systems [9]. The Directorate General of Drug Administration (DGDA) has taken some digitization initiatives, yet real-time data transfer, traceability in the supply chain remains limited [10].

2.2 Understanding Blockchain in the Context of Supply Chains

Blockchain is a decentralized, cryptographically secure technology that keeps transactions on a distributed ledger. In the supply chain behalf, blockchain offers immutable transaction histories, provenance tracking, and peer-to-peer verification [11]. In pharmaceuticals, these features are essential to monitor the movement of drugs from manufacturers to patients, ensuring authenticity, expiration compliance and storage conditions [12]. Unlike conventional databases, blockchain dispel the need for centralized trust by enabling consensus-driven verification.

2.3 Global Use Cases of Blockchain Technology in Pharma Supply Chain

Globally, blockchain integration in pharmaceutical supply chains has shown conquest. The Medi Ledger Project in the United States, supported by the U.S. FDA, has enabled real-time product verification and compliance with DSCSA (Drug Supply Chain Security Act) [13]. Likewise, IBM and Walmart's *Pharma Track* initiative in China successfully tracked vaccines and vital drugs from factory to clinic [14]. These cases illustrate blockchain's capacity to prevent diversion, falsification and pilferage.

2.4 Prospects of Blockchain in Bangladesh's Pharmaceutical Sector

In Bangladesh, introducing blockchain could fill the existing trust gaps in pharmaceutical logistics. By leveraging modern contracts and decentralized data sharing, blockchain can authenticate products, automate DGDA compliance checks and support real-time auditing [15]. Given the country's rising investment in digital infrastructure and mobile connectivity, there is a viable environment for blockchain pilots in urban health zones.

A feasibility study suggested that blockchain, when connect with QR codes and RFID sensors, could significantly decrease counterfeit drugs in the Dhaka metropolitan supply chain. Integration with current platforms like the DGDA's Track & Trace system may provide a hybrid model for gradual blockchain adoption.

2.5 Challenges to Blockchain Adoption in Developing Economies

Though its promise, blockchain faces critical obstacles in resource-constrained contexts like Bangladesh. Key challenges include:

- Lack of Technical Infrastructures: Most rural healthcare providers lack access to steadfast internet, cloud services, or blockchain-ready platforms [16].
- Costs of Implementation: Setting up a blockchain-based system needs high initial investment and ongoing technical support, posing a challenge for smaller pharmaceutical firms.

- Human Resource Constraints: There is a shortage of blockchain developers and awareness among regulatory bodies and pharmacists [17].
- Policy and Legal Barriers: Bangladesh lacks a clear legal framework for digital signatures, smart contracts or decentralized records, which are essential for blockchain execution [18].

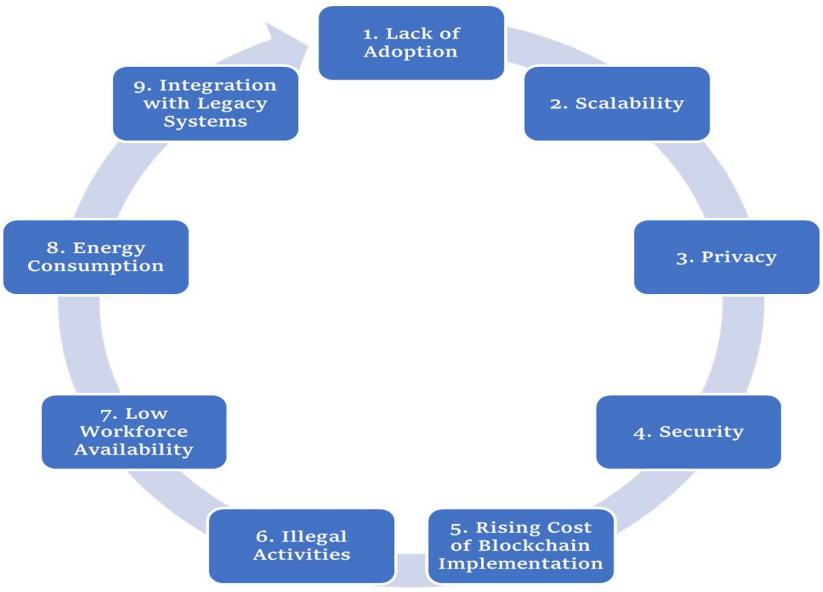


Figure 3: Key challenges of blockchain adoption

2.6 Strategic Roadmap Based on Literature

Based on present literature and global best practices, the following roadmap is necessary for Bangladesh:

1. Stakeholder Engagement: Collaboration between government, academia, private pharma companies and tech firms to make an implementation consortium.
2. Pilot Implementation: Begin with pilot blockchain programs in selected hospitals or urban pharmacies, focusing on high-risk drugs (e.g., insulin, vaccines).
3. Capacity Building: Launch blockchain training in pharmacy and IT curricula also conduct awareness programs for regulators.
4. Policy Reform: Upgrade and pass legislation to enable digital signatures, smart contracts, and data sharing.
5. Infrastructure Integration: Make a national blockchain gateway integrated with the DGDA's digital drug monitoring system.

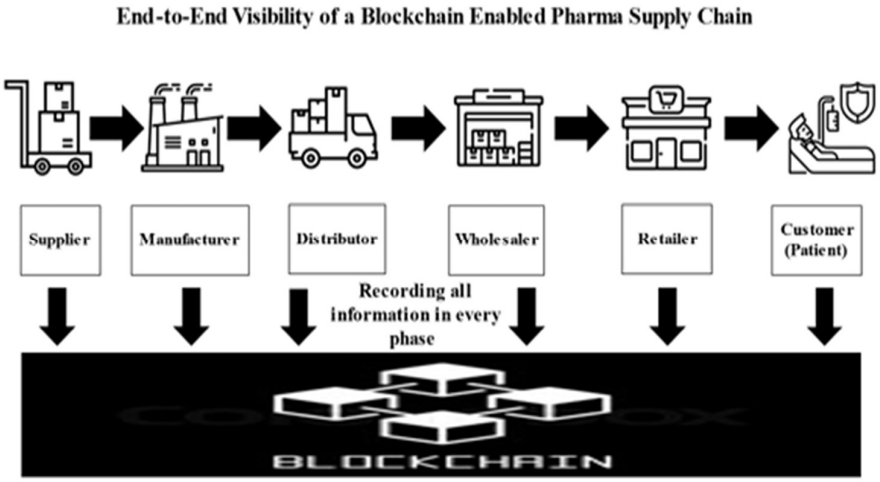


Figure 4: Blockchain Enabled (Proposed) Pharma Supply Chain

2.7 Future Research Directions

While blockchain shows potential, additional empirical studies are required to:

- Measure patient-level impact on medicine safety perception.
- Appraise the economic viability of blockchain deployment in SMEs.
- Explore interoperability between blockchain and current healthcare platforms in Bangladesh.

CHAPTER 3: METHODOLOGY

3.1 Research Design and Approach

This study takes up a qualitative and exploratory research design which aimed at understanding the transformative potential of blockchain technology in improving pharmaceutical supply chain in Bangladesh. Due to the outbound nature of blockchain applications in this domain particularly within the topic of developing economies. Qualitative analysis is considered most suitable for capturing conceptual frameworks, policy gaps and dynamic strategic interventions.

Our presence is normative also analytical in nature. We do both primary and secondary research also propose an ideal solution based on critical review and logical synthesis of current knowledge. The study describes why blockchain should be implemented and how it can be strategically used in the pharmaceutical sectors. The data

used in this research is derived from some health complexes in person and other sources. We performed an extensive review of:

- Academic journal articles and peer-reviewed articles emphasized blockchain, supply chain innovation and healthcare logistics.
- International reports from WHO, UNDP and regulatory bodies connected in pharmaceutical governance.
- Case studies from countries already implementing blockchain in healthcare or supply chain management (e.g., Estonia, UAE).
- Trustable news sources, financial magazines.
- Technological roadmap and strategy document related to digital transformation in Bangladesh.

3.2 Gantt Chart of Our Research

Topic	Week No.					
	1-2	3-4	5-6	7-8	9-10	11-12
1.Eatablishing Research Problem and Defining Research Approach Questions						
2.Collecting Research Data Using Selected Data Sources						
3.Conducting Secondary Analysis						
4.Developing Model						
5.Dicussion and Recommendation						
6.Completion of Research Writing						

3.3 Analyze the Problem Statement

Universal Health Complexes (UHCs) over the country are generally capable of meeting around 62% to 70% of the total medicinal needs of their patients. This is primarily fulfilled through the strategic procurement and right allocation of medicines funded into their existing budgetary frameworks. Besides these efforts, budget limitations and supply obstacles can sometimes lead to shortages of necessary medicines. Such situations where the required medicines are unavailable at the health facility and patients are advised to get the remaining prescriptions from nearby private or community pharmacies. The quantity of medicine provided to patients primarily depends on the availability of stock in the hospital. Under normal circumstances, when inventory levels are static, UHCs normally

dispense a complete two-day course of prescribed medication. Moreover, in the event of limited stock, patients may obtain a reduced supply that could be less than the standard course.

Table 1: Received medicine as percentage of prescribed medicine in both IPD and OPD at the Upazila Health Complex (in terms of type of medicine) in Bangladesh

Type of Patient	Indicators	Prescribed Medicine	Received Medicines
OPD (Outpatient department)	Average number of medicines	3.55	2.72
	Std	1.08	1.18
	Min	2	0
	Max	6	6
	% of received medicine of prescribed (in type)	-	**76.62**
IPD (Inpatient department)	Average number of medicines	5.54	3.42
	Std	1.73	2.03
	Min	2	0
	Max	10	8
	% of received medicine of prescribed (in type)	-	**61.73**

Some Health Complexes, particularly those located in small populated or rural areas, are more failure in addressing patients' medical needs, often fulfilling up to 35% of their requirements. In instances, where these facilities have an oversupply of certain medications, they can't notify other hospitals by sending formal communication. Hospitals experiencing shortages or out supply can then request and obtain these surplus medicines by the appropriate procedures, but it takes too time. In addition, data from prescription surveys indicates that outdoor (outpatient) patients typically get approximately 77% of the medications prescribed to them, based on the variety of medicine needed. Besides, indoor (inpatient) patients get a slightly lower percentage, with around 62% of the prescribed medicines being enacted.

Table 2: Received medicine as percentage of prescribed medicine in both IPD and OPD in the Upazila Health Complex (in terms of days) in Bangladesh

Type of Patient	Indicators	Prescribed Days of Medicine	Received Days of Medicine
OPD (Outpatient department)	Average days for which doctor prescribed the medicine	12.33	4.89
	Std	13.20	5.04
	Min	1	0
	Max	90	30

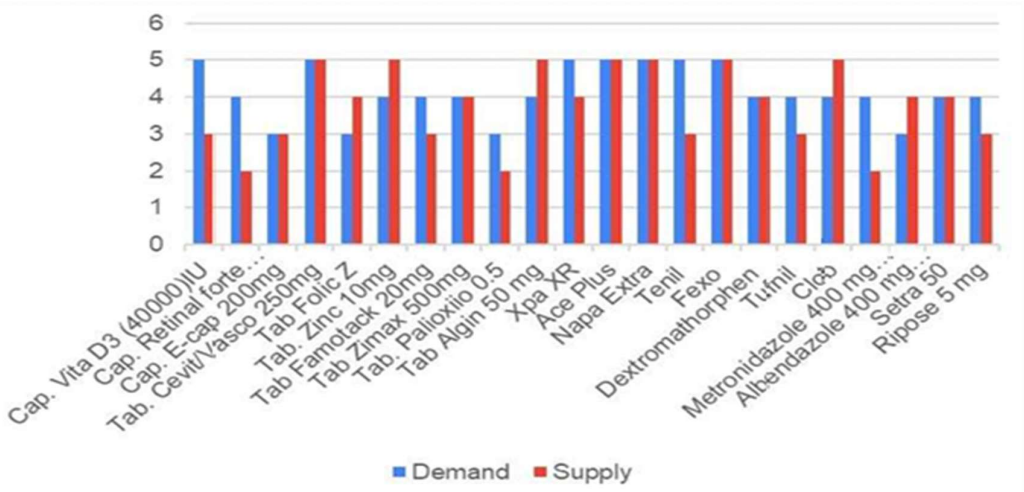
Type of Patient	Indicators	Prescribed Days of Medicine	Received Days of Medicine
	% of received medicine of prescribed (in days)	-	**39.66**
IPD (Inpatient department)	Average days for which doctor prescribed the medicine	5.12	3.15
	Std	6.44	3.35
	Min	1	0
	Max	90	20
	% of received medicine of prescribed (in days)	-	**61.52**

On average, outdoor doctors at Health Complexes prescribe a diversity of medications aimed at covering approximately 12 days of treatment. Moreover, outdoor patients typically get medicines for less than 5 days, that addressed for only 39.66% of the total prescribed duration. In addition, indoor patients get medicines from the hospital for about 61.52% of the days directed in their prescriptions.

Table 3: Received medicine as a percentage of prescribed medicine in terms of both IPD and OPD in the Upazila Health Complex (in terms of quantity) in Bangladesh

Type of patient	**Indicators**	**Prescribed medicine**	**Received medicines**
OPD (Outpatient department)	Average quantity of	17.58	7.20
	Std	19.31	6.04
	Min	1	0
	Max	180	30
	% of received medicine of the prescribed medicine (in terms of quantity)	-	**41.57**
IPD (Inpatient department)	Average quantity of	8.67	5.92
	Std	12.95	8.04
	Min	1	0
	Max	180	80
	% of received medicine of the prescribed medicine (in terms of quantity)	-	**70.29**

So, the prescription survey shows that outdoor doctors at Health Complexes prescribe on average over 17 units of medicine per patient. Also, patients receive only about 7 of those units, that equate to just over 41.5% of the total quantity prescribed. In contrast, indoor patients receive a significantly higher portion, more than 70% of the prescribed medicine in terms of quantity.



This bar chart shows the demand vs supply of medicines in Bangladesh.

3.4 Proposed models for solving these problems

3.4.1 Model 1- The drug development process

The pharmaceutical supply chain starts along with tangled process of drugs development. At its core remains research and development (R&D), a highly intricate and time-intensive journey which basically spans around fourteen years from the first discovery of a compound to securing continuous approval [20]. This process is separated into distinct stages. Starting with a company's strategic decision to invest in a promising project. Then progressing through multiple phases of appropriate testing and culminating in market authorization. These research phases begin off with drug discovery which is then followed by pre-clinical test. By reaching this stage, companies often look up patent protection to safeguard their innovations.

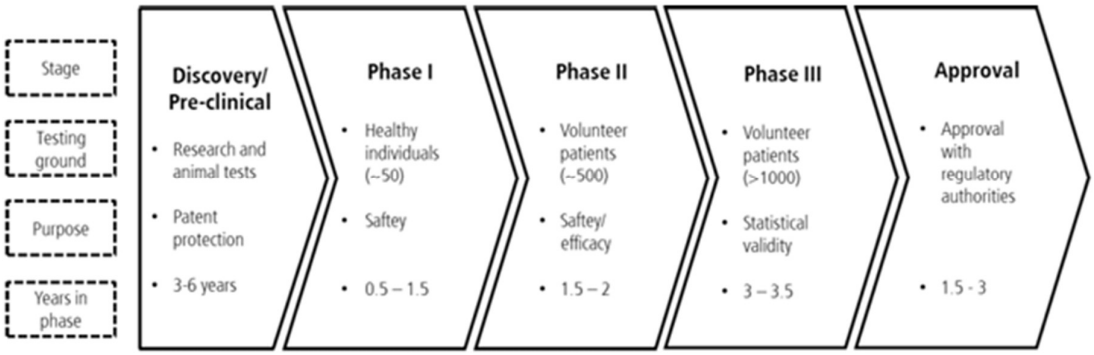


Figure 5: The drug development process

Clinical tests mark a central stage in the drug development process. It begins with initial testing on sound volunteers and continuing to larger patient groups to thoroughly grasp safety and efficiency. These trials are basically driven in three sequential phases (Phase I, Phase II and Phase III). Each designed to evaluate specific

sights of the drug, like its safety profile, overall efficacy and therapeutic effectiveness. Advancement from one phase to another is reliant upon positive outcomes from the preceding phase. In any stage, the result may lead to a decision to proceed, break or permanently stop the testing process. Pharmaceutical companies could withdraw their application for financial, strategic or commercial reasons or maybe discontinue trials in response to negative feedback. Regulatory authorities also keep the power to suspend or end trials at any time should safety concerns emerge [19].

Once a drug successfully finishes all phases of clinical trials, then pharmaceutical companies may ask for marketing approval. Moreover, this critical decision keeps primarily with regulatory agencies that hold the authority to determine whether a new drug can enter the market or not. These agencies run independently in many countries to safeguard public health and maintain rigorous accuracy of pharmaceutical products.

Then doing market authorization successfully, pharmaceutical companies thrust into a pricing negotiation phase, often in consultation with stakeholders like healthcare authorities. Such as, in Australia, a new drug must exhibit an added benefit over existing treatments prior market entry is permitted. The pharmaceutical companies propose this added value, that is strictly evaluated by IQWIG (Institute for Quality and Efficiency in Healthcare). These evaluations significantly press price negotiations. During the first 12 months of post-approval, the company has the right to set prices. In addition, starting from the 13-14th month, a negotiated price becomes legally leased. As the drug transitions to full-scale manufacturing and distribution process it ensures product quality and patient safety becomes paramount.

Use case of this proposed model: Pharma supply chain and counterfeit drug problem

Supply chain security and safety has become focus in the pharmaceutical industry, particularly with the application of the DSCSA (Drug Supply Chain Security Act). This enactment was introduced to combat the rising threat of counterfeit drugs. Medications that lack the proper active ingredients and pose serious risks to patient health. WHO (World Health Organization) also reported that over half of the medicines are purchased online from unauthorized websites, especially for those who hide their physical addresses. Even life-saving treatments like cancer and cardiovascular diseases have fallen victim to this illegal trade.

The primary force behind counterfeit drugs is the promise of huge profits. Developing countries are especially vulnerable, because the high cost of legit medications often puts them out of reach for large segments of the population [20]. Though the exact number of deaths connected to counterfeit drugs remains unknown, also the broader consequences for public health are important. In contrast to fatalities, counterfeit medications can avail to drug resistance and destroy trust in healthcare systems.

The pharmaceutical supply chain itself is an intricate, with products passing through various intermediaries (manufacturers, distributors, repackages and wholesalers) before reaching the end consumer. This lack of end-to-end visibility makes it difficult to ensure product authenticity, facilitating the spread of counterfeit drugs and creating inefficiencies in product recalls and returns. These issues not only lead to financial losses but also dissipate consumer trust.

Blockchain technology finds a promising solution to these challenges. By enabling greater transparency and traceability, blockchain can help build trust throughout the pharmaceutical supply chain. Every time a drug changes hands, its packaging can be scanned via barcode, recording the transaction on a secure, tamper-proof blockchain register. Only authorized parties can update the register also ensuring data integrity. This real-time visibility allows both consumers and manufacturers to track a product's journey from source to destination. Usually such a system supports drug identification, traceability, verification and immediate alerts in the contrast of counterfeit detection strengthening the war against fake medicines and securing public health.

Implementing this prototype: Life-Crypter

Life-Crypter is the prototype that we developed to illustrate the true potential of blockchain technology in healthcare sector. Its main goal is to show how a blockchain-driven solution can secure patient lives while empowering individual people with higher control over their medical data.

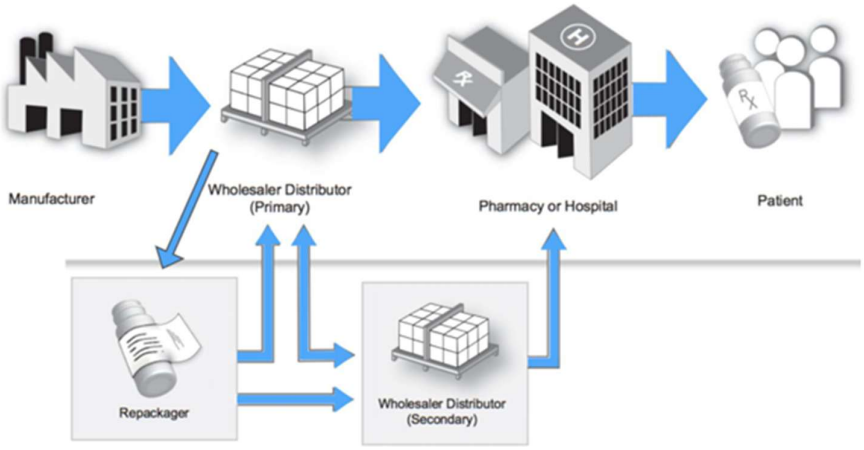


Figure 6: Smart contracts provide integrity, transparency and traceability

With the help of LifeCrypter, we offer a sophisticated blockchain-powered solution that enhances integrity, transparency and traceability across the whole pharmaceutical supply chain. This platform empowers patients through a mobile app that allows them to trace every medicine item along with its entire trade records and dramatically decreasing the incentives for distributing counterfeit medicines.

Figure 7: Tracing the supply chain of a drug

In the system, each unit of medicine is assigned an identical, tamper-proof tag which enables both physical and virtual ownership to be transferred seamlessly from suppliers to consumers. These transfers happen within a secure, decentralized network directed by digital contracts on the blockchain. This trusted framework mirrors the actual movement of drugs throughout the global supply chain and ensuring authenticity at every step.

Smart and digital contracts facilitate secure, transparent and automated transactions among all stakeholders, eliminating the need for intermediaries while enforcing predefined laws. This app ensures that every trade is not only visible to authorized parties but also self-executive and promoting a more secure as well as efficient pharmaceutical ecosystem.

By using of blockchain technology, our solution empowers stakeholders across the pharmaceutical supply chain in Bangladesh. Also, it significantly improves efficiency in the distribution of verifiable, authentic medicines. At the same time, patients benefited directly through our user-friendly mobile app which allows them to independently verify the authenticity of their medicines and ensure safety and building trust at the point of using this.

3.4.2 Model 2- Designing the information system of the drug turnover control (Hyperledger Fabric Platform)

In pharmaceutical supply chain, the stage plays a major regulatory role, overseeing interactions among stakeholders, registering medicines, issuing production licenses and managing prescriptions. Also, a private blockchain network managed by a state agency was chosen as the beginning for this project.

The solution is made on Hyperledger Fabric, a strong platform for creating private blockchain networks. Its architecture supports a clear dissociation of roles by three types of nodes:

- Client Peers – final users who initiate transaction requests.
- Endorser Peers – Nodes that validate and execute transactions with selected guarantor nodes handling digital contract code execution.

- Ordering Peers – Responsible for creating transaction blocks, updating the distributed register also managing consensus algorithm changes.

This model utilizes Hyperledger Composer, it's a development tool that simplex the creation and management of blockchain systems on Fabric. It generates a unique system configuration file based on four essential components:

1. Transaction Scripts – Contain digital contract logic which is written in JavaScript.
2. Model Files – Determine the structure of system entities like assets (e.g., medicines, licenses) and participants.
3. Query Scripts – Activate efficient data retrieval for frontend applications and smart contracts.
4. Access Control Lists (ACLs) – Individualize permissions for reading, writing and executing transactions.

Architecture of the proposed solution

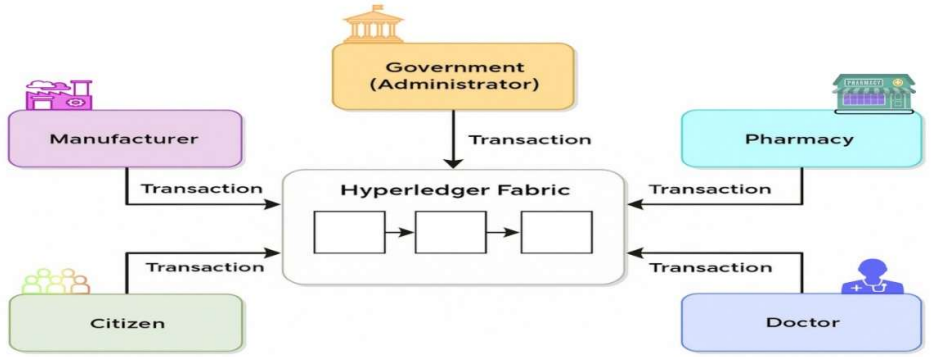


Figure 8: The information exchange participants

Each system unit has specific permissions for reading data and then executing transactions. To access each member's profile, the client application must authenticate the user by a secure system of public and private keys.

The developed system includes the following participants, each with separate roles and permissions:

1. Government
   It Acts as the administrator and network owner, control all registry nodes. Also registers new members, issues manufacturing licenses and add newly approved drugs to the system.
2. Manufacturer
   Liable for producing medicines and fulfilling pharmacy orders. They register each medicine unit using a unique identifier (UUID) and initiate ownership transfers to pharmacies.
3. Pharmacy
   They sells medicines to public. Pharmacies record drug sales either directly (for non-prescription drugs) or through verified prescriptions stored in the system. Prescription-based selling is validated by checking prescription links, patient identity and remaining dosage counts.

4. Doctor
   They issues digital prescriptions by recording the type and quantity of required drugs, attached to a citizen's account. The data is stored securely on the Hyperledger Fabric network.
5. Citizen
   They purchases medicines by presenting a smart ID connected to their state-registered account. The lifecycle of every medicine unit ends with a transaction marking its sale either to the citizen (with or without a prescription) or else to the government in the case of non-prescription.

A simplified relational model illustrates the connections between these participants and system assets:

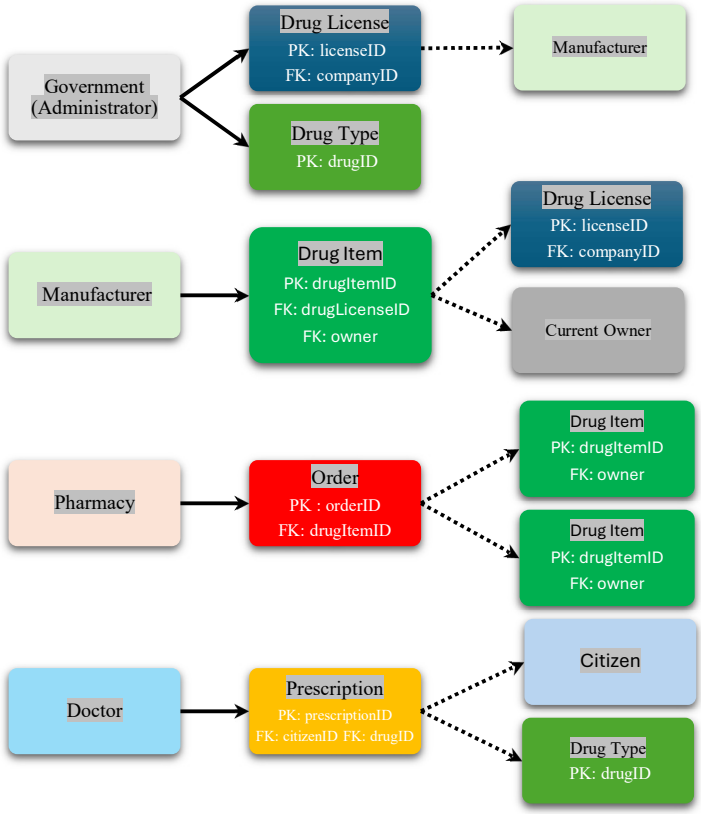


Figure 9: Simplified relational model of the proposed solution.

In this diagram, arrows with "+" symbol represent transactions where a specific network member makes an asset. "Dashed" arrows indicate relationships between assets, linked via foreign keys.

Principles of Operation, Strengths & Weaknesses of this proposed model:

The drug control system is still a work in progress, but the prototype shows main dealings across the life of a medicine product

1.The government registers a new drug - it makes a "Type of Medicinal Product" asset and gives a license to a producer. The license status can change or end through dealings.

2.Producers make single "Medicine" units. A code links a unit to its type and its end date.

3.A pharmacy places an order. The producer links product units to fill the order. Upon delivery, the pharmacy owns the units.

4.A doctor writes a prescription. The prescription links to a citizen's account. The citizen buys the medicine. Ownership transfers after checking the prescription and product availability.

Each licensed medicine unit leaves a digital record that one can trace. A record makes quick check and solving disputes possible.

Strengths:

• It improves following products in the official drug supply chain.

• It causes people to follow rules through blockchain responsibility.

Limitations:

• It only tracks permitted supply chains. Fake drugs given outside official paths remain unseen.

• The prototype runs in a fake setting, so its actual performance could be different.

3.4.3 Model 3-Pilot Project (Combating Counterfeit Drugs with Blockchain)

The pilot project targets to analyze the effectiveness of a blockchain-powered application in minimizing the risk of counterfeit drugs into pharmaceutical supply chain. It aims to detect tampering of medicine packs, ensure data integrity and prevent the entry of illegal or unauthorized data.

Some of the key features of this are its geolocation ability, enabling law enforcement and regulatory agents to record where a shipment or goods was verified. Using a mobile device, they can add photos, comments, facilitating real-time communication with pharmaceutical manufacturers.

This initiative is on SAP's Information Collaboration Hub (for life sciences). A blockchain solution planned to authenticate pharmaceutical packaging throughout its journey.

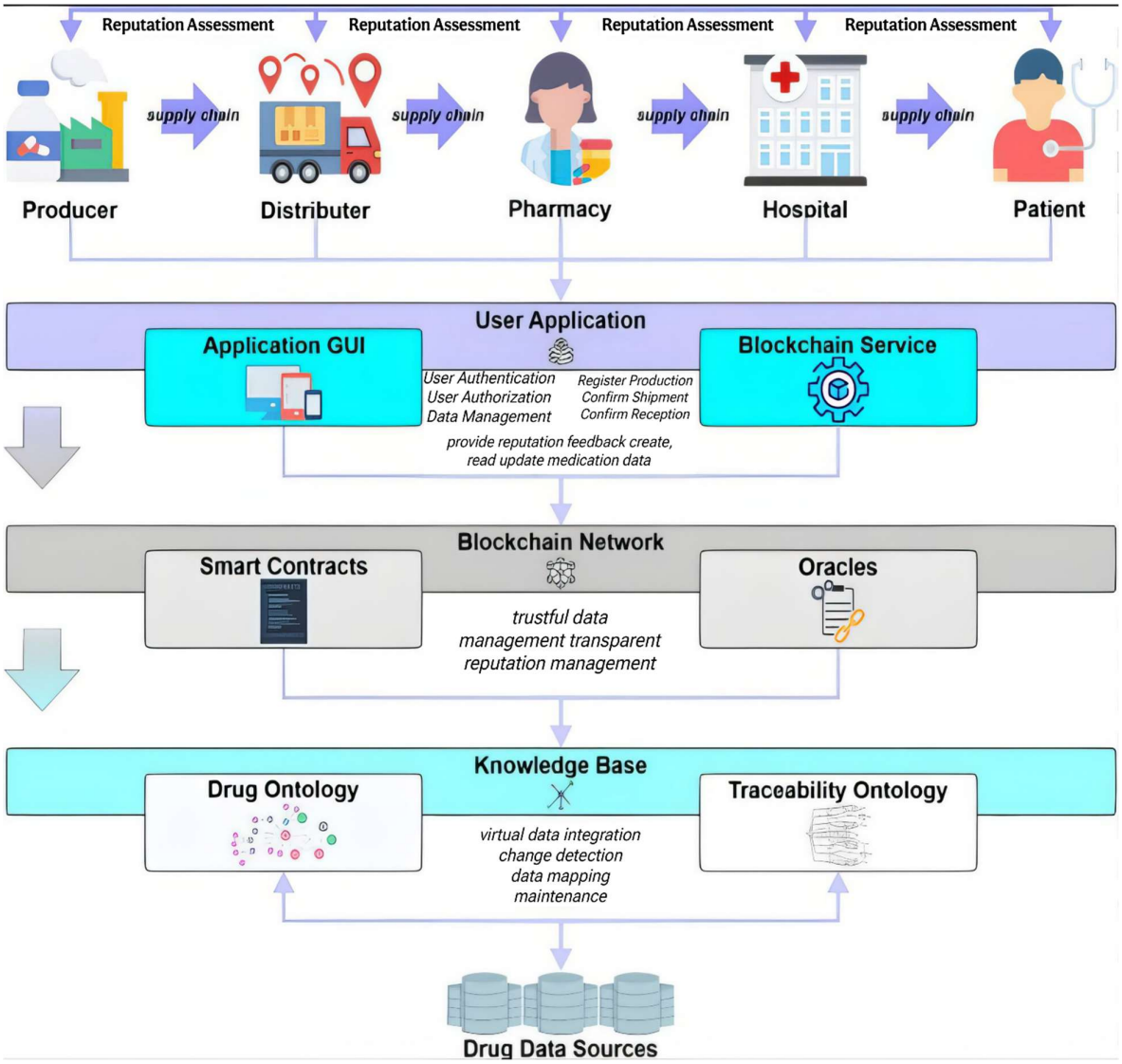


Figure 10: Pilot project (VERIFICATION ROUTER SERVICES)

Key Benefits of this model:

- **End-to-End Digital Tracking:** Blockchain gives reliable and tamper-proof tracking of drugs across all the stages of the supply chain.
- **Tamper-Proof Packaging:** The use of holograms, seals and shrink wraps enhances physical security, deterring counterfeiters.
- **Transparent Data Access:** All stakeholders including distributors, wholesalers, dispensers, pharmacies and hospitals can access serialized drug data and verify authenticity easily and digitally.
- **Rapid Response to Counterfeits:** If counterfeit drug is identified, blockchain then allows tracking of all entries tied to that product's ID then help pinpoint the source. Also, an automatic alert can then be broadcast to all parties potentially handling the suspect product, enable swift action.

CHAPTER 4: RESULT

Applying the three integrated blockchain models (Drug Development Tracking, Hyperledger-based National Control System and a Blockchain-Powered Pilot Project) can revolutionize Bangladesh's pharmaceutical supply chain. These proposed models bring off not only technological innovation but also an example that how drugs are traced, verified and distributed.

1. Bulletproof Drug Authenticity (End-to-End Traceability):

What can Happens:
Every unit of medicine will bear a unique digital identity, traced immutably from production to patient use.

Probable Impact:
Fake medicines lose all access points into the system.

Example:
A tuberculosis medicine produced by Beximco Pharmacy is scanned at every step (manufacturer, distributor, pharmacy). A patient in Khulna uses Life-Crypter to scan the QR code given on the box and instantly seeing proof that it's genuine also where it was produced, when it expires.

2. Exclusion of Counterfeit Drugs at the Root:

What can Happens:
Blockchain's tamper-proof design restrains unauthorized entries of fake drugs into the official supply chain.

Probable Impact:
Significantly reduced health risks and improved patient safety.

Example:
A vulgar supplier tries to input counterfeit hypertension drugs into the system. The blockchain prevents it at the pharmacy level because of ID mismatch. Authorities are concerned instantly also the distributor's license is snoozed for review.

3. Governments Digital Oversight with Smart Regulation:

What can Happens:
Regulatory agencies provide live, modern dashboards of every transaction (from prescriptions to pharmacy sales) secured via digital contracts.

Probable Impact:

Beneficial license control, prescription administration and better grip on market compliance.

Example:
Directorate General of Drug Administration uses the system to withdraw expired manufacturing licenses and trace suspicious prescription activities by a public clinic, preventing potential overprescription.

4. Crisis Management and Lightning-Fast Product Recalls:

What can Happens:
In case of quality failure, affected batches can be identified and isolated instantly.

Probable Impact:
Avoids massive health crises and decreases corporate liability.

Example:
A contaminated syrup batch is identified by a regulator. Within some time, system identifies all pharmacies and hospitals that stocked this. A recall alert is broadcast, prevents further sales and saves countless lives.

5. Tamper-Proof Records (Zero Data Manipulation):

What can Happens:
Every action (prescription writing, drug handover, sales) is cryptographically recorded and time strikes.

Probable Impact:
No stakeholder can delete transaction history, so it ensures full accountability.

Example:
An audit on a pharma chain finds no suspicious activities. Because every transaction from doctor's digital prescription to final sale was tracked, verifiable and immutable.

6.Empowered Patients (with Real-Time Verification Tools):

What can Happens:
Patients can verify drug authenticity, batch history and expiry date from a mobile app.

Probable Impact:

Trust will restore. Healthcare decisions will be safer and better.

Example:
A mother in rural Barishal checks her child's fever medicine with Life-Crypter app and confirms that it's authentic, manufactured two weeks ago and shipped directly from a verified Dhaka-zone supplier.

7.Seamless and Transparent Collaboration Among Stakeholders:

What can Happens:

All actors, government, manufacturers, pharmacies, doctors and patients operate within a shared, blockchain-secured ecosystem.

Probable Impact:
Misinformation and manual errors will be eliminated.

Example:
A pharmacy's smart inventory updates automatically when a doctor issues a verified prescription and triggering a reorder from the manufacturer without any human intervention.

8. Ready for Scale (Vaccines, Medical Devices and Beyond)

What can Happens:
The blockchain infrastructure can expand to track vaccines, diagnostic kits, medical devices and donor organs.

Probable Impact:
Bangladesh will get ready for future with a world-class, smart health logistics system.

Example:
During a decease outbreak, vaccine bottle is dispatched across the country. Each unit is traced in real time on the blockchain, ensuring cold chain compliance with equitable distribution.

Table 4: In Summary – Bangladesh's Pharma Future

Key Result	Real Impact	Illustration
Authenticity of Every Drug	Fake drugs blocked at every level	QR-scan confirms drug origin and batch
Public Health Protection	Counterfeit medicines intercepted before reaching patients	Life-threatening meds verified before sale
Government Control	Real-time prescription & license tracking	DGDA oversees the entire supply chain digitally
Efficient Recalls	Fast identification and removal of faulty products	Contaminated syrup recalled in hours, not weeks
Data Integrity	No unauthorized record changes or fraud	Full auditability of all transactions
Patient Empowerment	Verification power in every hand	Mothers, patients, caregivers make safe choices via app
Ecosystem Integration	Real-time coordination from production to prescription	Manufacturer auto-responds to prescription orders
Future Scalability	Expansion to broader healthcare logistics	Vaccines, kits, and devices added to the same blockchain track

By implementing these modern blockchain solutions, Bangladesh can position itself not only to solve the counterfeit drug problem but also to lead the South Asian region in secure, transparent and patient-centric pharmaceutical distribution. This is more than an upgrade, it's a healthcare revolution in motion.

CHAPTER 5: DISCUSSION

The application of blockchain technology in Bangladesh's pharmaceutical supply chain provides a comprehensive and good solution to persistent allegation such as drug counterfeiting, crumbled

information flows and low regulatory enforcement. With over 10-12% of medicines worldwide believed to be counterfeit. Many of them disclosing in middle- and low-income countries as like Bangladesh. The need for a safe, verifiable and transparent system has never been more necessary. Our three proposed models together address the issue by introducing a smart ecosystem that records, validates and monitors every single transaction within the drug or medicine lifecycle.

Model-1 captures the complication of drug development process including clinical experiments and regulatory approvals also ensuring that drug entering the market has a substantiate and traceable origin. This model not only secures product accountability from beginning but also amplifies the credibility of pharmaceutical innovations in the eyes of consumers and regulators. Model-2, which discuss the Hyperledger Fabric platform. It concentrates on making a permissioned, secure, government-controlled blockchain network which brings together major factors like government agencies, manufacturers, pharmacies, doctors and patients within a secure smart framework. This proposed design ensures that all stakeholders operate with fixed roles and transparent access also minimizing opportunities for data manipulation or scam activities. By smart contracts, processes like license issuance, prescription verification, drug sales and inventory tracing are automated and immutable also it significantly improving regulatory oversight. Besides the integration of patient profiles, pharmacy validation, digital prescriptions, it also helps prevent drug misuse and ensures proper distribution, especially for sensitive, costly or high-risk medications. Since the system has high potential to streamline authentic drug distribution, a boundary remains in its inability to directly trace counterfeit drugs operating outside the authorized channels. An area that will need additional measures such as public awareness campaigns and stricter law compulsion. The 3rd Model, a blockchain-based pilot project featuring real-time geolocation, mobile verification and serialization which demonstrates how emerging technology can empower frontier regulatory agents and consumers.

The Life-Crypter app, which enables end users to identify the authenticity of a drug with an easy scan, significantly lowering the chances of counterfeit medications outreach patients. Also, the system allows manufacturers and regulators to get immediate alerts in case of suspicious activity, assisting containing risks faster than current mechanisms. Moreover, inductive solutions to all will require overcoming infrastructure barriers, digital literacy gaps and resistance from individual supply chain intermediaries who benefit from the current fatuous system. Rather these challenges, the overall system is highly promising. With coordinated policy support, public-private partnerships and investment in digital infrastructure, blockchain can build a more resilient, transparent and patient-oriented pharmaceutical supply chain in Bangladesh.

CHAPTER 6: CONCLUSION

Blockchain technology is the best solution to the long-standing problems of unclear laws, unauthorized data systems and fake medicines in Bangladesh's pharma supply chain. Our three proposed models work together to build a digital ecosystem which is both promising and realistic. This ecosystem will have decentralized verification, national-level drug turnover control and drug development oversight.

The drug development model can make things transparent from the start of research to the end when the drug is ready and approved for sale. With the Hyperledger Fabric-based control system, one can have smart prescriptions, government-led monitoring system and drug cycle management. Finally, the pilot project uses geolocation tracing and mobile verification methods to make sure that both safety of public and real-time goods verification is possible.

The expected results are substantial:

- Drastic decrease in counterfeit drug cycle.
- upgraded regulatory compliance and data integrity.
- Real-time traceability and fast recall capability.
- Empowerment of patients with quick verification tools.
- Strengthened public believe in the healthcare system.

Moreover, successful implementation will depend on multi-stakeholder cooperation, strong digital infrastructure, policy alignment and capacity building. The journey ahead will need strategic investment, staged deployment and regular evaluation.

At the end, if implemented properly, these blockchain-based models can transform Bangladesh into a regional idol in pharmaceutical safety and supply chain innovation also setting a benchmark for other developing countries facing same challenges. The future of healthcare sectors in Bangladesh can be safe, secure, smart and transparent by the help of blockchain technology.

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