BLOCKCHAIN BASED FRAMEWORK FOR PREVENTING MEDICINE COUNTERFEIT IN CONTEXT OF BANGLADESH

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BLOCKCHAIN BASED FRAMEWORK FOR PREVENTING MEDICINE COUNTERFEIT IN CONTEXT OF BANGLADESH

DECLARATION

I hereby declare that the study reported in this thesis entitled as above is my own original work and has not been submitted before anywhere for any degree or other purposes. Further I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged and/or cited in the reference Section.

_____

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ABSTRACT

Blockchain based Framework for Preventing Medicine Counterfeit in context of Bangladesh

Medicine counterfeit has raised a major concern in recent years since it has become so widespread. Falsified and counterfeit drug production and distribution are not only illegal but also a public health concern. The intensity of this problem varies greatly among different geographical regions and countries; and highly dependent on how strongly the laws and procedures are maintained in a country. Preventing counterfeit medicines thus become a very important concern especially in developing and underdeveloped countries like Bangladesh. This research aims firstly, to outline the possible factors of medicine counterfeiting in the context of Bangladesh; secondly, to propose a blockchain based framework to prevent medicine counterfeiting; thirdly, to evaluate the proposed framework. Content analysis and systematic literature review were conducted to derive the current research gaps and future research opportunities. A semi-structured interview with the key personnel related to the medicine manufacturing and distribution system in Bangladesh was also carried out. Based on the interviews, content analysis, and systematic literature review, a set of use cases of preventing medicine counterfeit in the context of Bangladesh were explored. Considering the use cases derived, the required features for developing a digital solution were extracted. A blockchain based framework for preventing medicine counterfeit in the context of Bangladesh was proposed by adopting the extracted features. A prototype was developed based on the proposed framework and an evaluation study was also performed to evaluate the prototype. The evaluation study showed that the average block execution time is 646 ms. Again, the proposed framework was found as secured, scalable, customer-oriented, and practical comparing to other existing systems.

সারসংক্ষেপ

A Blockchain based Medicine Production and Distribution Framework Towards Preventing Medicine Counterfeit in Bangladesh

নকল ওষুধ সাম্প্রতিক বছরগুলিতে একটি বড় উদ্বেগের কারণ হয়ে দাঁড়িয়েছে। নকল ওষুধ উৎপাদন ও বিতরণ শুধু বেআইনিই নয়, এটি জনস্বাস্থ্যের জন্য উদ্বেগও বটে। এই সমস্যার তীব্রতা বিভিন্ন ভৌগোলিক অঞ্চল এবং দেশের মধ্যে পরিবর্তিত হয়। নকল ওষুধের বিস্তার নির্ভর করে একটি দেশের আইন এবং নিয়মকানুন কতটা দৃঢ়ভাবে মেনে চলা হয়। তাই বাংলাদেশের মতো উন্নয়নশীল ও স্বল্পোন্নত দেশগুলোতে নকল ওষুধ প্রতিরোধ করা খুবই জরুরি। এই গবেষণার লক্ষ্য প্রথমত, বাংলাদেশের প্রেক্ষাপটে ওষুধের নকলের সম্ভাব্য কারণ এবং বিদ্যমান গবেষণা ও উন্নয়নের অত্যাধুনিক রূপরেখা উত্থাপন; দ্বিতীয়ত, ওষুধের নকল প্রতিরোধে ব্লকচেইন ভিত্তিক কাঠামো প্রস্তাবকরণ ; তৃতীয়ত, প্রস্তাবিত কাঠামোর মূল্যায়ন করা। লক্ষ্যগুলো অর্জনের জন্য বর্তমান গবেষণার অপ্রতুল ক্ষেত্র এবং ভবিষ্যতের গবেষণার সুযোগগুলি কন্টেন্ট এনালাইসিস এবং সিস্টেমেটিক লিটারেচার রিভিউ এর মাধ্যমে তুলে ধরা হয় । অপরদিকে , বাংলাদেশে ওষুধ উৎপাদন ও বিতরণের সাথে সম্পর্কিত ব্যাক্তিবর্গের একটি ইন্টারভিউ নেওয়া হয়। সাক্ষাৎকার, কন্টেন্ট এনালাইসিস এবং সিস্টেমেটিক লিটারেচার রিভিউ ফলাফল পর্যালোচনার ভিত্তিতে, বাংলাদেশের প্রেক্ষাপটে ওষুধের নকল প্রতিরোধের কিছু ব্যবহারিক ক্ষেত্র চিহ্নিত করা হয়। প্রাপ্ত ব্যবহারিক ক্ষেত্র বিবেচনা করে, একটি ডিজিটাল সমাধান বাস্তবায়নের জন্য প্রয়োজনীয় বৈশিষ্ট্য বের করা হয়। উক্ত বৈশিষ্ট্যগুলি বিবেচনা করে, বাংলাদেশের প্রেক্ষাপটে ওষুধের নকল প্রতিরোধের জন্য একটি ব্লকচেইন ভিত্তিক কাঠামোর প্রস্তাব করা হয়েছে । অতঃপর, প্রস্তাবিত কাঠামো অনুযায়ী একটি প্রোটোটাইপ তৈরি করা হয় এবং কর্মক্ষমতা ও নিরাপত্তার পরিপ্রেক্ষিতে প্রোটোটাইপটি মূল্যায়ন করা হয়। কাঠামোটি মূল্যায়ন করে দেখা গেছে যে এর কর্মক্ষমতা যেমন গ্রহণযোগ্য তেমনি সুরক্ষিত। তদুপরি, বিদ্যমান সিস্টেমগুলির সাথে তুলনা করে দেখা গেছে যে প্রস্তাবিত কাঠামোটি অন্যান্য সিস্টেমের তুলনায় সুরক্ষিত, মাপযোগ্য (scalable), গ্রাহক ভিত্তিক, এবং ব্যবহারিক।

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LIST OF ABBREVIATION

API : Application Programming Interface

DHI : Digital Health Intervention

DGDA : Directorate General of Drug Administration

DI : Digital Intervention

EJS : Embedded Java Script

EJS : EPCglobal's Electronic Product Code Information Services

GPS : Global Positioning System

IDE : Integrated Development Environment

IoT : Internet of Things

NFC : Near-Field Communication

OECD : Organisation for Economic Co-operation and Development

P2P : Peer to Peer

PC : Personal Computer

QR : Quick Response

RFID : Radio-Frequency IDentification

SLR : Systematic Literature Review

SMS : Short Message Service

TLC : Thin Layer Chromatography

WHO : World Health Organization

CHAPTER 1

INTRODUCTION

This chapter firstly provides a brief discussion on the thesis background to introduce the thesis topic. Next, it highlights the motivation and problem statement of the thesis. Then, the thesis objectives are presented followed by a methodological overview and scope of the thesis. Finally, the organization of the remaining chapters is described.

1.1 Thesis Background

Counterfeit medicines (also known as falsified) are substandard, manufactured using wrong or harmful ingredients, and most of the cases are not produced by registered companies, according to Centers for Disease Control and Prevention (CDC) [1], Organisation for Economic Co-operation and Development (OECD) [2], SANOFI (2017). The current scenario of medicine counterfeit all over the world is not that satisfactory (Nayyar et al., 2019). According to the OECD report in 2019, the cost of the global trade of counterfeit medicines for a year was around 4.4 billion USD (OECD & Office, 2019). Moreover, due to the COVID-19 pandemic, the consumer demand for medicine and medical products is increasing significantly, and similarly, the global trade of counterfeit and falsified medicines is increasing (Interpol, 2020; Tesfaye et al., 2020). The consequences are increased drug resistance, life risk for the medicines of critical diseases, etc. World Health Organization (WHO) [3] reported that in developing and underdeveloped countries, 10% drugs are falsified. According to re-

[1] https://wwwnc.cdc.gov/travel/page/counterfeit-medicine
[2] https://www.oecd-ilibrary.org/content/publication/a7c7e054-en
[3] https://www.who.int/news-room/fact-sheets/detail/substandard-and-falsified-medical-products

search by Rahman et al. (2018) focusing on the adverse health effects of counterfeit medicine consumption along with geographical summary, among 48 incidents with around 3600 reported deaths, more than 56% cases were from developing countries. Counterfeit medicines are more available in developing and under-developed countries where manufacturing, distribution, supply, and sale management are less monitored, and the living standard of people is at a low level (M. N. Islam & Inan, 2021). In Bangladesh, the percentage of counterfeit medicine is increasing also. The Directorate General of Drug Administration (DGDA) is publishing laws and procedures to prevent medicine counterfeit in Bangladesh. Falsified drugs are available mostly in small and local shops. Most of the people in Bangladesh are known about the unethical proceeding in medicines but hardly take any steps against this. People have no way to know if a medicine is counterfeit or not. In most cases, they don't have any idea about where to inform. Thus, the patient safety and health risk of people due to falsified drugs must be reduced (T. K. Mackey & Liang, 2011). There are some drug monitoring and regulating authorities and additional framework working currently in different countries (Nayyar et al., 2019). Global and local regulations in the medicine supply chain can reduce the production and manufacturing of illegal drugs. Mackey also proposed a global policy framework with centralized supervision to coordinate among the organizations to fight against medicine counterfeit.

Digital interventions are the uses of digital technologies like websites, computers, wearable devices, mobile phones, software systems, mobile applications, etc. Adopting these digital solutions has made our life easier and more improved by providing several services (M. N. Islam et al., 2020; M. N. Islam et al., 2021; Khan et al., 2020; Munim, Islam, Sarker, et al., 2019; Promy et al., 2022; Zaman et al., 2020). Moreover, a digital system must be technically feasible, effective, efficient, and obtain user satisfaction to be acceptable/adoptable in our lives (UNICEF, 2018). So, this is very important to ensure a proper balance between human needs, perceptions, actions, and the functionalities of digital intervention. Digital interventions are considered a more cost-effective solution that requires less human and space to implement and maintain a positive relationship with the productivity as well as manpower and capital management of a system (Baily & Lawrence, 2001; Griffiths et al.,

2006; Oliner & Sichel, 2000). Following specific methodological procedures, digital interventions can be designed qualitatively and quantitatively to ensure effectiveness, feasibility, and the acceptability of it to the users and the stakeholders (Bradbury et al., 2014).

Again, to combat medicine counterfeiting, various areas need to be addressed like securing medical product and their packaging, ensuring traceability and integrity of the medicine supply chain, tracking the movement of a drug over the supply chain, enhanced regulatory procedure, strong law enforcement, raising public awareness, etc. (Berman, 2008; Isah, 2012). Counterfeit medicines are labeled and packaged almost the same as the original product. Moreover, both generic and branded products can be counterfeit (Kopp, 2019). Sometimes original product which is expired is packaged and labeled again with a false one and entered the market as a new product (Mukhopadhyay, 2007). So, it is very hard to detect, investigate, quantify and monitor counterfeit drugs (Isah, 2012). Moreover, existing analytical techniques like tamper-resistant tape, spectroscopy, radio frequency analysis, etc. have been introduced to regulate medical products. These digital solutions can detect counterfeit medicine in some limited cases (I. Islam & Islam, 2022). But these couldn't reduce counterfeiting significantly because of the increased extent of medicine counterfeiting due to the revolution of the internet and lack of awareness. People in Bangladesh are not that much conscious of medicine counterfeit. They don't have any idea about the actions that need to be taken or where to complain if they face any medicine counterfeit issues. In recent times, medicines are also available in online shops, people are not aware of buying from any trusted websites also. Thus, digital intervention or proposing digital solutions could help to detect counterfeit medicine by reducing the problems of human based manual systems and making the surveillance procedure easier. Similarly, digital intervention can also play a vital role to reduce the illegal entry of counterfeit, new, unapproved drugs into the supply chain.

1.2 Motivation and Problem Statement

Blockchain can be integrated into the pharmaceutical industry by ensuring the transparency, traceability, privacy, and immutability of data over the medicine production and distribution

system. These features may help to eliminate counterfeiting, identify any anomaly instantly, improving trust among the participants over the supply chain (Clauson et al., 2018). So, a blockchain based solution can be a convenient one to reduce the medicine counterfeit in developing countries like Bangladesh. Some studies (Ferdosi et al., 2021; Glass, 2014; Sultana & Sobhan, 2020; Uddin et al., 2017) were carried out to propose a solution to this issue but there is no blockchain based research to address the medicine counterfeit in Bangladesh. The problem statements could be formulated as follows:

a. A limited number of studies have been carried out implementing blockchain in medical production and distribution systems; which are primarily focused on applying codes to the medicine packages and ignore most other factors of medicine counterfeit in Bangladesh.

b. Few to none of the studies focused to detect fake medicines automatically in the context of Bangladesh.

c. Existing studies focused less to reveal the use-cases/ features for developing a blockchain based anti-medicine counterfeit system.

d. An updated blockchain based system needs to design to track each actor in the medicine production and distribution system.

Therefore, this research aims to study the existing medicine manufacturing and distribution process in Bangladesh from reference, formulate the features required from some studies and propose a blockchain based conceptual framework considering the features explored in the study.

1.3 Thesis Objectives

This research intends to explore the possible ways of medicine counterfeit in Bangladesh and to facilitate the prevention of the usage of counterfeit and falsified drugs in Bangladesh. In a broader perspective, this research covers the fields of *Blockchain* and *Health Informatics*. In short, the objectives of this research are stated below:

Firstly, to explore the possible factors responsible for medicine counterfeit in Bangladesh as well as the state-of-art views of current research and development focusing on the research area.

Secondly, to propose a blockchain based framework of medicine manufacturing and distribution to prevent medicine counterfeit.

Thirdly, to evaluate the performance of the proposed framework.

These research objectives will result in two expected outcomes. *Firstly,* the possible factors of medicine counterfeit in Bangladesh as well as research gaps focusing on reducing the counterfeit and falsified drugs. *Secondly,* a blockchain based framework to design and develop a trustless, scalable, and transparent medicine production and distribution system to prevent medicine counterfeiting in the context of Bangladesh.

1.4 Methodological Overview

The methodology adopted for this research can be divided into four major sections: (i) formulize the research problem, (ii) extract the features, (iii) propose and develop a system, and finally (iv) evaluate the system. To formulize the research problem a content analysis of the existing laws and procedures, and a Systematic Literature Review (SLR) of the existing research articles in Bangladesh were carried out. From these two the existing research gaps and recommendations were defined. Then, a semi-structured interview of the personnel involved in medicine production and distribution was conducted. Considering the interview findings and the results derived from SLR and content analysis, the use cases of medicine counterfeit were generated. From the use cases, the required features for a system to prevent medicine counterfeit were extracted. Considering the features, a blockchain based framework was proposed and a prototype of this framework was developed. Finally, an evaluation study was performed to evaluate the framework.

1.5 Thesis Scope

The scope of this thesis can be defined from a number of perspectives. Medicine counterfeit is a global problem, especially, in developing and underdeveloped countries over the world. But the scope of this research is limited to considering the possible factors responsible for medicine counterfeiting in the context of Bangladesh only. So, this research outcome doesn't imply different countries' perspectives. Again, there could be several approaches can be adopted. In this research, we are focusing on studying digital interventions and how they could be implemented and proposing a solution accordingly. Moreover, a digital solution can be device-oriented, hardware, or software based; can be developed on several platforms. this research was carried out by developing a blockchain based system that is only available through a web platform. The system is developed as software or a mobile application.

1.6 Organization of the Chapters

The organization of the thesis for the remaining chapters is as follows:

Chapter 2: This chapter presents the 'Theoretical Background' and the 'Related Work'. Here, the relevant concepts for the concerned research area are discussed. These concepts cover medicine counterfeit, digital interventions, digital interventions to prevent medicine counterfeit, blockchain technology, and implementation of blockchain technology in the prevention of medicine counterfeit. Then, the existing research those are related to this research has been presented. Finally, the focused research opportunity for this thesis along with a critical summary to highlight the issues for which it was chosen for further research is outlined.

Chapter 3: This chapter presents the 'Research Methodology' which shows the methodology adopted for this research which can be divided into the sequential phases: research problem formulization, features extraction, framework design, and development, and evaluation. For this, the detailed procedure of the content analysis, systematic literature review, user study, development, and evaluation are described.

Chapter 4: This chapter contains the 'Research Problem Formulization and Feature Extraction', the detailed procedure of feature extraction including outlining the existing scenario of medicine counterfeit in Bangladesh and current research gaps in the research area. The methodology of the content analysis, systematic literature review, and user study are discussed elaborately followed by the outcomes of the studies as well as research gaps and future research opportunities.

Chapter 5: This chapter presents 'The Proposed Framework' and 'Implementation'. Here, the architectural design of the proposed framework along with its workflow is described. An example scenario for this framework has also been discussed. After that, the development of a prototype has been depicted including the tools and application used for it, considering the architectural design of the framework presented previously in this chapter.

Chapter 6: This chapter presents the 'Evaluation of the Prototype'. The prototype is simulated and an evaluation study of the developed prototype, as well as the framework, are depicted.

Chapter 7: This chapter presents the 'Discussions and Conclusions'. Finally, the thesis is concluded in this chapter with a summarized discussion of research outcomes and research implications. This chapter also includes certain limitations and possible future work of this research.

CHAPTER 2

THEORETICAL BACKGROUND AND RELATED WORK

This chapter briefly depicts some of the key conceptions that are essential for fundamental theoretical knowledge regarding the background of this thesis. Then, the existing related research focusing on reducing falsified and counterfeit medicines are briefly discussed followed by a critical summary of research opportunities.

2.1 Research Background

To discuss the research background, first of all, an elementary discussion on medicine counterfeit is represented. Next, the existing medicine supply chain is explained. Then, a brief description of the digital interventions, as well as blockchain, is discussed followed by the impact of blockchain in our daily lives.

2.1.1 Counterfeit Medicines

Counterfeit and falsified medicines are manufactured using wrong or harmful ingredients, and most of the cases are not registered, out of specification or quality standard [1] (OECD & Office, 2020; SANOFI, 2017). These medical products including medicines, and vaccines, are manufactured and packaged falsely to represent their origin, authenticity, or effectiveness information [2]. Firstly, in 1992, WHO (Kopp, 2019) defined a counterfeit medicine as: "A product that is deliberately and fraudulently mislabelled with respect to source and/or identity".

[1] https://wwwnc.cdc.gov/travel/page/counterfeit-medicine
[2] https://www.who.int/news-room/fact-sheets/detail/substandard-and-falsified-medical-products

Recently, after some modifications according to WHO the terms 'falsified', 'substandard', 'unregistered/unlicensed' will be used with the following definitions [3]: *"Falsified medical products may contain no active ingredient, the wrong active ingredient, or the wrong amount of the correct active ingredient."* Substandard and unregistered medicines were referred to as: *"Substandard also called 'out of specification', these are authorized medical products that fail to meet either their quality standards or specifications, or both. Unregistered/unlicensed medical products that have not undergone evaluation and/or approval by the National or Regional Regulatory Authority for the market in which they are marketed/distributed or used, subject to permitted conditions under national or regional regulation and legislation."*

Thus, all the drugs that are falsified, substandard, and unregistered can be referred to as counterfeit medicine. Consumption of the toxic or replaced element in counterfeit drugs can cause several health risks like- poisoning, untreated disease, treatment failure unexpected reactions, side effects, or worsening health conditions even death (Buckley & Gostin, 2013; Ham, 2003; Rahman et al., 2018). Medicine is taken to cure a disease, diminish the symptoms, or slow down the progression of a disease. Toxic or wrong amounts of ingredients in a falsified medicine can make the medicine a poison rather than a way of treatment which can result in unexpected reactions or side effects on the patients like kidney failure, heart attack, stroke, etc. Again, the medicine can also be inactive for treatment. Mostly, the falsified medicines contain ingredients (i.e: chalk, pollen, or flour) instead of medicinal chemicals. For this, the medicine won't work for the disease anymore.

2.1.2 Digital Intervention

Digital interventions (DI), also known as digitalization, are adopting information and communication technologies like the Internet, mobile phones, software systems, mobile applications, etc. to accomplish any specific jobs, improve work performance, provide better services, and the like (Iivari et al., 2020; M. N. Islam & Islam, 2020; Munim, Islam, & Islam, 2019). DIs have become an essential part of everyday life by serving many functions

[3] https://www.who.int/news-room/fact-sheets/detail/substandard-and-falsified-medical-products

and purposes. In the beginning, DIs were costly and difficult to develop requiring good expertise in programming. But now people can easily develop DIs using free software without having less knowledge about programming (Park, 2016). Moreover, in recent years, a special type of DI referred to as Digital Health Interventions (DHI) includes digital and mobile technologies for supporting health system needs. DHIs are very common to adopt all over the world. Devices and software are being adopted for patient diagnosis, treatment, prevention of disease, self-management of chronic diseases, delivery of healthcare services, etc. DHIs are health services that are delivered electronically to the patients and easily accessible (Michie et al., 2017; Soobiah et al., 2020). Based on the targeted user, WHO (2018) categorized DHIs into some classes:

- *DHI for clients:* Clients are the potential users of health services. Caregivers of clients are also included in this group.
- *DHIs for healthcare provider:* Healthcare providers deliver health services to clients.
- *DHIs for a health system or resource managers:* Health system and resource managers are responsible for administration and monitoring activities.
- *DHI for data services:* Tasks related to data collection, storage, management, usage, and transfer are included in this type of DHIs.

2.1.3 Digital Intervention and Medicine Counterfeit

To reduce medicine counterfeiting globally, various factors need to focus on like ensuring the authenticity of medical products and their packaging, ensuring traceability and integrity of the medicine supply chain, tracking the movement of a drug over the journey from the manufacturer to the end customer, enhanced monitoring procedure, strong law enforcement, raising public awareness, etc. (Berman, 2008; Isah, 2012). Counterfeit medicines are labeled and packaged almost the same as genuine products. Moreover, both generic and branded products can be counterfeit (Kopp, 2019). Sometimes original product which has expired already is packaged and labeled again with a false expired date and sent to the market as a new product (Mukhopadhyay, 2007). So, it is very hard to detect, investigate, quantify

and monitor counterfeit drugs (Isah, 2012). Moreover, existing analytical techniques like tamper-resistant tape, holograms printing, image processing, spectroscopy, attaching edible micro-taggant, usage of color shifting inks or Radio Frequency Identification (RFID) code, etc. have been introduced to monitor the medical products (Chambliss et al., 2012; X. Chen & Zhang, 2019; Han et al., 2012; Koster, 2013). But these couldn't prevent counterfeiting significantly because of the increased range of medicine counterfeit, especially after the revolution of the internet. Thus, digital intervention could help to detect counterfeit drugs by eliminating the problems of human based manual systems and making the surveillance procedure easier. Similarly, digital interventions can play a vital role to reduce the illegal entry of counterfeit, new, unapproved drugs into the supply chain.

2.1.4 Blockchain Technology

Blockchain is one of the latest technology introduced which can be implemented to regulate human and business activities. Blockchain (Swan, 2015), a distributive ledger, can provide a new procedure to monitor human activity on a wide scale. Blockchain (I. Islam et al., 2020) can be referred to as a distributed ledger of time-stamped blocks organized by different nodes. Blockchain integrated the peer-to-peer (P2P) file sharing using public key cryptography (Yli-Huumo et al., 2016). Blocks, permanent records of cryptocurrency transactions between the nodes of a P2P network, are linked in a sequence by using a hash function. So, blockchain can be considered as an embedded layer in the web to accomplish certain jobs like payments, cash exchange, receiving and distributing tokens, transferring digital assets, issuing smart contracts, etc between two parties without involving any third party. Blockchain can be considered a major innovative technology for all operating standards like- computers, the internet, or mobile devices, with the same potential to recompose all human activities as the Web. From the point of view of providing service, blockchain includes scalability, validation of data, multiple writers, and distributed trust as properties (I. Islam et al., 2020). The properties of storing immutable and timestamped records offer audibility, variability, reliability, robustness, and auto-synchronization of the system. Blockchain can be considered a revolutionary technology since it can eliminate security

risks by ensuring transparency in a scalable and immutable structure.

2.1.5 Applications of Blockchain

Blockchain was primarily designed for the transactions using bitcoin, a digital cryptocurrency, over a P2P network (Tasatanattakool & Techapanupreeda, 2018). Transactions using bitcoin maintains more trust, security, and transparency by implementing cryptographic proof (digital signature). But over the time, blockchain is not only limited to the bitcoin, it is now implemented in several sectors like- in the healthcare sector to facilitate treatment as well as secure all data in EHR efficiently (Bell et al., 2018), in cybersecurity to prevent as well as identify unexpected cyber attacks (Schlatt et al., 2022), blockchain based voting system to eradicate the anomalies in existing voting system (Gupta et al., 2022), in the product supply chain to assist its sustainability (I. Islam & Islam, 2022; Saberi et al., 2019), in financial and banking sectors to facilitate secured and fast transactions (Garg et al., 2021), blockchain based agri-food supply chain to ensure the authenticity and verified information regarding food (Ehsan et al., 2022), in governance to improve the economy (Beck et al., 2018), in land administration Niverd Pereira et al., 2021, incorporating Human-computer Interaction in blockchain Hossain et al., 2020 etc.

2.1.6 Medicine Counterfeit and Blockchain

Blockchain can be implemented to trace the shipping chain of goods. During the Annual Meeting of the World Economic Forum at Tianjin, China, Christian Lanng depicted the contribution of blockchain technology in current days as [4]: *"[Supply chains] often have many different stakeholders touching goods, moving them around ... If you want to have authenticity, if you want to know where it is sourced, that it is done in a responsible way ... (blockchain) is a great technology to manage that kind of flow and be sure of the integrity."*

Blockchain can be implemented to guard against counterfeiting in the pharmaceutical sector (Mettler, 2016). The structure of this technology doesn't allow any single person to modify any data of a transaction that has already occurred. Moreover, all the metadata related

[4]https://www.cryptoglobe.com/latest/2018/09/current-blockchain-tech-nology-cannot-manage-the-global-supply-chain-tech-veteran-says

to every transaction is stored in the blocks. Participants can easily exchange digital assets without any help from any third party also. So, integrating the blockchain may help to facilitate procedures for eliminating medicine counterfeit by providing features like increased security, trust, transparency, visibility, privacy, etc. (Haq & Esuka, 2018). Blockchain is currently considered a solution to control the medicine supply chain in some developing countries (Glass, 2014). Blockchain can be implemented to record as well as authenticate a medicine during its journey over the supply chain (Radanović & Likić, 2018).

2.2 Related Work

The existing studies in this research area are briefly discussed in this section. A critical summary is depicted also to highlight the issues in the focused research opportunity that inspired to conduct further study.

The related literature was found by performing a search in the major scholar databases including ACM Scholar, Google Scholar, Science Direct, IEEE Explorer, and Springer Link. The related articles are divided into three categories including uses of blockchain in healthcare, reducing counterfeit medicines, and anti-counterfeit model using blockchain.

2.2.1 Blockchain in healthcare

Blockchain has a wide range of implications in the field of healthcare. The distributed ledger can provide enhanced security and transparency in managing Electronic Health Records (EHR), research in healthcare, etc. Ekblaw and Azaria (2016) developed a blockchain based medical data management system named "MedRec" considering patients, the treatment community, and medical researchers as stakeholders. It keeps EHRs of the patients for further use or research purpose also in a secured architecture. Gul et al. (2021) proposed a blockchain and IoT based smart healthcare business model. The model was able to predict the status of a customer and give rewards to the customers based on the preset business rules. The adoption of blockchain in the model made the business model more secure, effective, and friendly. Moreover, S. Y. Jung et al. (2021) proposed two blockchain based mathematical models of token economy in case of real-world scenarios. The incentive mechanism

modeled on personal health records of the patients managed health care organizations and funding companies can motivate one another to join the platform.

Siyal et al. (2019) reviewed the key elements along with the workflow of blockchain. Siyal et al. also described some applications of blockchain in the healthcare sector like EHR, pharmaceutical industry, medical fraud detection, clinical research, etc. Blockchain can offer a personalized, synchronized, and secured healthcare management system with real-time medical data. In the pharmaceutical industry, the supply chain should be visible to all the participants to track each transaction. Moreover, the possible challenges, in this case, are security and privacy risk of transaction data (due to validation from all the participants over the network), requiring larger storage capacity than before, difficulties to address a large number of certified standards from international standardization authorities, etc. On the other hand, Yaeger et al. (2019) depicted the impact of the features of blockchain followed by the benefits and pitfalls of integrating blockchain in the healthcare and medicine sector. Yaeger et al. also stated blockchain as to be a solution to manage and store large size of electronic and health data securely, and handle payment mechanisms, medical equipment, and the medicine supply chain. But this infrastructure requires more computing power to execute and it results in being expensive and difficult to implement in real life. Yeager et al. also presented some blockchain based solutions in the healthcare system that are theoretically proposed, developed, or clinically implemented. Another research conducted by Khezr et al. (2019), presented the opportunities and future research directions for implementing blockchain in the medical sector like- introducing healthcare management systems, developing healthcare applications, deploying supply chain management systems, etc. Khezr et al. discussed some existing tamper-resistant systems and their working principles. Khezr et al. also showed a comparative view of the different management mechanisms of the supply chain dealing with a different types of records. For example, scalability and cost of implementation are serious concerns in the case of clinical trial records. On the other hand, transparency is very helpful for successful trials. For medical records, lack of consistency is a limitation but particular medicine can be prescribed easily from the stored data. Massive data related to the healthcare sector can be processed, stored, and managed quickly

and timely also using blockchain. Moreover, blockchain will be helpful to track the flow of legal drugs from manufacturers to patients.

2.2.2 Digital Interventions to prevent medicine counterfeit

In recent years, several studies have been carried out to propose a digital solution to reduce medicine counterfeit. Han et al. (2012) introduced a Quick Response (QR) code based microtaggant encoded with medicine data. This special type of microtaggant didn't lose data during the medicine manufacturing procedure. Medicine could be authenticated anytime over the supply chain since the QR code could be read through a smartphone QR code reader app. Ting et al. (2010) researched to enhance the information transmission over the medicine supply chain. For this, the existing solutions as well as challenges to transmitting information were analyzed. The research concluded that RFID and IoT can be easily adapted to eliminate the existing problems in pharmaceutical industries. Another RFID based medicine supply chain was proposed by Schapranow et al. (2011). A qualitative analysis was also performed on data related to the amount and cost of medicine from the point of medicine service providers. Implementing the model could help the medicine service providers by enabling a concrete pharmaceutical supply chain.

El-Jardali et al. (2015) constructed a conceptual framework of different strategies to reduce medicine counterfeit. The systematic review found regulatory measuring methodologies or prequalification procedures, implementation of specific technologies at various inspection points of production and supply chain model, campaign for public awareness, training for the drug inspectors, supervision for quality control, etc. may help to reduce the buying and selling of counterfeit or illegal medicines. Finally, they concluded that to prevent medicine counterfeit a standard definition of falsified medicines with the elements is required.

2.2.3 Anti-counterfeit model using blockchain

To prevent medicine counterfeiting, it is very important to monitor and track the medicine production and distribution system. A number of studies were found that especially proposed blockchain based solutions to reduce medicine counterfeit drugs. For example, Bry-

atov and Borodinov (2019) discussed the features and function of the blockchain system and then designed a conceptual framework to prevent the availability of counterfeit medical products. The framework involves government as the administrator and owner, and the manufacturer, doctor, pharmacy, and citizens each with their account to establish interconnection by blockchain using Hyperledger Fabric. The manufacturer creates a node named "medicine", the doctor creates "Prescription" for the patient, and for the pharmacy, the name of the created node is "order". Again, Sylim et al. (2018) introduced two instances (on Ethereum and Hyperledger Fabric) on Distributed Application (DApp) with Distributed File System (DFS) on a private blockchain network for simulation. The system would ensure drug quality according to the GS1 pedigree standard and guidelines from US Food and Drug Administration (FDA). There were five types of participants: FDA, manufacturer, wholesaler, retailer, and customer. FDA would supervise the whole system and verify each medicine. The manufacturer will create a node for each medicine and the end customer can check the supply chain history of the medicine by scanning the code printed on the packaging. The result of the simulation of the system in a controlled simulated network might be differehttps://www.overleaf.com/project/6215f04dc0f7304da39c9befnt from the result of actual practice. Moreover, Schöner et al. (2017) presented a framework to ensure medicine supply chain security using blockchain. Schoner et al. also developed a prototype of the system to show the benefits achieved from blockchain features. The framework solved two issues: medicine counterfeit, and information asymmetry and consequences due to pharmaceutical R&D.

Kumar and Tripathi (2019) proposed a framework to identify counterfeit medicine by combining PKI (Public Key Infrastructure) and digital signature. The framework was able to trace the medicine manufacturing and supply chain from the company to the end customer. The sender will share information as encrypted in a QR code by using his/her public key (validated by the participants over the network). Only the receiver can access the information using his/her public key. After each transaction, all the information will be stored and shared over the network. Haq and Esuka (2018) also worked to combine blockchain and the pharmaceutical industry to address the counterfeit medicine issue. Haq and Esuka proposed

a layout of the pharmaceutical supply chain management system along with the working procedure. In another research, Tseng et al. (2018) recommended the Gcoin blockchain involving each unit in the drug supply chain model for transparency. As a result, the model will prevent medicine counterfeit and store medical data securely. Showing a comparative view between the existing and blockchain based models, Tseng et al. proposed a system architecture involving manufacturers, wholesalers, retailers, pharmacies, hospitals, and customers as participants. Tseng et al. also showed the theoretical explanation of the results of implementing the proposed model.

I. Islam and Islam (2022) reviewed all the existing research to prevent medicine counterfeiting all over the world. Mostly, authors from India and USA worked in this research area. Most of the selected articles proposed digital solutions to prevent medicine counterfeit using technologies like blockchain, pattern recognition, RFID, image processing, etc. Moreover, mostly focused research area was the medicine supply chain and blockchain was adopted as the major technology for those research. T. K. Mackey and Nayyar (2017) reviewed the existing digital solutions to prevent medicine counterfeit in several fields like health, information technology, computer science, and alike. Mackey found several solutions using mobile technology, RFID, online pharmacy validation, blockchain technology, advanced digital computational methods, etc. Most of the existing research focused on laboratory and field based solutions to test and identify falsified medicines. Amongst all the solutions, Mackey suggested that blockchain can help this sector as it provides a more secure, trustworthy, and decentralized digital ledger.

2.3 Chapter Summary

In sum, the literature survey related to reducing medicine counterfeit indicated that a number of research have been carried out to solve the issue of medicine counterfeit which primarily focused on the integration of RFID, mobile technology, applying codes to the medicine package, etc. and ignore most other factors of medicine counterfeit. Again, few to none of the studies focused on detecting falsified medicines automatically in the context of Bangladesh. Moreover, existing studies focused less to reveal the use cases in the context

of Bangladesh for developing a digital solution to prevent medicine counterfeiting. So, a more updated and reliable system is required to track and trace the medicine production and distribution system and eliminate the consequences of drug counterfeiting.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter discusses the overview of the methodology for conducting this research that includes the detailed procedure of four phases: formulize the research problem, extract the features, propose and develop the system, and evaluation of the prototype.

3.1 Key Phases of Research Methodology

This section briefly presents the key phases of this research. The methodology followed for this research can be divided into four phases (Figure 3.1):

In *formulize the research problem* phase, there are several steps like formulating the research problem, determining the features, and then designing the system architecture accordingly. To formulize the research problem, a content analysis of the existing laws, procedures, and policies in Bangladesh as well as a Systematic Literature Review (SLR) of existing related research were performed. From these, the research objectives were defined. Then in the phase of *extract the features*, a user study of people involved in medicine manufacturing and distribution was conducted. Use cases of preventing medicine counterfeit were generated from the user study and the analysis of SLR and content analysis. From the use cases, the features for a system preventing medicine counterfeit were extracted. After that, in the *propose the framework and development of prototype* phase, a framework was proposed by considering the features defined in the previous phase. A prototypical system was developed by addressing the features of the framework. For this, four steps were followed: (a) configuring the blockchain, (b) developing the front end, (c) deploying the blockchain, and

(d) simulating the system. In *evaluation* phase, the prototype was evaluated by performance analysis in terms of block access time and operation time; and a comparison with existing systems in terms of features and block access time.

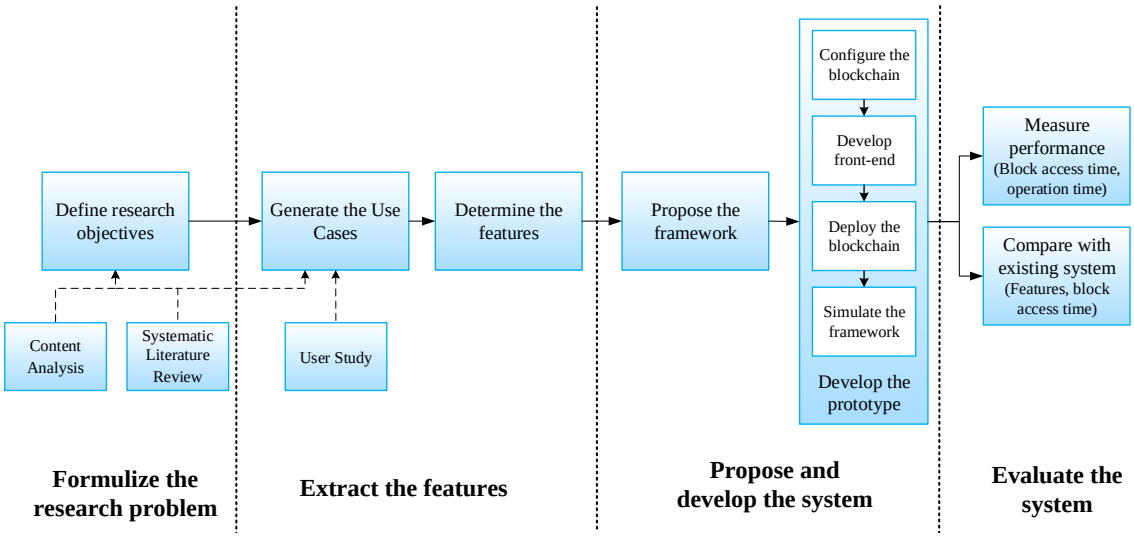

Fig. 3.1. Overview of the research methodology

3.2 Content Analysis

The existing rules and protocols to prevent medicine counterfeiting in Bangladesh were reflected through content analysis. Content analysis is a systematic approach to qualitative research methodology to generate valid inferences from data regarding any specific topic or event in any available form (verbal, visual, or written) (Downe-Wamboldt, 1992; Hsieh & Shannon, 2005). To conduct the content analysis, all the documents, procedures, policies, and regulatory measures taken by Bangladesh Government were selected by extensive search over the internet. All these documents were gone through, analyzed, and summarized as the study findings.

3.3 Systematic Literature Review

This section discussed the detailed procedure of the SLR conducted for formulizing the research problem as well as extracting the features.

The SLR approach suggested by Kitchenham (Kitchenham & Charters, 2007) was adopted in this research. An SLR methodologically outlines, evaluates, and finds the gaps in the pub-

lished information according to some research questions and research topics in an unbiased manner (Kitchenham, 2004). SLR helps to summarize the existing work, its benefits, and limitations, and to depict the study gaps for future research opportunities. This literature review intended to explore the existing studies and the development of systems, concepts, and techniques aiming to prevent medicine counterfeiting and falsifying. Three major phases of the SLR are: planning the review, conducting the review, and reporting the review (Figure 3.2). The steps for this literature review are briefly discussed chronologically as follows:

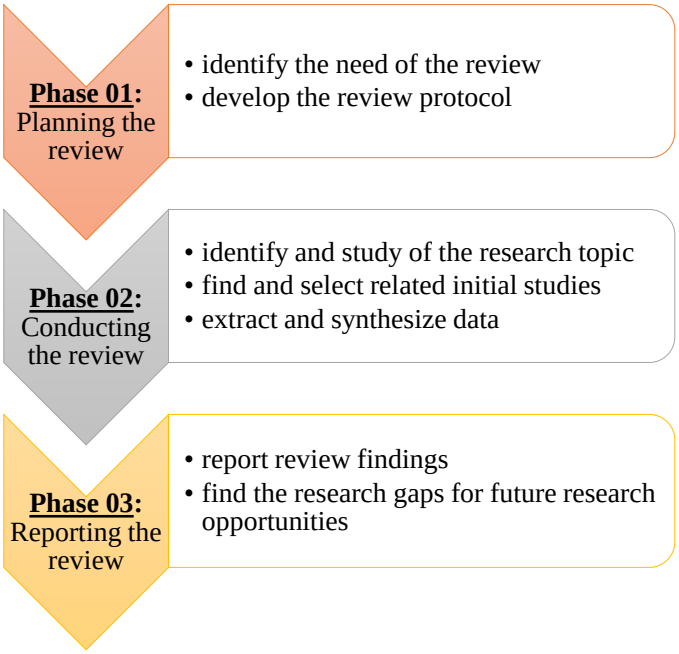

Fig. 3.2. Methodology for the systematic literature review

3.3.1 Specifying Research Questions

This review aims to understand the current status of medicine counterfeiting; explore the existing studies focusing to detect and prevent medicine counterfeiting through digital interventions; provide a comparative view among the studies aiming to reduce or prevent medicine counterfeiting through the use of ICTs; to find out the current research gaps; to provide the possible scopes for pursuing potential future research. To obtain these review aims, the following questions were formulated:

RQ1: What kind of digital solutions exist to combat counterfeit and falsified medicines?

Table 3.1: Keyword used for search

Category	Keywords
Medicine	”Medicine”, ”Drug”
Medicine Counterfeit	”Medicine Counterfeit”, ”Drug Counterfeit”
Falsified Medicine	”Fake Medicines”, ”Falsified Medicine”, ”Falsified Drugs”
Prevent	”Prevent”, ”Fight”, ”Combat”,”Solution”, ”Reduce”, ”Authentication”, ”Track”, ”Trace”
Technology	”Technology”, ”Digital”, ”ICT”, ”IT”, ”Software”, ”DBMS”, ”Blockchain”, ”RFID”, ”Barcode” , ”2D Data Matrix”

RQ2: How much do the existing studies contribute to preventing counterfeit and falsified medicines?

RQ3: What are the challenges and limitations of the existing research on falsified and counterfeit medicine?

RQ4: What are the scopes of potential future research to reduce the usage of counterfeit and falsified medicines?

3.3.2 Selection of the Sources and Searching Keywords

Several scholarly digital databases were searched for selecting the related works; that includes Google Scholar, ACM digital library, ScienceDirect, SpringerLink, IEEE Xplore, PubMed, Medline, and Wiley Online Library. Global keywords and their synonyms were selected as searching keywords (presented in Table 3.1) that would answer the research questions. The combination of the selected keywords was also identified as a searching keyword (See Table 3.1). For this, Boolean operators *AND* and *OR* were used with the keywords like the following pattern: (“Medicine Counterfeit”) AND (“Prevent”) (“Falsified Medicine”) AND (“Reduce”)

3.3.3 Defining Inclusion-Exclusion Criteria

The inclusion and exclusion criteria defined to select the related articles are presented in Table 3.2. Considering these criteria, articles that were not related to this study were removed.

Table 3.2: Inclusion and exclusion criteria used to select relevant articles

Inclusion/ Exclusion	Criteria
Inclusion Criteria	Articles proposing ICT based solution for preventing medicine counterfeit
	Articles written in English.
	Articles being available with full text.
	Articles published in a conference proceedings, journals, thesis, magazines, and techreport.
	Articles published since 2000 to 2021.
Exclusion Criteria	Same articles found from different databases.
	Articles proposing an assumption.
	Articles not related to the research objective.
	Articles not referring to ICT based solution
	Articles lacking of proper justification of the proposal.
	Articles measuring the chemical composition of medicine.

3.3.4 Selection of the final articles

Using the keywords, an intensive search was performed in the listed databases and Google search engine. The character * (asterisk) was used along with the keywords to select the matching results with one or more characters. The summary of the search and selection of final articles are illustrated in Figure 3.3 through Prisma diagram Stovold et al. (2014). Performing the preliminary search, a total of 1253 research works were found. After removing duplicate or repeated articles, primarily 528 articles were selected. Considering full-text availability and language, 350 articles were chosen. Analyzing the title, the first level screening resulted in 139 articles and excludes 211 articles that are not related to reducing counterfeit and falsified medicines and discussed non-digital solutions. Then, excluding the articles that proposed solutions based on only assumption and lack of proper justification of the proposal by reading the abstract and introduction, and in some cases, discussion, a final list of 51 articles were selected for this review study.

3.3.5 Data Extraction

For data extraction, seven themes were considered to explore the appropriate answers to the research questions. Some of the themes were formulated into features to extract data in a structured way (Figure 3.4). To collect the specific kind of data, a set of questions was

outlined on each theme.

a. Topical association: This theme points out how the selected articles are correlated;

   (a) Are the articles' keywords reappearing?

   (b) Are the titles closely associated?

b. Research profile: This theme depicts the year of the publication and the publication type;

   (a) When the article was published?

   (b) What was the publication type? Was the article published in a conference, workshop, journal, tech report, or as a thesis dissertation?

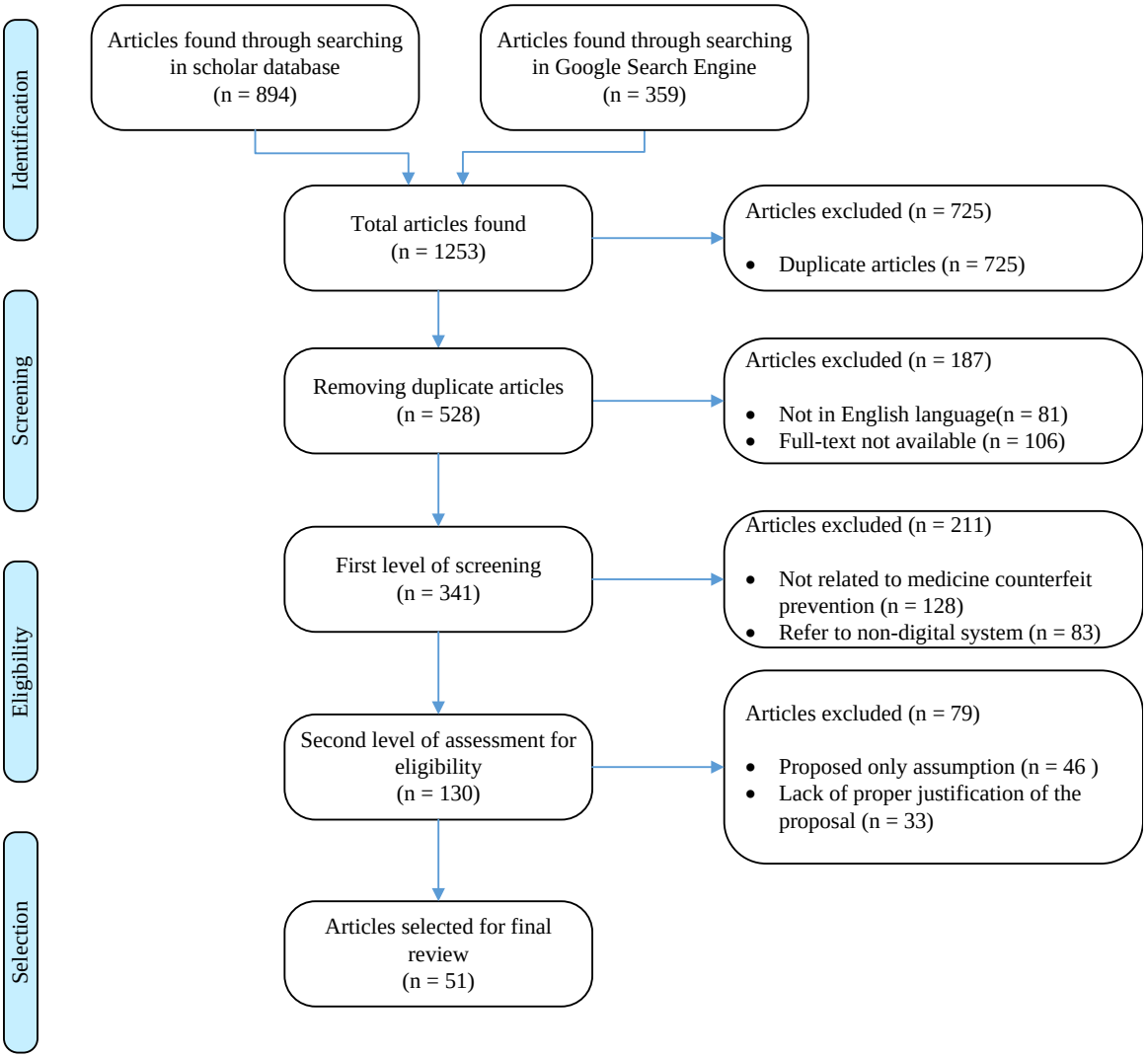

Fig. 3.3. PRISMA flow diagram for selection of the articles

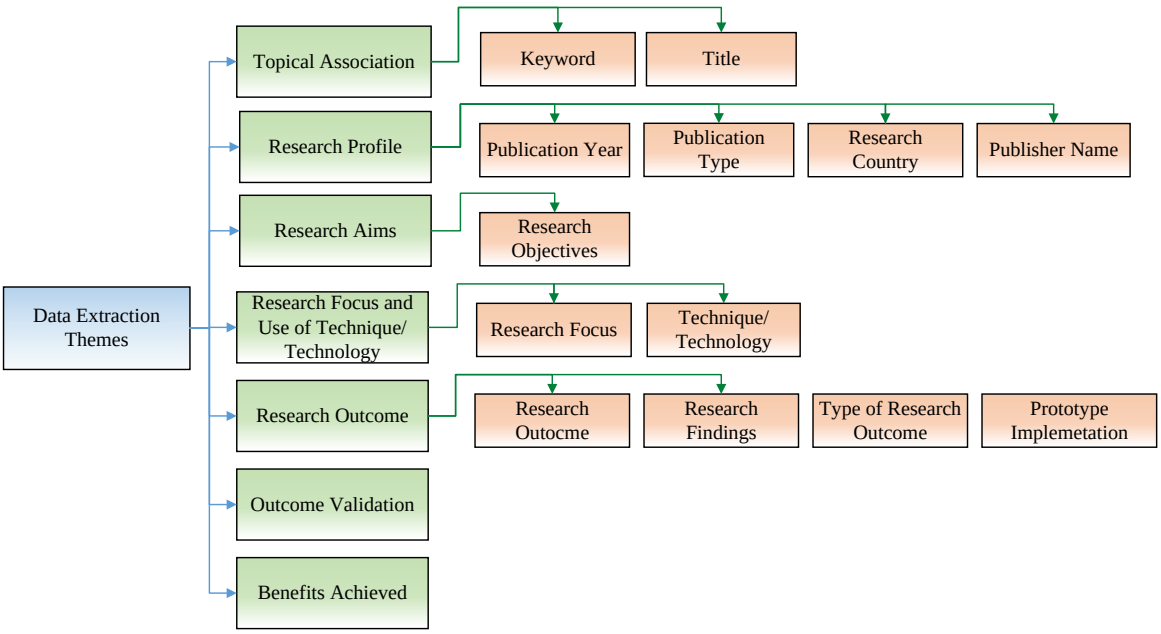

Fig. 3.4. Themes with features for data extraction

(c) In which country was the research conducted?

(d) What was the name of the publisher?

c. Research aims: This theme identifies the research aims and objective;

(a) What was the aim of this research?

d. Research focus and use of technique/ technology: This theme presents the research focus and the usage of technology/ technique to prevent the usage of counterfeit and falsified medicines;

(a) What was the primary focus of the research in the case of reducing the usage of counterfeit and falsified medicines?

(b) Which technologies were used to propose the solution?

e. Research outcome: This theme extracted the data portraying the research outcomes;

(a) Was there a clear statement of the research outcome?

(b) What were the main research findings?

(c) What was the type of research outcome?

(d) Was any prototype implemented?

f. Outcome validation: This theme characterizes the data related to validating the study outcomes;

(a) Were the results of the study validated?

(b) How the study outcome was evaluated?

g. Benefits achieved: This theme retrieved the benefits achieved as a result of this research.

(a) What benefits/ research goals were achieved by conducting this research?

Related data against the theme-based questions were retrieved. A sample set of data extracted against each question is included in B. The extracted data were analyzed and synthesized to provide effective answers to the stated research questions (discussed in Chapter 4).

3.4 User Study

To generate the use cases of reducing medicine counterfeit in Bangladesh, semi-structured interviews were conducted.

3.4.1 Participant Profile

To understand the existing scenario of counterfeiting in the pharmaceutical industry, interviews with 6 medicine users, 5 wholesaler shopkeepers, 6 retailers, and 5 people working in the manufacturing industry were conducted. Among the medicine users, three were female and three were male participants each taking medicine according to a schedule for 3 years with an average age range of 25 to 54 years. The participants working in the wholesaler and retail medicine shops were 21 to 40 years old and all of them were male. Each of them had 2 to 15 years of experience. All participants from the quality assurance department of the renowned pharmaceutical industry were male each having at least 8 years of experience. Their age range was 35 to 45 years. The medicine users and participants from industries

Table 3.3: Profile of the interview participants

Ser	Participants' Type	No. of Participants	Age (yrs)	Gender	Experience (yrs)
1	Manufacturer	5	39.8 ± 4	Male: 4 Female: 1	13 ± 5
2	Wholesaler	5	38 ± 4	Male: 5 Female: 0	9 ± 5
3	Retailer	6	30.2 ± 7	Male: 6 Female: 0	8.7 ± 6
4	Customer/ Medicine user	6	38.5 ± 10	Male: 3 Female: 3	7.5 ± 5

were recruited from the personal network. The retailer and wholesaler were chosen randomly in different parts of Dhaka city. Their profiles are briefly presented in Table 3.3.

3.4.2 Interview Procedure

The interviews were conducted following a semi-structured approach. The interviewers asked the participants about their personal experiences and actions regarding any incident related to medicine counterfeiting. All the interviews were performed one-to-one and in Bengali. All information provided by the interviewers was recorded. Each interview session was for about 15-20 minutes. For each participant, the conducted interview session can be summarized as:

- In general, consent was taken from each participant and they were briefed about the purpose of this interview.
- Biographical information of the participants was collected that includes their age, experience, and more information depending on the type of their profession. For example, the retailer shopkeepers, age, and experience of working in the shop were asked. For medicine users, age, experience, and type of medicine they are taking currently were collected.
- Depending on the type of the participants, they were asked several questions like if the participant has experienced any incident related to medicine counterfeit. and

based on the responses some other related questions were asked as the interview was semi-structured. For example, in case of any incident regarding medicine counterfeit, manufacturers, wholesalers, and retailers were asked how were they informed, how medicine was identified as counterfeit, and what actions/ measures were taken against the incident. For the medicine users, the question was how they identified medicine as a fake one, what they did, and whom they informed.

- For each type of participant, the frequency of experiencing any event regarding medicine counterfeit as well as the mostly suspected/ reported medicines were noted.
- If the participant was asked to share their opinion about the approach to preventing medicine counterfeit.

A detailed version of this interview procedure with different types of participants is shown in Appendix C. An example of interview response is also shown in Table C.1. All the information collected from the user study was analyzed to outline the study findings (Chapter 4).

3.5 Development and Evaluation

The process of development of the prototype of the proposed framework can be described as: Firstly, the blockchain was configured in a Linux Virtual Machine running on Windows 10. Next, the corresponding smart contracts for medicine transfer from one node to another were built. Then, using the multiple containers the blockchain architecture was emulated in a single PC. After that, a web terminal was developed to access the blockchain framework. For each transaction, a new block was created and all the created blocks are immutable.

The prototype was evaluated by conducting performance analysis, security analysis, and comparison with existing systems. For this, the blockchain was deployed and simulated in the lab environment. Different containers were created as different nodes to access the blockchain by creating blocks and fetching medicine information. Firstly, the performance analysis was carried out in terms of block access time and operation execution time. Each

operation implemented in the prototype was executed a number of times to calculate the average execution time for a type of operation. The average execution time for each operation was plotted in a graphical view. To calculate the operation time, some selected operations that create a block to the blockchain were executed a specific number of times (i.e: 20, 40, 60, 80) in several rounds. For each round, the average time of block creation time was calculated and plotted in a graph to outline the trend of block access time with an increasing number of blocks. Next, a theoretical security analysis was also performed considering the key factors. Lastly, a comparison with an existing similar system based on features and properties was outlined.

CHAPTER 4

RESEARCH PROBLEM FORMULIZATION AND FEATURES EXTRACTION

This chapter briefly discusses the phase of research problem formulization and extracting the features. Firstly, the findings of content analysis and SLR are presented. Based on the findings a number of research gaps and future research opportunities are described. Next, the findings of user study is depicted. Then, the generated use cases for preventing medicine counterfeit in context of Bangladesh is described followed by the extracted features.

4.1 Findings of Content Analysis

From the content analysis of existing laws and procedures related documents, the findings can be summarized as:

- **Publishing Drug Control Ordinance and Policy:** Directorate General of Drug Administration (DGDA) of Bangladesh published Drug Control Ordinance[1][2] , National Drug Policy[3], and Drug Quality Policy[4] to monitor the manufacturing by maintaining the quality, supply and sale of medicines. Table 4.1 shows a summary of current rules and regulations to prevent medicine counterfeit in Bangladesh.

- **Declaring punishment against Unlawful Acts:** In case of production and sale of

[1]http://dgdagov.info/index.php/laws-and-policies/1123-drug-control-ordinance-1982/file

[2]http://dgdagov.info/index.php/laws-and-policies/1113-the-drug-control-ammendment-ordinance-1984/file

[3]http://dgdagov.info/index.php/laws-and-policies/1118-national-drug-policy-2016-english-version/file

[4]http://dgdagov.info/index.php/registered-products/suspend-cancel-products/1635-notification-date-20-04-2021/file

Table 4.1: Rules and regulations to prevent medicine counterfeit in Bangladesh

Ser	Procedure Name	Key concern regarding
1	License revocation	selling false, counterfeit, adulterated, expired, unregistered, and misbranded drugs
2	Legal action	prescribing medicines and drugs from unauthorized manufacturer and sellers
3	Punishable offense	storage and display of expired medicine in the pharmacy, or changing/ obscuring the expired date
4	Compensation	appropriate compensation of the consumers harmed from the use of substandard, fake, adulterated drugs.
5	Legal cell Formation	expedite legal proceedings against the person or organization involved in medicine counterfeit

Table 4.2: Actions taken against the counterfeit medicines in Bangladesh

Year	Action	Key concern regarding counterfeit	No of organization
2020	Temporarily license cancellation	Quality of medicine was out of standard	15
2021	License suspension	Medicine was found as counterfeit	10

substandard drugs, and unauthorized import of drugs, the ordinance declares the punishment (license cancellation, imprisonment or fine) of the charged person or organization. If any medicine is proved to be substandard or out of standard quality, DGDA can suspend the license of the manufacturing organization (notified through official Gazette) till it can attain the correct standard of the medicine. DGDA banned license of some manufacturing companies due to manufacturing fake/ low quality drugs, collecting raw materials from illegal source, and not maintaining any quality control procedure [5][6][7]. Table 4.2 shows the punishments of the medicine counterfeit issues against companies in Bangladesh in recent years.

[5]http://dgdagov.info/index.php/registered-products/suspend-cancel-products/1634-notification-date-21-01-2020/file

[6]http://dgdagov.info/index.php/registered-products/suspend-cancel-products/1633-notification-date-22-12-2020/file

[7]http://dgdagov.info/index.php/laws-and-policies/1620-quality-policy/file,Lastaccessed:05October2021

4.2 Findings of Systematic Literature Review

By conducting SLR of the related articles, the findings can be stated as follows:

a: **Topical Association:** To represent the topical association, the *Word Cloud* approach Heimerl et al. (2014) was used to depict how the articles are closely associated according to the theme. In a word cloud, the bigger and bold word represent its frequency and importance. Here, the word clouds visualize the word frequencies in the keywords (see Figure A.1) and titles (see Figure A.2) of the articles.

The word cloud generated using the keywords (Figure A.1) and titles (Figure A.2) depicts the depth of the relationship among the fields of the selected articles. For both title and keywords, highly focused words are blockchain, chain, counterfeit, drug, medicine, supply, and pharmaceutical. Words found smaller in size in the cloud was used in some specific articles as the title but they are not the commonly used ones. For example, RFID, mobile, chromatography are used in those research that was conducted based on these technologies only. This illustrates that the articles selected for the review are closely related.

b: **Research Profile:** In response to the question of finding the publication year, Figure A.3 shows the number of publications from 2007 to 2021. The review finding showed that studies focusing on proposing digital solutions to prevent counterfeit and falsified medicines have been published since 2007, while studies focusing on the chemical composition of medicine for preventing medicine counterfeiting and falsifying were conducted since a long ago. In 2020, the number of publications was increased compared to the previous years pointing that the research in this area has risen significantly.The publication year indicates that research focusing on preventing medicine counterfeit is increasing day by day.

The country of publication is presented in Figure A.4. The name of the country represents the location of the institute to which the first author of the article is affiliated. Though medicine counterfeit has become a global problem, authors from India and

the USA have researched this topic most. Again, the publication type and publisher name are showed in Figure A.5 and Figure A.6 respectively. Most of the research is getting published as conference papers and journals, while various publishers are also involved to publish studies focusing on medicine counterfeit.

c: **Research Aims:**The aims of the existing research along with the number of studies are presented in Table A.1. Most of the selected articles focused on multiple research aim. So, the aims are classified into five categories: prevent counterfeit and falsified medicines, performance and security, smart health care, public health and awareness, and technology acceptance. The reviewed articles primarily aimed to propose a digital solution for preventing medicine counterfeit. While some studies intended to enhance the performance and security of medicine supply chain systems to prevent medicine counterfeit. Again, a good number of studies have aimed to emphasize providing smart health care to address the medicine counterfeit problem to some extent.

Mapping between the study aims with the publication year (Table A.2) showed that a very limited number of studies were conducted till 2015. Among them, most of the studies were conducted aiming to reduce the usage of counterfeit and falsified medicines. Again since 2016, the number of research has been increased significantly focusing on counterfeit and falsified drugs. These findings thus indicate that in recent days, the supply chain is focused more to prevent counterfeit and falsified medicines.

d: **Research Focus and Use of Technique/ Technology:**Existing studies primarily focus on five areas (see Table A.3) to reduce the usage of counterfeit and falsified medicines while the major portion of the articles focused on the medicine supply chain. The movement and transaction data related to medicine over the supply chain are considered for research. The reviewed articles primarily aimed to propose a digital solution for preventing medicine counterfeit. While some studies intended to enhance the performance and security of medicine supply chain systems to propose a solution to reduce counterfeit and falsified medicines. Again, a good number of studies have aimed to emphasize providing smart health care to address the medicine counterfeit

problem to some extent.

Table A.4 presents the usage of technology or techniques to propose a digital solution for preventing drug counterfeiting. Mostly, blockchain based solutions have been introduced to reduce falsified medicines. Then RFID, image processing, and mobile technology have been used in several studies. Table A.5 shows the number of articles using more than one technology to propose a solution. Moreover, the usage of ICT has been changed according to the time (see Table A.6). Earlier (2007 to 2016), RFID, NFC, image processing, TLC analyzer, pattern recognition, etc. were quite popular technology to conduct research. But later from 2017 to 2020, it can be found that research based on blockchain technology has been significantly increased to prevent counterfeit and falsified drugs. These findings indicate that blockchain technology could be used to ensure a secured and traceable logistic medicine supply chain I. Islam et al. (2020) for reducing the usage of counterfeit and falsified medicines.

e: **Research Outcome:**The outcomes of the studies were synthesized and classified into six categories: architectural framework, conceptual idea, software, quantitative analysis, algorithm, and edible element (see Figure A.7). Most of the review articles proposed architectural frameworks and a few of them also simulated their proposed framework as study outcomes. Apart from these, a limited number of studies presented the development of a system to prevent the business of falsified and counterfeit medicines.

From the implementation point of view, prototypical systems were developed in 24 (47%) studies. The rest of them (53%) didn't implement their proposed concept or framework. Among the articles that implemented the prototypical solution, thirteen studies included experimental implementation or simulation of their proposed solution.

A mapping between the research aim and outcomes is depicted in Table A.7. The mapping results showed that most of the studies aimed to enhance the performance and security of the medicine supply chain and management system, and to reduce

medicine counterfeiting and falsifying. The results thus indicate that mostly architectural frameworks and conceptual ideas were proposed. Considering the relationship between the technology used and the research outcomes as presented in Figure A.8.

f: **Outcome Validation:**A total of 29 among the reviewed articles (57%) validated their research outcomes (see Figure A.9). Most of the selected articles performed an outcome validation. Again, the validation studies largely preferred to perform computational evaluation and to show a comparison between the existing solutions and their proposed ones and conduct a simulation of their framework.

This review study also found that most of the architectural frameworks were validated using computational evaluation, while a good number of conceptual ideas have been validated by experimental implementation followed by accuracy measurements (Figure A.10 and Table A.8).

g: **Benefits Achieved:** The summary of the achieved benefits is presented in Table A.9. The most highlighted benefits achieved through the digital intervention are: enhancing the performance, improving trust and transparency, monitoring the supply chain easily, authenticated manufacturer, and tracking any unusual event that occurred in the pharmaceutical supply chain for reducing medicine counterfeit.

4.3 Research Gaps and Future Research Opportunities

The findings of this systematic literature review reveal some constructive research opportunities in the broad area of blockchain and health-informatics. Some of the potential future research opportunities are recommended below which can be considered in order to meet up the research gaps related to improvement in medicine supply chain management system in case of prevention of falsified and counterfeit medicine. Figure 4.1 shows a diagram that briefly outlines the recommendations.

The outcomes of this systematic literature review present the existing research gaps or lim-

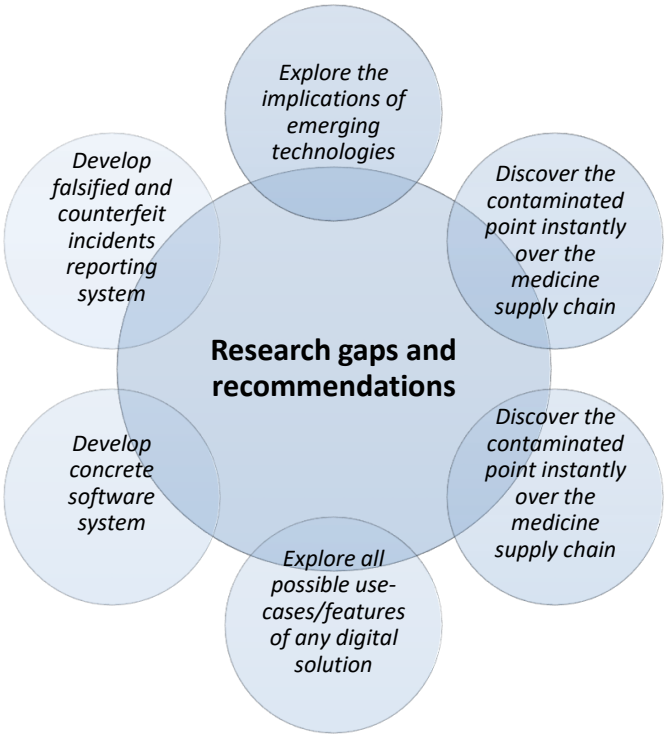

Fig. 4.1. Overview of the recommendations

itations in the broad area of healthcare to determine the possible future research directions for preventing the medicine counterfeit. A specific set of research directions revealed from this review study are discussed below:

- **Explore the implications of emerging technologies:**

  The review showed that several emerging technologies like Blockchain, IoT, RFID, and the like were used to propose different types of digital solutions to prevent counterfeit and falsified medicine (Alzahrani & Bulusu, 2018; Kumari & Saini, 2020; Ting et al., 2010; Wazid et al., 2017); while a few studies adopted multiple technologies to propose a distinct solution for reducing counterfeit and falsified medicines (Archa et al., 2018; Banerjee et al., 2016). Usage of multiple technologies may facilitate the whole system to perform more effectively and efficiently. However, in this vein, further research could be conducted focusing on (i) exploring the necessities and benefits of using multiple technologies (instead of a single technological solution) for developing a digital solution to prevent the usage of counterfeit and falsified medicines; (ii) adopt the artificial intelligence (AI) and machine learning (ML) to bring a revolu-

tionary in the elimination of counterfeit and falsified medicines; and (iii) investigate which emerging technology offers the best performance in terms of effectiveness, efficiency, time, latency, and cost-effectiveness in offering a solution to the medicine counterfeit.

- **Discover the contaminated point instantly over the medicine supply chain:**
  Some studies (Bryatov & Borodinov, 2019; Haq & Esuka, 2018) were conducted that facilitates to track any event of a dispute over the medicine supply chain but no empirical assessment or evidence has been presented regarding its accuracy and efficiency. Again, although it is very important to detect the point of entry (i.e., retailer, wholesaler) of a counterfeit or falsified drug in the medicine supply chain instantly for the prevention of counterfeit and falsified medicines, the existing studies did not explicitly focus to discover the original scenario or detect the responsible one for contamination over the supply chain. If it could be possible to detect any contaminated point over the medicine supply chain immediately, the medicine will not be able/allow traversing further over the supply chain. Therefore, further research can be conducted to detect the infected point as well as the involved person over the medicine supply chain instantly.

- **Investigate the less emphasized concern of counterfeit and falsified medicines:**
  A significant amount of research (n =25) focused to the whole pharmaceutical supply chain to propose a solution Anand et al. (2020), Schöner et al. (2017), and Shuaib (2013); while a limited number of other studies focused to authentication (Corona et al., 2015; Sylim et al., 2018), medicine appearance (C. R. Jung et al., 2012), medicine ingredients (Han et al., 2012; Yu, Le, et al., 2016), medicine ownership (Pham et al., 2019). Moreover, some important issues were not focused on in the earlier studies like the process starting from purchasing the raw material to the production of a drug, data security of manufacturer organizations, etc. Future research could be carried out focusing on the less emphasized or ignored issues to enhance or develop new solutions for preventing counterfeit and falsified medicines.

- **Explore all possible use-cases/features of any digital solution:**

  Several existing studies have proposed a framework or a software solution to reduce the usage of counterfeit and falsified medicines primarily by authenticating a counterfeit/ falsified drug (Adsul & Kosbatwar, 2020), adding traceability in the supply chain for real-time surveillance (Saxena et al., 2020), enhancing transparency over the supply chain (Kamble et al., 2020), and ensuring a balance between security and performance of the supply chain (Schapranow et al., 2011). But none of the studies has been conducted focusing on developing a system considering all these features (or uses-cases) together.

  Again, the existing research/solution can detect a medicine as counterfeit or falsified if the code on the label is not stored as a valid one (Anand et al., 2020). On the contrary, a medicine can be falsified or counterfeit but may use a valid code that is already used (in another item of a similar type of medicine); and the existing solution can trace this medicine properly. Similarly, according to the existing blockchain-based solution (Anand et al., 2020), detecting a medicine as an invalid/fake one is not possible at this moment for the following scenario - a medicine that should be located at a shop in city "A". But the same code can be given as input to check the validity from city "B". Here, the medicine at "B" must be the counterfeit/ falsified one; and not detectable through the existing solution. Moreover, the existing research/solutions have focused on the packaging of the drug which is meant for some of the primary packaging like the blister packs or sachets (Y. Huang et al., 2018; Koster, 2013). But in the case of vials, bottles, ampules, or even for secondary packaging like boxes or cartons, it is very possible to replace the medicines inside of them with fake ones. And using the existing solutions, it is impossible to detect falsified/ counterfeit drugs since the original packaging remains to compel the system to give the wrong output.

  Therefore, potential future research scopes are open to reveal all possible use-cases or features; and to develop a digital system considering all the revealed use-cases or features to improve the performance and security of the medicine supply chain and

to reduce the usage of counterfeit and falsified medicines more effectively.

- **Develop concrete software system:**

  Most of the existing studies have emphasized proposing a conceptual (34%) or architectural framework (42%) rather than implementing concrete digital solutions for preventing counterfeit and falsified drugs. Again, prototypical solutions were discussed in around 42% of articles, while a limited number of studies (18%) presented the concrete software solutions to adopt in real life aiming to reduce the usage of counterfeit and falsified medicines. For example, Nilsson et al. (2011) proposed a conceptual framework for a secured medicine supply chain using time-controlled numeric tokens but no prototypical implementation was conducted. Though a computational measure of performance was performed as theoretical validation, it was not sufficient to validate the proposed conceptual framework. The review thus indicated that most of the proposed conceptual and architectural frameworks are not implemented yet to justify their feasibility, effectiveness, and efficiency. On the other hand, only 23 of the selected articles (Figure A.9) have validated their research outcomes mostly by providing theoretical validation, comparison with existing solutions, or experimental simulations. These findings revealed that implementation/development of the proposed theoretical solutions (architectural frameworks, conceptual design, etc.) is a great concern to evaluate their performances and feasibility in real context for preventing counterfeit and falsified drugs. These in turn indicated that materializing or implementing the existing theoretical proposals and evaluating the implemented solutions in the real context would be potential scopes for future research as well.

- **Develop falsified and counterfeit incidents reporting system:**

  Existing research was conducted having research aims like to fight against counterfeit and falsified medicines (Paik et al., 2009; Rehman et al., 2011; Yu, Le, et al., 2016), to ensure smart healthcare Bryatov and Borodinov (2019), Pandey and Litoriya (2020), and Singh et al. (2020), to provide increased performance and security of the supply chain (Haq & Esuka, 2018; Sahoo et al., 2020; Tseng et al., 2018) and so on, but there

is no study explicitly focusing to report any incident occurred to the local authority. Detection of a falsified or counterfeit medicine by any customer can at most refrain him/her to consume that medicine. And so, no one (even the manufacturer and local authority) has any idea about this issue unless the customer/shopkeeper informs them while informing the manufacturer can make aware and help them to be more careful. Again, informing the local authority immediately about such an incident with proper proof and data may help to identify the responsible one, which in turn will prevent people not from doing anything further and prevent the medicine from counterfeiting and falsifying. Thus, potential future research may focus on designing and developing a reporting system (mobile or web portal) to facilitate reporting any incident related to counterfeit and falsified medicines and taking appropriate legal actions to reduce the usage of counterfeit and falsified medicines.

4.4 Findings of User Study

The findings of user user study, content analysis, and SLR can be summarized as as:

4.4.1 Counterfeiting Approach:

The ways of counterfeiting any medicines are:

- **Targeting the popular and costly products in the market:** Those medicines are sold mostly in the pharmacies are targeted for counterfeiting. These medicines are stocked in the shop for a very few days and people doesn't bother much about these medicines. For example, medicines for treating gastric and heartburn, vomiting etc. An interviewer from the manufacturing company responded as "*Popular products with high marketing demands are mostly found as falsified one.*"

- **Performing the packaging same as the original one:** The outer package of the counterfeit medicines are almost same as the original one, which is very difficult to differentiate. One of the interview response was "*Very subtle change is found on the fake product packaging making it very difficult to identify.*" For example, very slight

spelling mistake in product name, fake expired or manufacturing date, duplicate foil etc.

- **Changing the medicine ingredients:** In most of the cases, the packaging and the outer shape of the medicine is tried to keep as same of the original one as possible. It is done so that it can't be identified easily. But the ingredients of the medicine is changed. The medicine contains less or no active ingredients. As a result, after consumption of these drugs, no health improvement is noticed. An respondee from the industry quoted as "*The fake one contains less active elements than we provide reducing the cost of production.*"

- **Making a copy of the medicine:** Sometimes, a duplicate copy of a medicine is produced where the packaging is the same as the original one like containing the correct date of a batch including the batch number and bar code, and the medicine itself is changed. So, there is no visible difference in the original medicine and the fake one.

- **Selling the duplicate one at low cost:** If the price of a duplicated medicine is higher than the original one, people won't buy it. On the other hand, if the duplicated medicine is offered as lower price by claiming that the shop is selling medicines at a discounted price, people will be interested to buy from that shop. Moreover, the production cost of duplicate medicine is much lower than that of the genuine one. So, it is very possible and convenient to sell duplicate medicines at lower price.

4.4.2 Frequency of counterfeit cases:

Among the 5 medicine users, two have never experienced any incident of medicine counterfeit. But three of them suspected some of their daily medicine as counterfeit. This happened once or twice in their lifetime.

According to the wholesalers and distributors, the counterfeit medicines are very much available to them. The registered and unregistered, both manufacturers offer their products of various quality as well as cost. Two products with same appearance but different quality and cost have different manufacturer. An interviewer responded as "*The original*

product provided by the industry is comparatively more costly than provided by a local and unauthentic source."

The retail shops has a similar response to the wholesaler shops. The distributors shows the samples of all products available to them. One retailer responded as "*The same medicine for example, paracetamol is manufactured by A, B, and C companies. They are registered. Moreover, some local and unregistered companies also produce paracetamol with low quality ingredients. All of them are available in the market.*" In industry level, the frequency of the counterfeit incidents reported are different for different companies. Two of them found 10-12 cases annually, one got 10-15 cases per year, and one of them found no cases till now.

4.4.3 Measures taken to prevent medicine counterfeit:

The participants who were medicine users and experienced medicine counterfeit assumed that the local and small retail shops are more responsible to sell falsified medicines. So, they decided to go to branded shops for medicine. While buying any medicine, they would be more careful to check the outer packaging as well as the dates printed on it. One of them stated as "*Small retail medicine stores have a limited stock and only the mostly sold medicines. Moreover, they sell less than the branded shops as well as must have less profit. Therefore, it's very much easy to deal for counterfeit medicines for more profit.*"

The four wholesaler shops responded that while buying any medicine, it can be manufactured by the authentic source or any unknown one. They are informed about the quality and cost of the medicine. The fake medicine packaging contains the name of any registered manufacturer. But they never buy those unauthentic products. One response was "*We can buy any medicine from any manufacturer. Though it's up to the shop owner that which medicine he would buy, we don't buy any counterfeit products.*"

The participants from retail shops also informed that they get offer for buying falsified or substandard drugs from the distributors. Though they can buy them if they wish, they don't buy and sell any drug that is not genuine. An interviewer told as "*In current market, the counterfeit drugs are very much available. But we never buy the fake medicines due to*

ethical issues. We need not make more profit by defrauding with the customers."

As the medicines are quite different from the outer packaging the manufacturer companies take some steps to differentiate their products from the fake ones. The measures can be listed as follows:

- **Employ medical representatives to monitor the local market:** Basically the marketing team of a company is responsible to handle and investigate the issues related to drug counterfeit. So, the team generally employs medical representatives to monitor the local market. They visits the shops and try to know if there is any medicine which can be substandard or falsified (contains their company name as manufacturer but actually not manufactured by themselves). If they suspect any medicine to be fake, they take the medicine from the shop and deposit it to the marketing department. The Head of the Marketing Department transfer the medicine to his team to identify if the medicine is actually produced by them. They at first check that the complain is justified or non-justified. "*Any incident reported to our industry is investigated first to figure out as justified or unjustified. We take actions for only the justified complains.*" was a response.

- **Print codes on the package:** The manufacturer often print bar code, unique code or QR code on the inner carton of each drug. While any medicine is suspected, they check the codes printed on it to identify the medicine. One interviewer said, "*We print barcode on inner the carton in costly and possible counterfeiting products.*". In case of some factories, an unique code is printed on each blister which can be verified by sending SMS to an prespecified number. One participant reported as "*We use an unique code on each blister. Customer can send SMS before buying containing the code to a given number. It will send reply by saying if the code is correct.*"

- **Preserve samples of each batch:** The companies preserve samples for each medicines of each batch called 'Retention sample'. The samples include a full package with medicines in blisters/ any other form. In case of any reporting of fake medicine, these samples help to identify if the medicine is actually genuine. They match the

style of the printing and information printed on the package, and the shape and color of the medicine itself. "*We store samples for all batches to match with any suspected product in future.*" was a response.

- **Modify the medicine and the packaging:** The manufacturing company changes the medicine appearance (i.e.: shape, color, etc.) as well as the packaging style (i.e.: carton color, printing color, font, date format etc.) after specific time interval. This helps to identify any counterfeit medicine easily. One responder told, "*We perform modification in case of medicine itself and packaging after some days to prevent medicine counterfeit.*" was a response. Sometimes, different formats (like font, color, printer etc.) are used on the packaging of the products for different batches.

A summarized view of the result and findings of the interview is presented in Table 4.3.

4.5 Generating the Use Cases and Extracting the Features

The following use cases that are revealed from the findings of content analysis, SLR, and user study:

Use Case 01. *A medicine with wrong QR code:* A medicine may have a wrong QR code printed. For example, a medicine has a QR code printed on its package which doesn't exist in the list of valid codes. In this case the medicine must be counterfeit.

Use Case 02. *A medicine with different location:* A medicine can be located at different place that it was to be. For example, a medicine is now at any distributor shop located at an address X. But a medicine found at location Y with the same QR code. So, any one of these medicines must be fake. If the current location of a medicine can be stored along with valid QR codes, it will easily identify fake medicines.

Use Case 03. *A medicine located at different owner:* A medicine can be found to a different owner. For example, a medicine has been sold to a customer already. But another medicine with same QR code can be found to a distributor shop. Here, any one must be counterfeit.

Use Case 04. *Ensuring quality of a medicine:* The process of manufacturing a medicine must be monitored to ensure the standard quality of a medicine. For example, a registered manufacturer can perform any rearrangement of ingredients or amount in a medicine. In this case, the medicine is also considered as a counterfeit one. This issue must be identified.

Use Case 05. *Selling a medicine at different node:* In case of not being permitted to sell medicine, if any node sell a medicine, it must be identified. For example, a medicine has been removed from the market for any reason. Before this, the medicine was available in the market with valid QR codes. But now all these are invalid codes. If any node sells any medicine having any of these codes must be identified.

Use Case 06. *A medicine not found:* A medicine can't be found after a specific node indicates an anomaly. For example, a medicine is currently located at a distributor. It has not been sold for a long time and physically the medicine is not found at the node. So, there can be a chance of anomaly (the QR code of the medicine has been duplicated and sold to customers secretly).

Use Case 07. *Updating the manufacturer:* Whenever an incident related to identifying a counterfeit drug, the manufacturer of that drug should be notified for further procedure. For example, a QR code printed on a medicine is found as invalid. The manufacturer will receive a notification about the event so that he can go to the node where the legal medicine exists, pick up the medicine, declare the QR code as counterfeit, label the medicine with new valid QR code after Quality control again and create a new product.

Use Case 08. *Informing the local authority:* The local authority should be informed about any medicine counterfeit incident. For example, when a medicine is found as counterfeit, the local authority gets a notification about the incident. It will help to punish the responsible people and reduce medicine counterfeit from the country.

By analyzing and synthesizing the use cases derived for preventing medicine counterfeit in

context of Bangladesh, the following features were extracted to address the use cases:

- **Identify a medicine as counterfeit:** Identifying a medicine as falsified or not would address the use case 01, 02, 03 and 04. Checking the QR code of a medicine will identify if the QR code exists or not. Again, if the QR code is valid one, the node which is checking the QR code, the location or the node type (i.e: manufacturer, distributor, retailer, or customer) can also detect a counterfeit issue. For example, A customer at retailer shop can give the medicine code of a medicine as input to know the status of the medicine. if the medicine is already ”SOLD”, the blockchain will provide notify the user that the medicine is not genuine. It has a valid medicine code printed but still it is not the original one. The medicine is genuine only if the medicine is at ”RETAILER” node and the location is same. For example, For example, a medicine is currently stored at any distributor. So, the user account of checking this medicine should be any retailer. If a customer is checking the medicine ID, there is a chance that the medicine has been duplicated using the original medicine ID from the distributor's node. If the current location of the medicine provided by the blockchain and the user's location is not the same, then the system will generate an alert to the user as the medicine may be counterfeit. Moreover, if the stored current node and location is different from the checking one, there is a chance for that medicine to be counterfeit. Moreover, if the quality standard of a medicine is monitored through a digital solution, any counterfeit issue at manufacturer node can also be solved.

- **Determine any anomaly in the medicine production and distribution:** Abnormality in the medicine manufacturing and distribution can be identified through a digital solution by checking the node of selling a medicine. If a medicine isn't sold from a valid/ correct node, there is a chance of medicine counterfeit. Again, if the history of a medicine is not found after a certain node, the medicine may be duplicated. So, checking these issues can address use case 05 and 06.

- **Inform relevant people:** Informing the manufacturer as well as the local authority can facilitate the prevention of medicine counterfeit. Involving them into the system

by providing used ID or contact address, and sending them notification would address the use case 07 and 08.

Table 4.3: Summary of the semi-structured interview

Ser	Topic	Participant	Information
1	Mostly counterfeited products	Customer	Mostly consumed ones
		Retailer	Popular and costly products
		Wholesaler	Popular and costly products
		Manufacturer	- Popular medicines - Branded and costly products
2	Buying price	Customer	Same as the original one
		Retailer	Less than the original one
		Wholesaler	Less than the original one
		Manufacturer	Less than the original one
3	Identification of a fake product	Customer	- Doesn't work after consumption - Looks different
		Retailer	Almost same as the original one
		Wholesaler	Almost same as the original one
		Manufacturer	- Checking the packaging - Checking the blister - Noticing the medicine itself - Performing chemical analysis
4	Measures taken to prevent medicine counterfeit	Customer	- Being more careful while buying medicines - Avoiding small and local medicine shops
		Retailer	Never buying any counterfeit products from the wholesaler
		Wholesaler	Never buying any counterfeit products from any unauthentic source
		Manufacturer	- Employing medical representatives for the local market - Printing codes on the package - Preserving retention samples - Modifying the medicine and the packaging
5	Frequency	Customer	1-2 times in lifetime
		Retailer	Available always
		Wholesaler	Available always
		Manufacturer	10 cases on average each year

CHAPTER 5

THE PROPOSED FRAMEWORK AND IMPLEMENTATION

This chapter describes the architecture of the proposed framework as well as the development of the prototype. The first section presents an overview of the design of the framework as well as the workflow of the framework and the smart contract. An example scenario involving the system generated blocks is also presented. Next section depicts the development of the prototypical system.

5.1 Overview of the Proposed Framework

By conducting content analysis, SLR, and user study the use cases of preventing medicine counterfeit was revealed (Section 4.5). Blockchain is a innovative technology to record transaction information as immutable and timestamped blocks (I. Islam et al., 2020). The blocks are linked through hash values forming a chain and shared by all corresponding nodes in a network. This makes data impossible or difficult to be updated or hacked. The transparency properties of blockchain facilitates the regulatory procedure of the system. Each block is authorized by the digital signature of the owner to ensure the data valid and tamper proof. The framework is proposed primarily to address the revealed use cases to reduce medicine counterfeit in context of Bangladesh. Moreover, data related to medicine must be distributed and ensuring secured and smooth delivery of drugs between each participant of medicine production and distribution system. So, blochckahin technology was adopted to propose a framework involving the participants of medicine production and distribution system to prevent drug counterfeit in Bangladesh. Figure 5.1 depicts the proposed blockchain

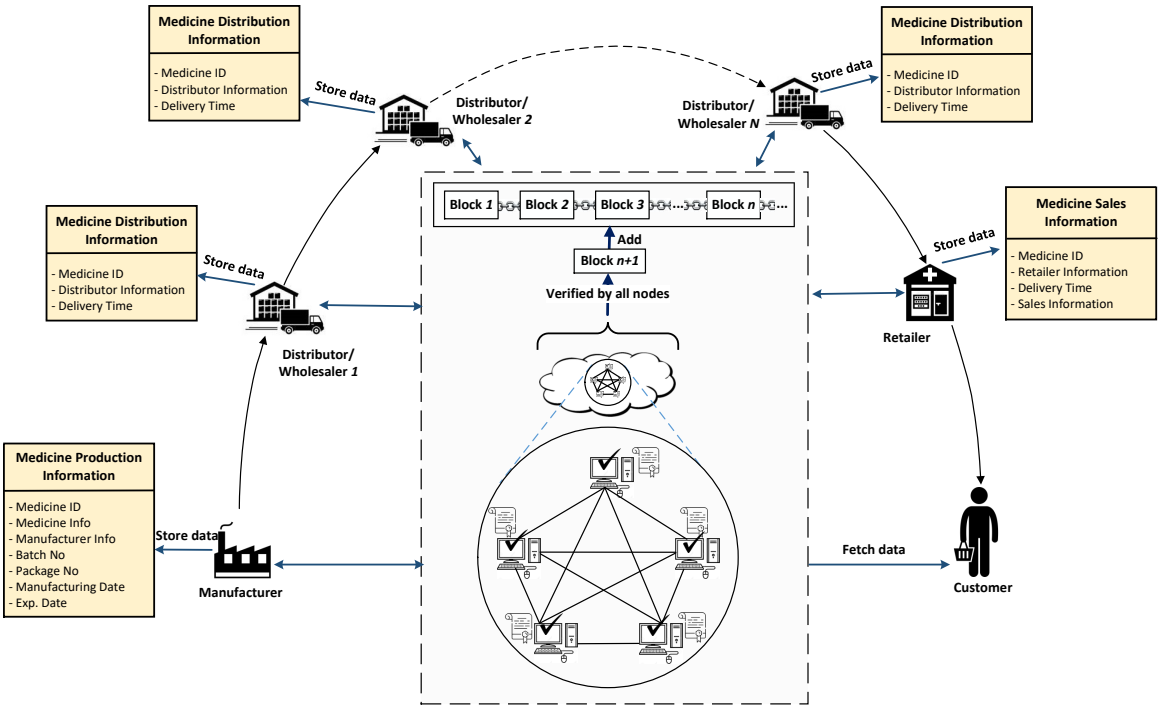

Fig. 5.1. The blockchain based anti-medicine counterfeit framework

based framework. Each participant of the medicine manufacture and distribution system are considered as a node and will have a separate account in the system. These accounts can be accessed using personal access credentials.

- **Manufacturer**: Manufacturer will produce medicine and take order from the next node. The manufacturer account is able to add a new block in the blockchain for adding a medicine using digital identifier (numeric code, barcode, QR code etc.). Adding a new medicine involves 'Medicine Production Information' like medicine ID, medicine info, manufacturer info, batch number, package number, manufacturing date, expiring date. Using the identifier (medicine ID) the medicine can be tracked all over the production and distribution. The account can also insert transactions to transfer the ownership of a medicine to another node. Then, a manufacturer account is required to provide details information of distributor.

- **Distributor**: Distributor can view the product list provided by a manufacturer and buy any drug. Distributor can again sell it to the next node by adding transaction information. Distributor can add a new block by updating the 'Medicine Distribu-

tion Information' of a medicine through inserting information related to distributor or retailer information.

- **Retailer**: Retailer buys medicine from the distributor and sells to the customer. The account will also be able to add the transaction information about selling a medicine. Retailer can change the medicine information by providing the 'Medicine Sales Information'.

- **Consumer**: The customer buy medicine from the retailer shop. This account can input the code given on the medicine to know the movement from the manufacturer to customer.

There can be none to more than one intermediate node between the manufacturer and customer in a medicine production and distribution (like more than one or no retailers). Finally the customer buys a medicine from a retailer medicine shop. Each node can store data related to specific fields. For example, distributor can store information about the medicine ID, information about the next and previous node, delivery time of the medicine. Each node can fetch data up to the current status of the medicine from the blockchain also. So, the whole journey of a medicine from the manufacturer to the customer is visible from any node at anytime. Hashing function is used to generate a hash value for sending and receiving a medicine by any node. The hash value is used to validate the event of reception by the node.

When a node performs a transaction, the system will create a new block *(n+1)* containing specific data and broadcast the block to corresponding nodes over the network. The block *(n+1)* will be added to the blockchain after successful verification.

5.1.1 Workflow of the Framework

In the proposed framework, whenever the medicine ownership is updated, there occurs a transaction. This happens until a medicine is sold to a customer or returned to the manufacturer as defected. For each transactions, a smart contract is executed.

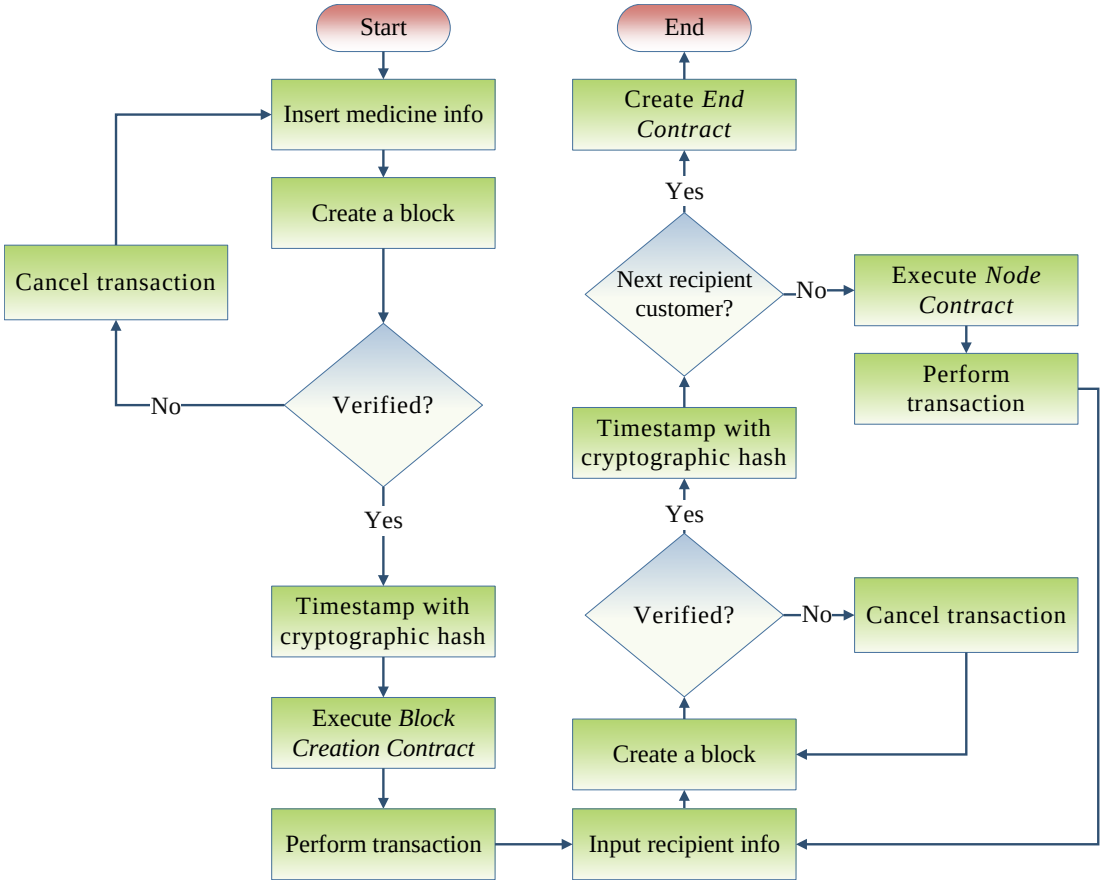

Fig. 5.2. The workflow of the framework

5.1.1.1 Smart Contract

Smart contracts will be used to create a new event and record this event in blockchain to track the medicine as it has added, moved from one intermediate node to another, and delivered. Between the manufacturer and the customer, there can be more than one nodes involved.

Between each two consecutive nodes, a smart contract is created. Smart contracts are self-executable program to perform an digital agreement between two nodes without any involvement intermediary or time loss Alharby et al. (2018), Cong and He (2019). Smart contract is basically a set of predetermined rules or programs written which are executed automatically as a response to meet the preset conditions. Each contract except the ending one, points towards the next contract. All the contracts executed for a medicine will make a chain of contracts similar to the chain of blocks. So, each contract has the address of the previous contract so that anytime the any contract can be accessed. The chain of contracts should have at least three contracts implying that after the manufacturer there must be at

least one wholesaler and one retailer. While involving one more node will result in one more contract to be created. In this framework, three types of contracts was designed based on the node type and their activities.

5.1.1.2 System Workflow

The detailed workflow of the proposed blockchain based framework is depicted in Figure 5.2. When the manufacturer wants to add a medicine to the blockchain, the manufacturer inserts all the information related to the new medicine including medicine name, generic name, form, dosage, expired date, manufacturing date etc. A block is created containing the information and is verified at first. If the information is valid, the block is timestamped with cryptographic hash value. Then, 'Block Creation Contract' is automatically executed and the transaction is performed. In case of invalid info, the transaction is cancelled.

While sending the medicine to the next node, the information regarding the next recipient (recipient name, address) are also inserted. A new block with medicine, sender and recipient info is created. If the block information is not valid, the transaction is cancelled. After successful verification, the block is timestamped with hash value. Now, if the next node is a customer then the Block 'End Contract' is executed. In any other case, the 'Node Contract' is executed and the transaction is performed. In all cases, the current node (owner info, address) for the medicine is updated.

If we consider, one manufacturer, two distributors, one retailer, customer for a medicine to be sold, the 'Block Creation Contract' will be created when the manufacturer will add a medicine, then 'Node Contract' will be created for each transaction among the distributor (1), distributor (2), and retailer. And Block 'End Contract' will be created for the transaction between the retailer and the customer.

5.1.2 An Example Scenario of the Framework

The workflow of the system is discussed through an example scenario of the data stored over the blockchain involving total four nodes: one manufacturer, one distributor, one retailer

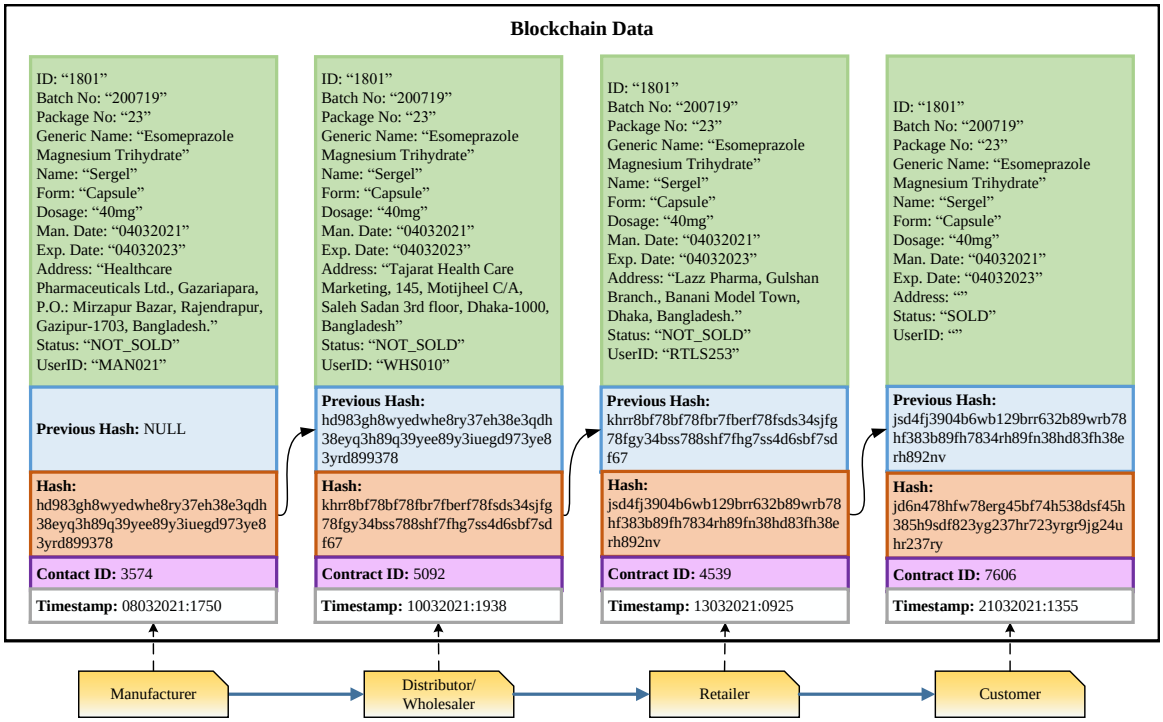

Fig. 5.3. A use case of data stored in a block of the proposed blockchain based framework

and one customer respectively as depicted in Figure 5.3. Each user is assigned with an unique userID and account to access the system. At each node, a new block will be created with updated information and tagged with a timestamp. A medicine can be tracked anytime while moving from the manufacturer to the customer. A digital code will be used with every medicine package as a data pointer. The codes will be printed on the package while manufacturing.

After manufacturing, the manufacturer creates a new block for adding a medicine. The block has the detailed information about the medicine like name, generic name, batch name, production date, expired date, form, address, dosage, batch no, package no, status, etc. The address contains the address of the manufacturer indicating the current location of the medicine. Moreover, the status field is 'at manufacturer' as it is not sold yet. A hash value is calculated of the data in the block as 'Hash' while 'Timestamp' contains the time of creating the block and the 'UserID' shows the id of the user who created the block.

When the manufacturer wants to sell the medicine to a distributor, he inserts the distributor information (Name, address) along with medicine info in another block. After the trans-

action, medicine information is updated. Then, the address shows the new location of the medicine and the previous block is linked with this block by storing the previous hash in it.

To sell the same medicine to a retailer, the distributor updates the new address with the retailer's address. The new block contains a link to the previous block by the 'Previous Hash'. The 'Timestamp' contains the time of creation of the block.

When a customer buys the medicine from the retailer, the retailer creates a new block for the event by updating the status as 'SOLD', address of the customer (not mandatory). New hash will be stored in the 'Hash' and a link will be created with the previous block also.

The system will be able to detect any anomaly or inconsistency over the production and distribution and all the users related to the product will be notified. For example, when the manufacturer ships a package of drugs to the distributor, the information will be hashed and compared with the stored one on the blockchain. If they both are matched, then the verification is successful. Otherwise, the package is identified as counterfeit one and the corresponding nodes will be notified.

Among the use cases revealed from the content analysis, SLR, and user study, four use cases were addressed in this framework. Checking the code printed on a medicine can provide the status and location of the medicine. From this, the framework will determine if a medicine is genuine. Analyzing the travel of a medicine from the manufacturer to current node any anomaly over the medicine production and distribution can be detected. Again, whenever a medicine is searched from a customer account which is located at different place than the location stored in the blockchain, there is a huge chance for the medicine to be counterfeit. Since the medicine can be suspected to be falsified, this also indicate any anomaly happened in the medicine production and distribution chain. However, in case of any counterfeit incident, the manufacturer of the medicine and the local authority is notified to handle the issue and to take necessary steps.

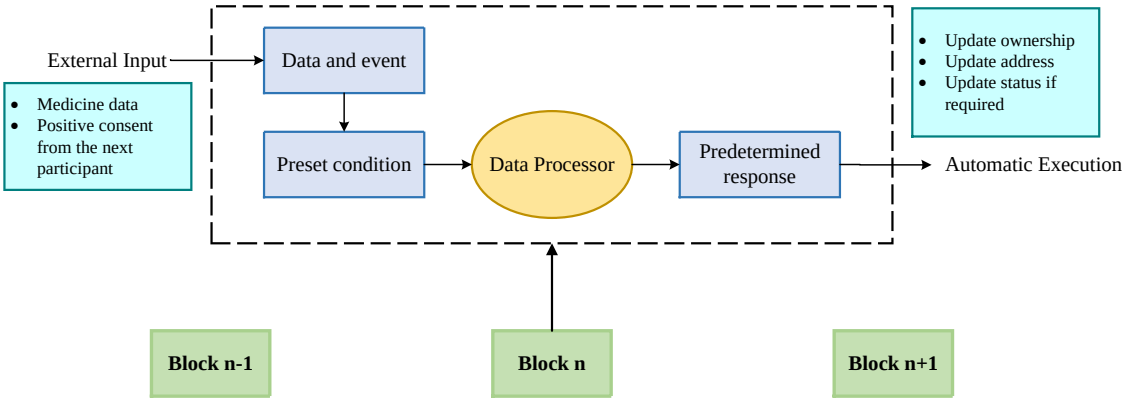

Fig. 5.4. A chain of contracts involving the participants of medicine manufacturing and distribution system

5.2 Implementation of the Prototype

A prototypical system was developed according to the features of the proposed framework. For this, at first the blockchain was implemented in Linux Virtual Machine on Windows 10. Then, the front end application was developed. Table 5.1 shows all the tools and applications used for developing the system. The development can be summarized as follows:

5.2.1 Blockchain Implemtation

The platform used to develop the blockchain based system was Ubuntu Linux 18.04 LTS with an Intel Core i5-10210U @ 1.60GHz processor and 4 GB memory were used. As medicine production, distribution, and sale can't be shared with the general people, the blockchain used in the prototypical system was implemented in a private modular architecture named *HyperledgerFabric* (Androulaki et al., 2018), an open source framework and toolkit for developing blockchain applications, hosted by The Linux Foundation. Smart contracts are designed and implemented in the *Hyperledger Fabric*. To implement the smart contracts as *Chaincode*[1] the programming language *golang* (Pike, 2009) was used. Each smart contract in Hyperledger consists of four components: model, query definition, script, and access control rules.

Figure 5.4 shows an example of a smart contract for a block. For execution, the mechanism takes external inputs (i.e.: medicine data, positive consent from the next node to receive

[1]https://hyperledger-fabric.readthedocs.io/en/release-1.3/chaincode.html

Table 5.1: Tools and applications used for developing the prototype

Category	Ser	Purpose	Component/ Application	Specification
Back End Development	1	To edit codes	Visual Studio	Version 1.68
	2	To implement private blockchain framework	Hyper Ledger Fabric	Version 4.5
	3	To build smart contract/ chaincode	golang	Version 1.17
	4	To generate multiple container	Docker	Version 20.10.6
	5	To test the developed APIs	Postman	Version 9.1.1
	6	To run Ubuntu	Virtual Box	Version 6.1.26
	7	To simulate	CPU	Intel(R) Core(TM) i5-10210U CPU @ 1.60GHz 2.11 GHz
	8	To simulate	Operating Systems	Ubuntu 18.04
	9	To simulate	Memory	6 GB
Front End Development	1	To develop the web terminal	EJS	Version 3.1.7
	2	Programming Language	HTML, CSS, JavaScript, jQuery	-
	3	Operating System	Windows	Windows 10 (64 bit)
	4	Browser	Google Chrome, Microsoft Edge, Firefox	-
	5	Library and Framework	Bootstrap	Version 5

the medicine). The input data and the already predetermined conditions are sent to the data processor for calculating the state. After that, based on the preset response statements the automatically execution is performed (i.e: update the address of the medicine, update the ownership like from manufacturer to the wholesaler).

In this system, there were four type of nodes: manufacturer, distributor, retailer, and customer. Each node were modeled as an identifier having some properties. All the nodes have access to some specific properties to update and are able to perform transactions in their network in blockchain technology. For identify each medicine a numeric medicine ID has been used instead of QR code. Smart contracts implemented in blockchain needs no external human involvement. It automatically executes when the certain conditions are satisfied (X. Chen & Zhang, 2019). Figure 5.4 shows an example of a smart contract for a block

Table 5.2: Transactions implemented in the proposed system

Transaction Name	Description
Add_med()	Adds a new medicine
Show_med()	Shows all the available lists of medicine
Update_med()	Updates the location and current participant having the medicine
Check_med()	Checks a medicine if it is counterfeit considering the location and node type
Show_loc()	Shows the current location of a medicine
Show_hist()	Shows the history of a medicine including all past nodes and location
Add_node()	Adds a new node in the blockchain
Show_shop()	Show nearby shops having a medicine

n. For execution, the mechanism takes external inputs (i.e.: medicine data, the next node information etc.), while the conditions and responses are already predefined. The input data and the conditions are sent to the transaction processor for determining the state, contract value, and contract status. After that, based on the response statements predefined actions are automatically executed (i.e: update the address of the medicine, update the ownership of a medicine like from manufacturer to the distributor).

To run the *Chaincode*, Docker[2] (Version 20.10.6) was used. Docker can be considered as a container isolated from the endorsing peer process. For testing the APIs Postman[3] was used. During smart contact modeling and implementation, transactions were defined to interact with the assets. Table 5.2 shows the definition of transactions introduced in the proposed system. Blockchain records any changes in the state as a transaction log and stores as a file. In case of blockchain. These transactions are encrypted and compiled as blocks to link cryptographically. The blocks are linked as a chain structure to store the transactions in a sequence of timestamps.

In Hyperledger Fabric, queries, used for retrieve data from the server, are required to define in a separate file. Each query is divided into two parts: statement (statement operators like SELECT, UPDATE, INSERT, DELETE, FROM, AND, OR, etc.) and description (a string defining the function of the query).

[2]https://www.docker.com
[3]https://www.postman.com/

Algorithm 1: Add A Medicine

Input: $MedicineName$, $BatchNo$, $PackageNo$, $FormOfMedicine$, $Dosage$, $MfgDate$, $ExpDate$

Procedure `addMed(`$Input$`)`**:**

```
    ManufacturerInfo ← take from LoginInfo
    MedicineID ← generate from system
    Create an object Medicine

    % Check conditions
    if (Length of Medicine == 0) then
        showErrorMessage("Medicine data is null")
        return
    end
    if (error in Medicine != NULL) then
        showErrorMessage("Error in medicine data")
        return
    end

    % Response
    setEvent ← Transaction
    Transaction.Timestamp(Medicine)
    Transaction.Hash(Medicine)
    Transaction.CreateAsset(Medicine)
    getTransactionID()
    setState()
    return
return
```

Algorithm 1 shows the algorithm followed to write the chain code for adding a new medicine to the blockchain. The medicine name, generic name, form (tablet/ capsule/ injection etc.), dosage, manufacturing date, expiring date are taken as input. Manufacturer information (id, name, address, latitude, longitude) is taken from the login information. Medicine ID and current node are auto generated. After checking for errors in medicine information, finally the medicine is added by creating a block and performing a transaction.

Algorithm 2 presents the algorithm for updating the status of a medicine. The recipient information as well as the medicine ID are taken as input. Sender information are taken from login details of the user. A block is created containing all information related to the medicine. After verification, the block is timestamped with a hash value of its data. The status of the medicine(current node, address, owner name, owner ID, latitude, longitude)

Algorithm 2: Update A Medicine Status

Input: $MedicineID$, $Recipient$

Procedure `updateMed(`$Input$`)`**:**

$SenderInfo \leftarrow$ take from $LoginInfo$

% Check conditions
if *Length of* $MedicineID$ *== NULL* **then**
  $showErrorMessage$("Medicine ID is incorrect")
  return
end
$Err \leftarrow$ getState.($MedicineID$)
if *(*$Error$ *!= NULL)* **then**
  $showErrorMessage$("Failed to fetch medicine data")
  return
end
if *(*$MedicineID$ *== NULL)* **then**
  $showErrorMessage$("Medicine doesn't exist")
  return
end

%Response
Create an object $Medicine$ with updated info
$setEvent \leftarrow$ Transaction
Transaction.$Timestamp(Medicine)$
Transaction.$Hash(Medicine)$
Transaction.UpdateAsset($Medicine$)
$getTransactionID()$
$putState(Medicine.ID)$
return
return

is updated. Depending on the type of the recipient, the current node will be 'at manufacturer', 'at distributor', 'at retailer', 'sold' for being at manufacturer, distributor, retailer, and customer respectively.

5.2.2 Front End Development

For front-end development, EJS[4] (Embedded Java Script) was used. EJS is a simple template language that works with HTML markup, CSS, and plain JavaScript. For this system, HTML5, CSS3, and JavaScript were used. Some third party tool-kits like jQuery[5] and Boot-

[4]https://ejs.co/
[5]https://jquery.com/

strap[6] were adapted to make the front end application more efficient, and user friendly. As an editor for the front end codes *Visual Studio*[7] (version 1.68) was used. It is basically a redefined and optimized code editor to build and debug web and cloud applications.

5.2.3 UI of the prototype

Figure 5.5 shows the screenshot of the homepage of the prototypical system. There are several options like Add medicine, Search medicine, See history of a medicine, See current location of a medicine, Add a node, See medicine location. Figure 5.6 shows the UI of adding a new medicine to the blockchain. Only manufacturer can add a new medicine. Figure 5.8 presents the UI of searching of a medicine using medicine ID. Any node of the blockchain can perform this operation. In Figure 5.11, the history of the medicine by its nodes and address names is shown. This can be performed by any node. Figure 5.10 shows the UI of updating the status and current address of a medicine. This operation is basically performed by any node while changing the ownership of the medicine like when the medicine is sent to any retailer from the distributor and alike.

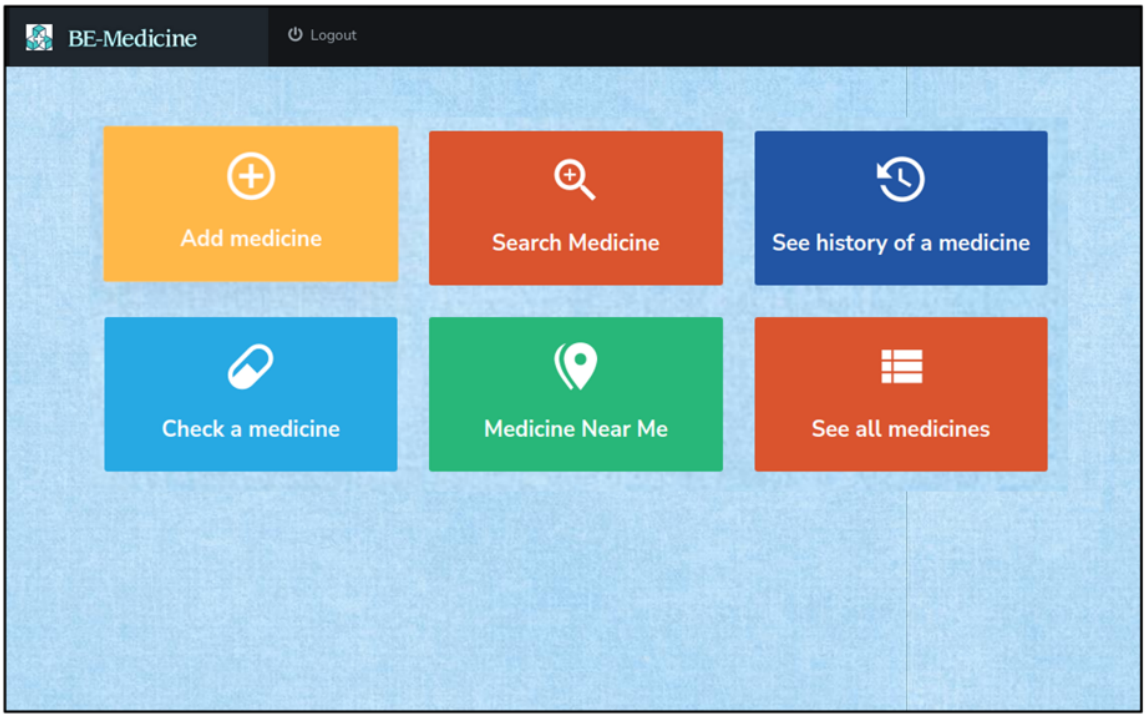

Fig. 5.5. The UI for the homepage of the developed prototype

[6]https://getbootstrap.com/
[7]https://code.visualstudio.com

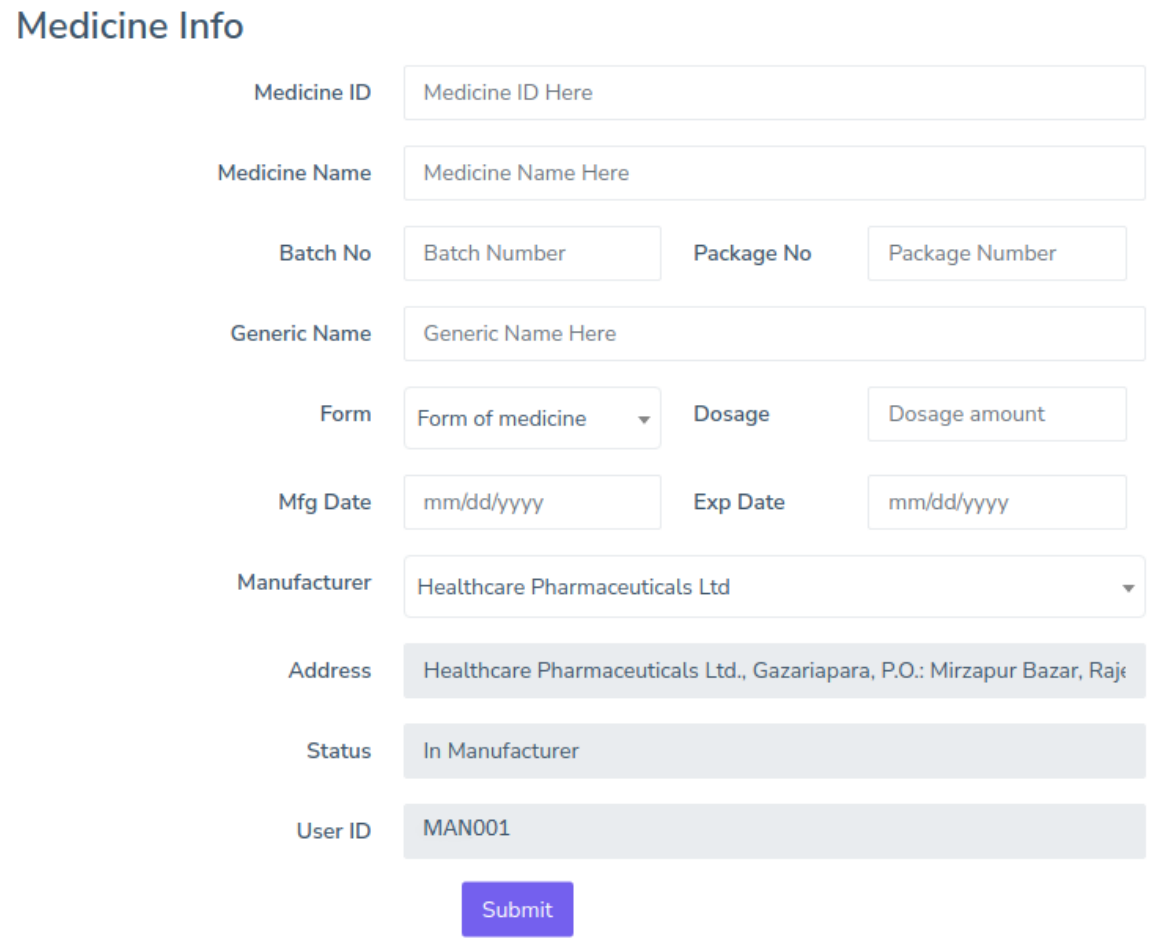

Fig. 5.6. The UI for adding a new medicine

```go
func (s *SmartContract) CreateMedicine(ctx contractapi.TransactionContextInterface, medData string) (string, error) {

    if len(medData) == 0 {
        return "", fmt.Errorf("Please pass the correct medicine data")
    }

    var medicine Medicine
    err := json.Unmarshal([]byte(medData), &medicine)
    if err != nil {
        return "", fmt.Errorf("Failed while unmarshling medicine. %s", err.Error())
    }

    medicineAsBytes, err := json.Marshal(medicine)
    if err != nil {
        return "", fmt.Errorf("Failed while marshling medicine. %s", err.Error())
    }

    ctx.GetStub().SetEvent("CreateAsset", medicineAsBytes)

    return ctx.GetStub().GetTxID(), ctx.GetStub().PutState(medicine.ID, medicineAsBytes)
}
```

Fig. 5.7. Chaincode for add a new medicine

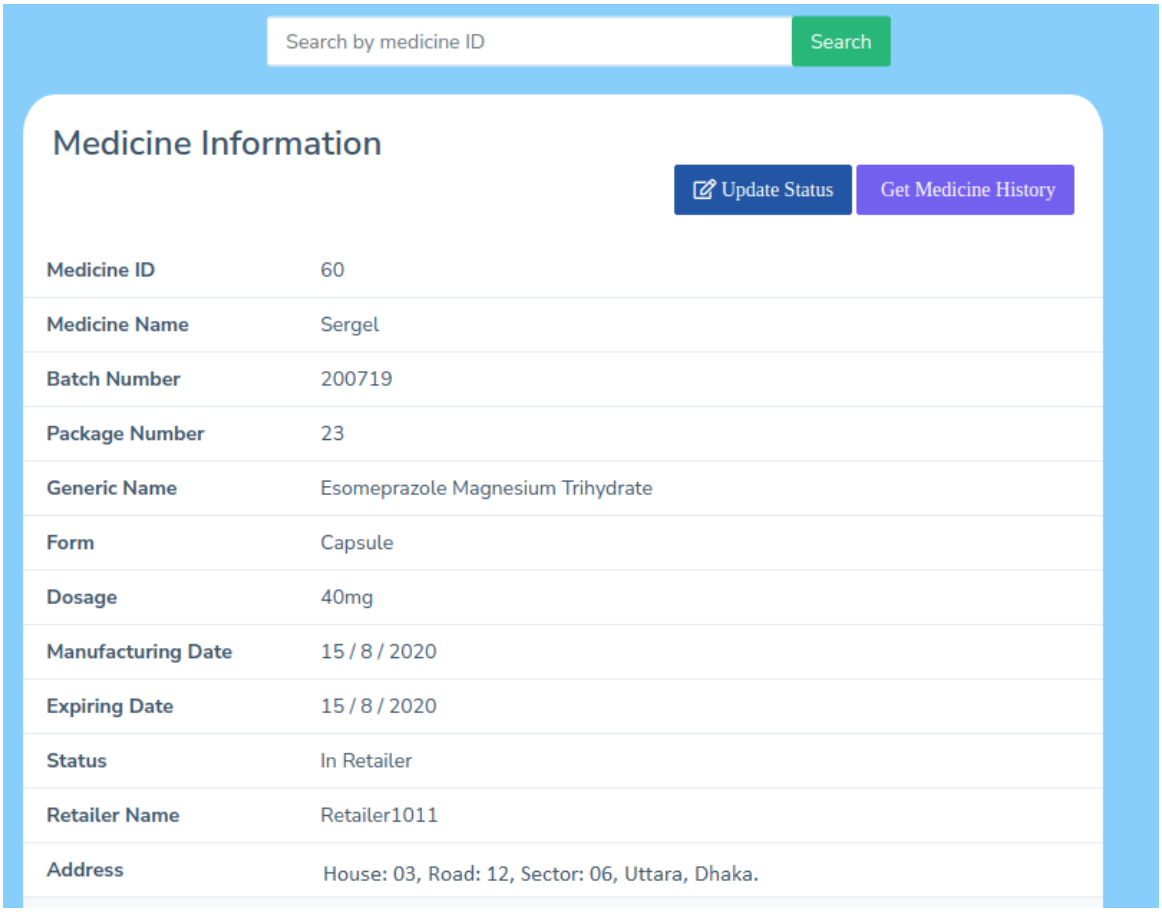

Fig. 5.8. The UI for searching a medicine

```
func (s *SmartContract) GetMedById(ctx contractapi.TransactionContextInterface, medID string) (*Medicine, error) {
    if len(medID) == 0 {
        return nil, fmt.Errorf("Please provide correct medicine Id")
        // return shim.Error("Incorrect number of arguments. Expecting 1")
    }

    medAsBytes, err := ctx.GetStub().GetState(medID)

    if err != nil {
        return nil, fmt.Errorf("Failed to read from world state. %s", err.Error())
    }

    if medAsBytes == nil {
        return nil, fmt.Errorf("%s does not exist", medID)
    }

    medicine := new(Medicine)
    _ = json.Unmarshal(medAsBytes, medicine)

    return medicine, nil

}
```

Fig. 5.9. Chaincode for search a medicine

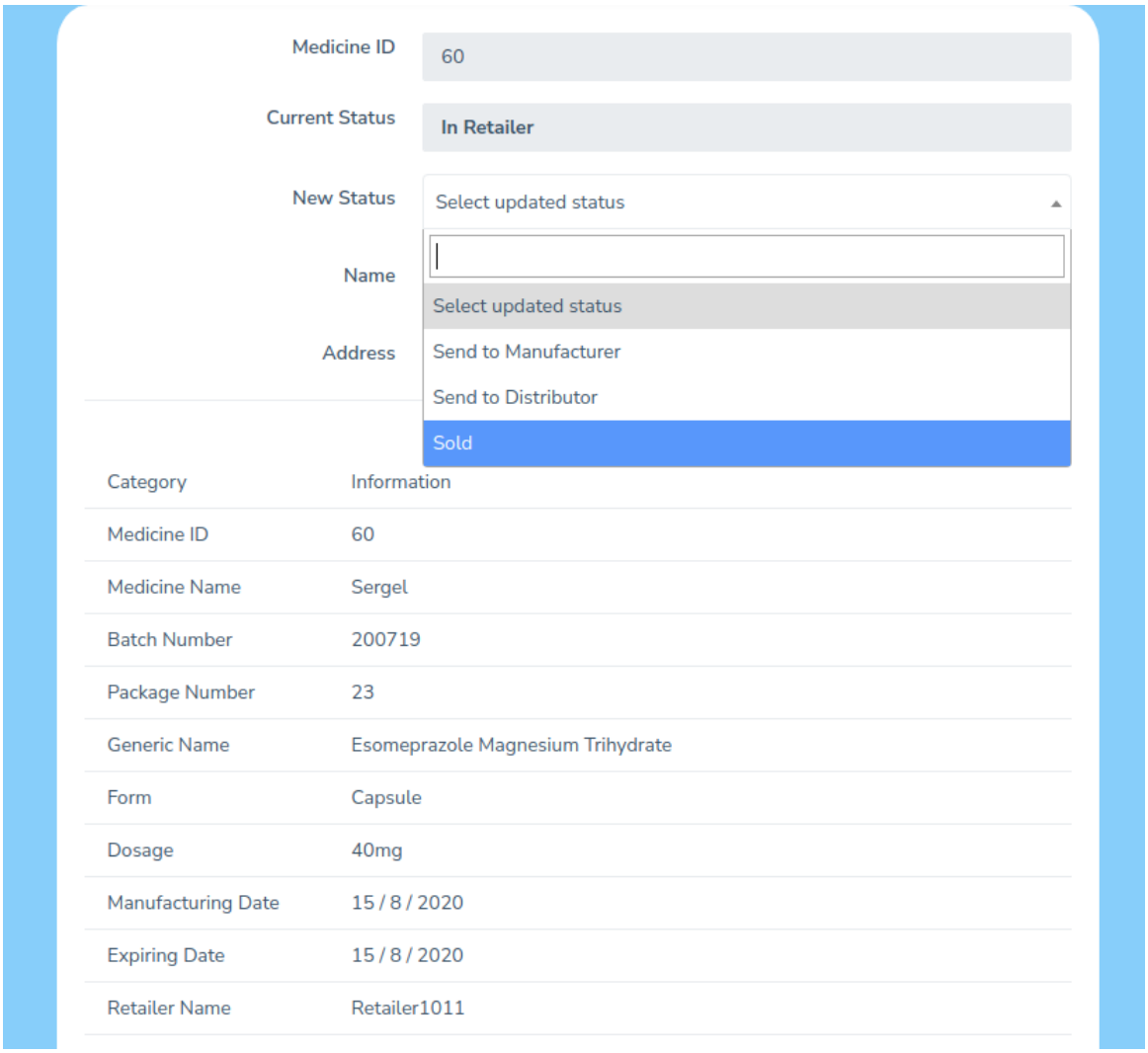

Fig. 5.10. The UI for updating a medicine

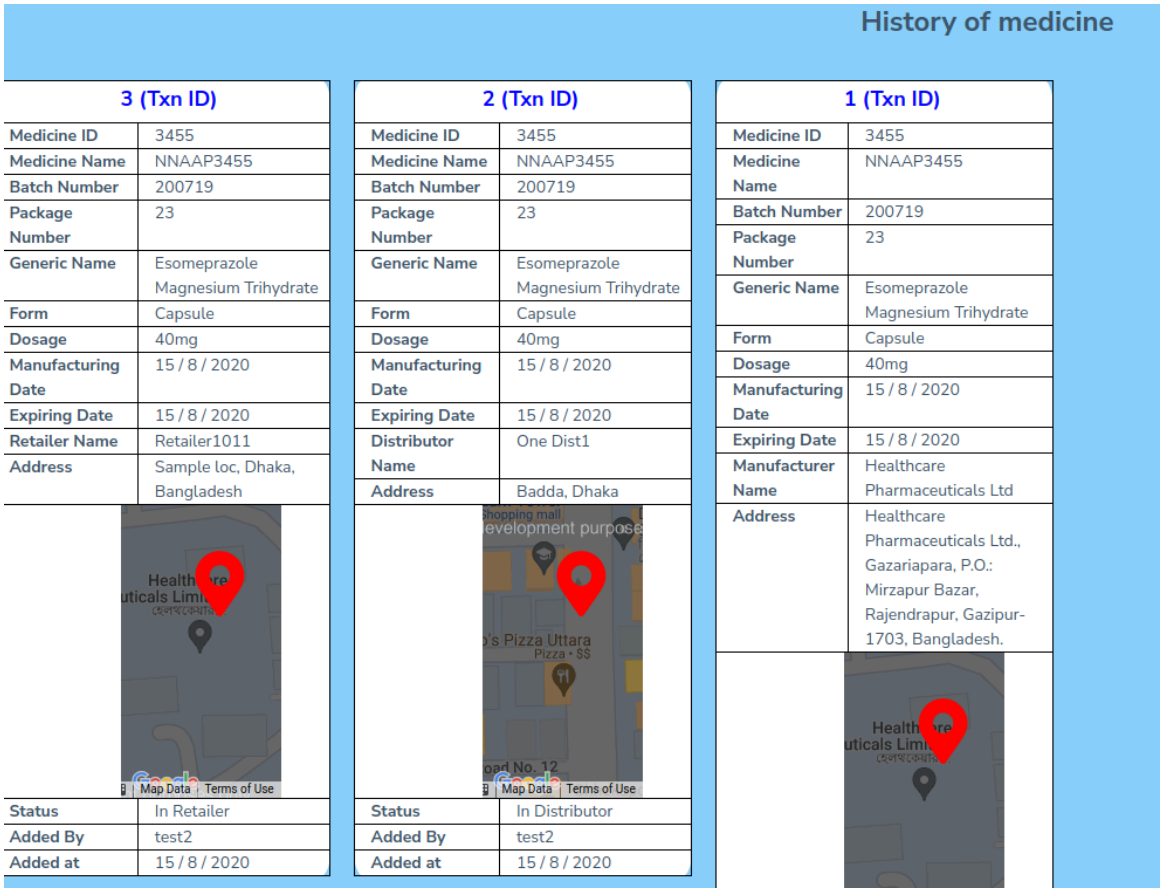

Fig. 5.11. The UI for showing the history of a medicine

CHAPTER 6

EVALUATION OF THE PROTOTYPE

This chapter presents the evaluation of the developed prototype. Firstly, the performance analysis is discussed. Next, security analysis is outlined followed by a comparison with existing systems.

6.1 Performance Analysis

The performance analysis of the prototype was performed in terms of execution time and block time. The procedure and evaluation result are as follows:

6.1.1 Experimental Setup

The prototype was evaluated in laboratory environment. The blockchain based system was simulated through a Linux virtual machine on a 64-bit windows 10 running on a PC with Intel i5 2.60GHz and 4GB RAM with C#. Using *Docker* multiple containers were created which acted as separate nodes in the local PC. For measuring execution time total 20 rounds execution were performed. The *Add Medicine(), Add User(), and Update Medicine Location()* operations were considered to calculate the block access time with 20, 40, 60, and 80 rounds of execution.

6.1.1.1 Experiment Findings

Findings of the performance analysis can be presented as follows:

(a) **Execution time:** The execution time for five different operations like *Login(), Reg_user(),*

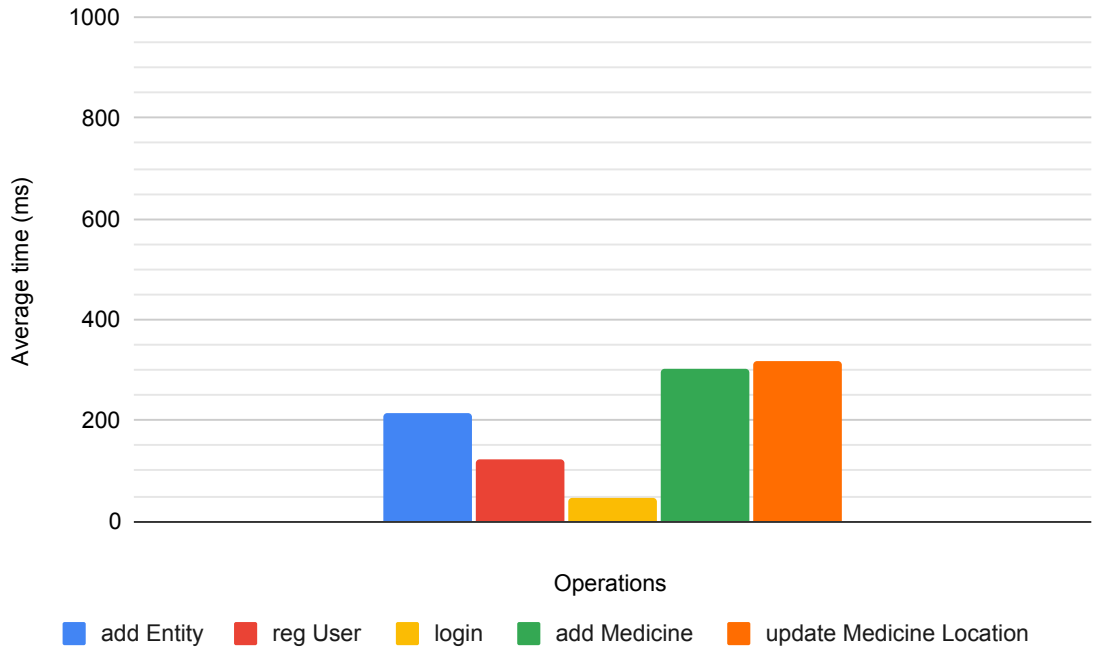

Fig. 6.1. average execution time for different operations

Add_node(), Add_med(), and Update_med(), were measured in milliseconds (Figure 6.1). For each operation total of 20 rounds of execution were considered for calculating the average execution time. Among the operations *login* was the only operation not creating a block in the chain. So, the operation *login* took significantly less time than the others to execute. The other four operations were creating blocks since they were altering/ adding data for the medicine. The execution time of an operation depends on the type of operation (involving block creation or not), the size of the block to be created (processing time, block creation time), etc. The size of a block depends on the size of the data to be stored in the block. For example, *Add_Med()* operation requires more data to store than *Update_Med()* operation. So, the block size also differs accordingly.

(b) **Block Time:** The operations *Add_med(), Add_node(), and Update_med()* were considered to calculate the average block access time of the proposed system in milliseconds as shown in Figure 6.2. Here, only the operations that include creating a block over the blockchain were considered to calculate the block access time more accurately. The average of 20, 40, 60, and 80 blocks were calculated which are 304 ms,

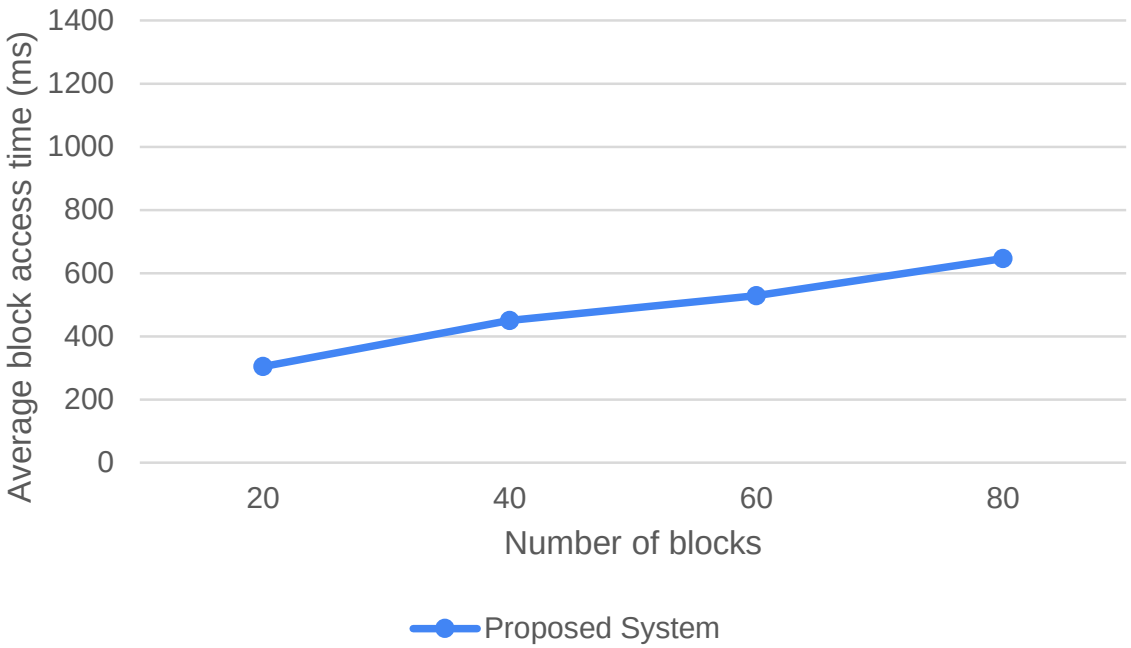

Fig. 6.2. Trend of the average block access time

450 ms, 528 ms, and 646 ms respectively. While the number of blocks is increased, then the processing time as well as the storing time of the blocks will also be increased accordingly. In this system, the trend of change in the average block access time is very less with the increasing number of blocks.

6.2 Security Analysis

The prototype was developed in Hyper Ledger Fabric which is a private blockchain platform. The Hyper Ledger Fabric provides its own privacy as well as security mechanisms. No participant or node which is unauthorized, can access (i.e: store data, get data, etc.) the blockchain. The privacy of data over the blockchain is protected by privacy of data, channel privacy, zero knowledge proof mechanisms Brotsis et al., 2020. Considering these aspects security analysis of the framework was performed as follows:

(a) **Privacy:** All the transactions over this blockchain network is private. Again, data regarding a medicine shouldn't be accessed by any public node. Only nodes with permission and registered can be a valid node for the blockchain network. So, through the authorization a node can be validated first to access any data over the blockchain.

Table 6.1: Comparison with the existing works

Ref	Scalable	Customer-oriented	Practical	Cloning Resistant	Outcome Validation	Platform
Kumar and Tripathi (2019)	✗	✗	✗	✗	✗	N/A
Tseng et al. (2018)	✗	✗	✓	✗	✗	Public
Singh et al. (2020)	✓	✗	✗	✗	✓	Private
Sylim et al. (2018)	✓	✗	✗	✗	✗	Public
Pham et al. (2019)	✓	✓	✓	✓	✓	Public
Saxena et al. (2020)	✗	✓	✓	✓	✓	Public
Y. Huang et al. (2018)	✓	✓	✓	✓	✓	Public
Proposed System	✓	✓	✓	✓	✓	Private

(b) **Channel Privacy:** A channel is a state partition, configured with a set of access policy rules and transaction mechanism for the resources like ledger, transactions, chaincodes etc. (Brotsis et al., 2020). For a registered peer with unique identifier, a ledger is created and run for transaction data in an identical and consistent data store with other peers over the channel. So, the privacy and confidentiality preservation mechanism provides all the peers a consortium environment.

(c) **Zero Knowledge Proof(ZKP):** Hyper ledger fabric uses ZKP as a method of verification. Here, one party proves or agrees that the other party is a valid one before any transaction occur. Here, the party has a secret value to prove to another party without revealing the secret itself (zero-knowledge). As authorization allows only the identified and known nodes, so it makes easier to ensure that all the transactions are being performed by valid nodes.

6.3 Feature comparison with existing systems

A comparative view between the proposed framework and the existing seven works found to prevent the medicine counterfeit using blockchain is shown in Table 6.1.

Most of the existing systems don't offer features like scalibility, customer-oriency, practicality, and cloning resistance. Two systems developed by Y. Huang et al. (2018) and Pham et al. (2019) were also scalable, customer-oriented, practical to implement in real life, low

cost to execute, and cloning resistant, but both of them were developed in public blockchain. Since data over the medicine production and distribution should not be accessible by all, private blockchain is the most suitable one to store all information and continue further procedures for prevention of counterfeit and falsified medicines. The proposed system offers all of these as well as private blockchain network to simulate.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

This chapter presents the concluding statements from a number of perspective: thesis outcomes, thesis implications, thesis limitations, future work. Firstly, the thesis outcomes are depicted. Then the implications of the research are stated. Next, the limitations of this research is described along with some future research opportunities.

7.1 Thesis Outcomes

The thesis outcomes can be discussed as below:

a. **Research gaps and future research opportunities:** During the stage of research problem formulization, SLR and content analysis were performed. The analysis of these two study summarized the current research gaps and the future research directions in the field of medicine counterfeit prevention and digital intervention that includes (a) Explore the implications of emerging technologies, (b) Discover the contaminated point instantly over the medicine supply chain, (c) Investigate the less emphasized concern of counterfeit and falsified medicines, (d) Explore all possible use-cases/features of any digital solution, (e) Develop concrete software system, and (f) Develop falsified and counterfeit incidents reporting system. So, the state-of-art of the research gaps and recommendations are presented in this research while we have focused on exploring the implications of emerging technology (blockchain), discovering contaminated point instantly over the supply chain (the contaminated node over the medicine production and distribution system), and exploring possible use cases

of digital solution.

b. **A set of use cases as well as features for preventing medicine counterfeit:** Conducting the user study generated possible use cases for medicine counterfeit in context of Bangladesh. The generated use cases were then outlined three features: identifying a medicine as counterfeit, determining any anomaly in the medicine production and distribution, and inform relevant people. These features basically outlined the measures should be taken to improve the existing scenario of medicine counterfeit in Bangladesh. All the developing and under developed countries all over the world have a high percentage of falsified drugs. So, the current scenario draws an instance of the medicine counterfeit in other developing countries also.

c. **A blockchain based framework:** Considering the analysis and result of the content analysis, SLR, and user study, required features for a system to prevent medicine counterfeit in Bangladesh, were extracted. Blockchain is an emerging technology which stores information related to each transaction as blocks. The blocks are permanent, timestamped, and hashed to create a chain of blocks. Any changes are always recorded as a new block. Thus, blockchain makes anonymous update and delete impossible. Moreover, all the blocks are accessible (read only) to all the relevant nodes over the network. This helps a system to be monitored properly. From the use cases and features extracted, it was summarized that detecting counterfeit medicines instantly and tracing the medicine from the manufacturer to the customer is most important to reduce availability of falsified medicines. Blockchain could offer these features because of its built in properties. So, a blockchain based framework involving medicine production and distribution system in Bangladesh adopting all the extracted features was proposed. After that, a prototypical system of the proposed framework was developed.

d. **Evaluation of the framework:** The prototype was simulated and evaluated in lab environment. For evaluation, three approaches were follwed: performance analysis, security analysis, and comparison with existing systems. For performance analysis,

five operations were considered to calculate the average execution time of each operations. The result showed the operations those includes block generation, take more time than the others. For three block creation operations, the average block access time was calculated. The result showed that, with the increase of number of blocks, the block access time is increasing. Moreover, block access time depends on the size of the block. In security analysis, the framework satisfied several security aspects for a digital system. So, the framework is secured and safe from cyber attacks. Comparing the prototype with existing system showed that several properties like scalability, customer-oriency, practicality, cloning resistance are available in the prototype. Again, the framework used private blockchain platform which would help to keep medicine data secret to the general public except the relevant ones.

7.2 Thesis Implications

Counterfeit medicines are be very dangerous to the health status of a patient including side effects, treatment failure, toxicity, even death. In this research, the current situation of medicine counterfeit in Bangladesh was portrayed. This may help the future researchers of Bangladesh to conduct their research in the research area. Again, a blockchain based framework was proposed in this thesis to prevent medicine counterfeit in context of Bangladesh. This system allows to reduce medicine counterfeit by detecting the fake medicines, sending alert message to the user, showing the history of the journey of a medicine, and suggesting nearby shops with a specific medicine. So, this framework helps not only the customer while buying medicines from any shop but also the retailer and distributors before buying bulk of medicines. In developing countries like Bangladesh, this blockchain based framework will help all the nodes over the medicine production and distribution system to include any medicine after proper verification. However,implementation of this framework in large scale real practice can impact in reducing medicine counterfeit significantly from this country. Currently, the DGDA in Bangladesh has taken several important actions (publishing drug control ordinance, declaring punishment to responsible ones etc.)to prevent medicine counterfeit. This blockchain based framework will facilitate their objective as well as pro-

vide the customer a better experience of buying medicines. On the other hand, it is also important for the pharmaceutical companies, health care professionals, and patients to be aware of the counterfeit issue. Till now, people in Bangladesh are not that much conscious regarding the medicine counterfeit issue. With increased awareness and the promotion of public health, the growing threat of counterfeit medications in Bangladesh may begin to decline.

7.3 Thesis Limitations

The limitations of this research are:

- **The use cases were generated considering factors in Bangladesh only:** For generating the use cases, content analysis, SLR and user study were carried out. Among these, content analysis was performed by reviewing all articles, laws, documents over the internet related to Bangladesh only. Moreover, at the time of conducting the user study, only participants of Bangladesh, to be specific Dhaka city, were chosen. Participants from all over the country or from different countries were considered.

- **Any medicine counterfeiting in manufacturer end can't be identified:** A required feature for preventing medicine counterfeit in context of Bangladesh was to monitor medicine quality at the manufacturer. This would help to reduce medicine counterfeiting by a registered manufacturer also. This feature was not adopted in the prototype. To implement this, it requires to perform sample analysis of medicine along with a digital solution.

- **Prototype is accessible from web platform only:** Though the proposed framework could allow its user to access blockchain via software, mobile application or web application, the prototype was developed in web platform only. So, currently the system can be accessed using the web application only.

- **Containers in single PC were considered as different nodes:** As there are many nodes who can access blockchain, during the prototypical development, the blockchain

was not deployed in multiple nodes (devices). In the prototype, using *Docker* container were created in a single PC, and each of the containers interacted with the blockchain as a separate node.

- **Number of participants were not adequate:** There were a total of 22 participants in the user study for semi-structured interview. Since the framework was proposed in context of Bangladesh, more participants from different locations could contribute more precisely to design the framework.

7.4 Future Work

Potential future research could be conducted in the following directions:

a. **Updating the corresponding authority for getting any counterfeit issue:** Whenever any node gives any medicine ID for checking if it counterfeit, the system gives output according to the preset conditions as well as the stored information regarding the medicine in the blockchain. Whenever a medicine is predicted to be counterfeit, the system will send a notification to the authority via email, SMS, or any other way. This will help the authority to take necessary actions against the related ones.

b. **Developing the system for different platforms:** In the prototype, only web application was considered for development. But the framework supports other platforms also like software, mobile apps. So, future research can be carried out to develop the system in cross platform (mobile, PC, and web).

c. **Integrating Quick Response (QR) code:** Integrating QR code instead of the medicine ID may help to deal the system faster. In that case, the user need not to input the medicine ID for a medicine rather scan the QR code (containing the medicine ID) printed on a medicine using a QR code scanner. The system will automatically take the medicine ID as input. In this case, all the nodes must have an additional QR code scanner connected.

d. **Conducting user study with more participants:** In future, the semi structured interview can be arranged with more participants to design the framework more precisely with the medicine counterfeit issue in Bangladesh.

e. **Developing concrete implementation in large scale:** Currently, only the prototype of this framework was developed in web platform. A concrete software development involving numerous real nodes will be carried out in large scale for real life practice.

f. **Exploring use cases from different countries:** Medicine counterfeit is no longer just a problem of developing and under developed countries, it is a global problem around the whole world. So, in future, other countries, specially developing and under developed countries can be considered to explore the use cases of medicine counterfeit from different countries. Considering those use cases may help to revise the framework so that a generalized system could be developed.

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APPENDIX A

DATA SYNTHESIS AND ANALYSIS GRAPHS OF SLR

Fig. A.1. Wordcloud for the keywords of the selected articles

Fig. A.2. Wordcloud for the title of the articles

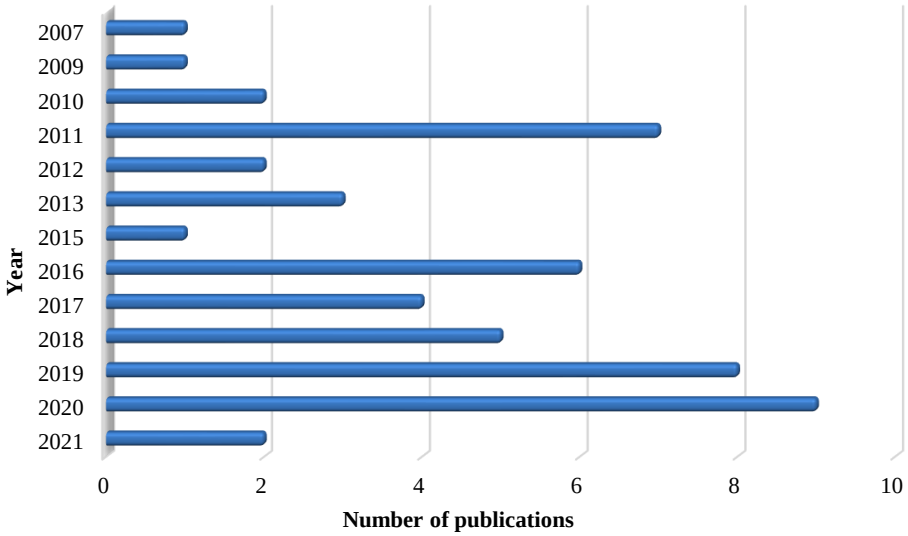

Fig. A.3. The number of publications during 2007 to 2020

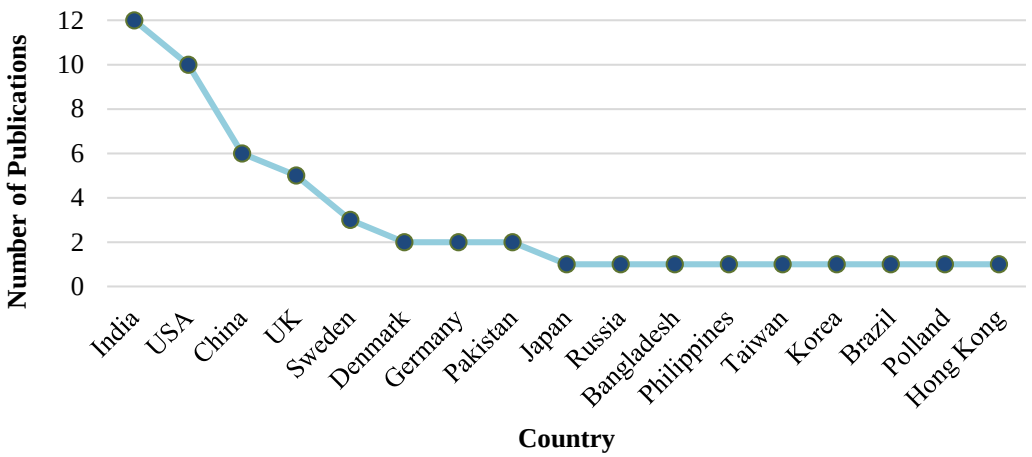

Fig. A.4. Number of articles from the country where the first author affiliates

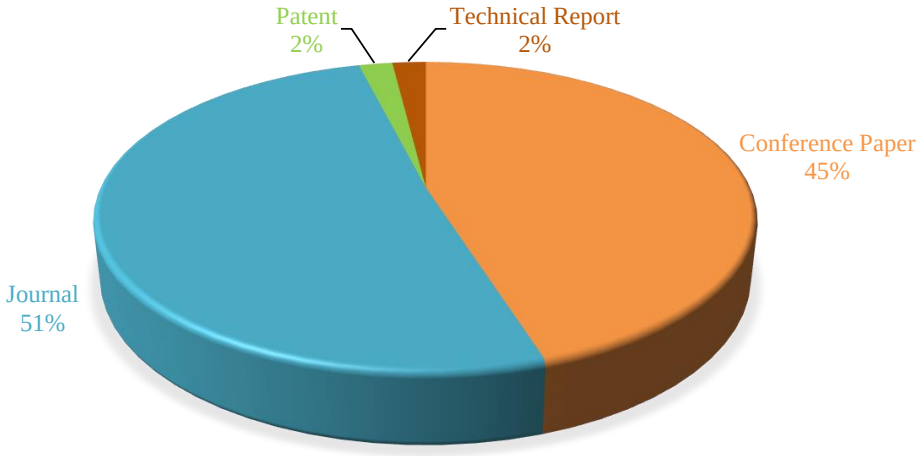

Fig. A.5. Number of articles according to publication type

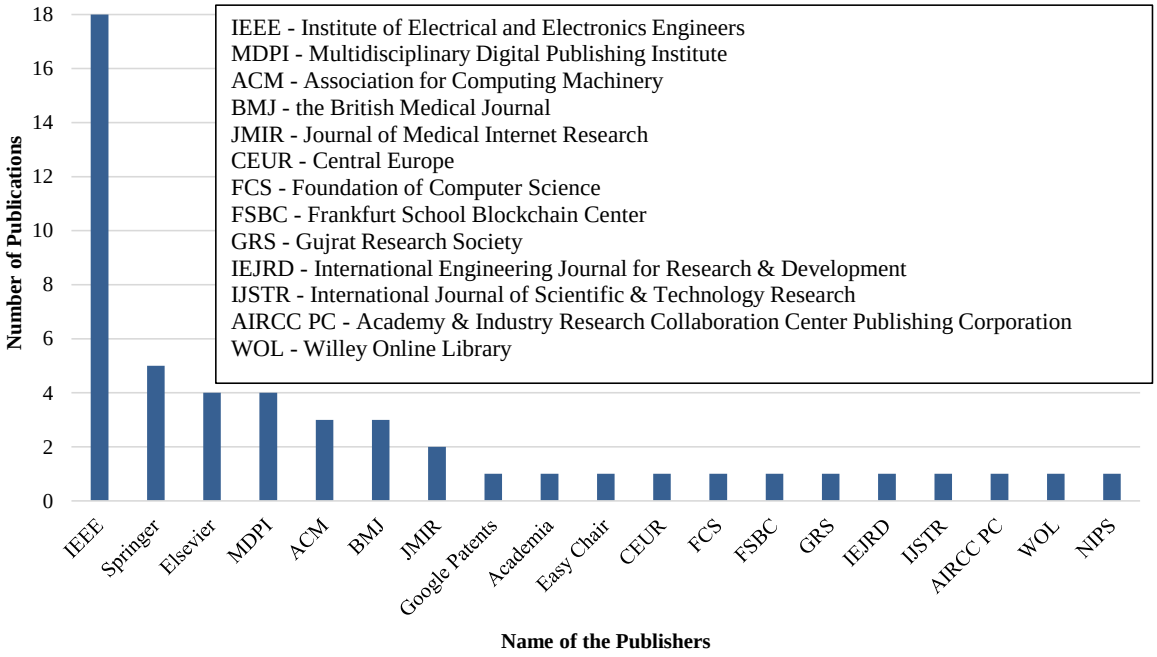

Fig. A.6. Name of the publishers with number of articles

Table A.1: Summary of the research aims and their categorization

Ser	Name of the category	Research Aims	Freq	Total
1	Prevent medicine counterfeit	Authenticate a medicine/ identify counterfeit drug	28	29
		Determine the concentration of a drug	1	
2	Performance and security	Add traceability for real time surveillance	18	39
		Ensure secured logistic supply chain	11	
		Enhance transparency	4	
		Increase trust	2	
		Protect privacy	2	
		Balance between security and performance	2	
3	Smart health care	Store and encode large amount of medicine data easily	4	11
		Develop a central pharmaceutical turnover control system	2	
		Reduce the cost of medication	4	
		Ensure proper medication to the patients	4	
		Enable a viable and resilient smart electronic healthcare ecosystem	3	
4	Public health and awareness	Protect public fitness	2	5
		Raise awareness	2	
		Eliminate the development of unusual information resources and tools	1	
5	Technology acceptance	Explore the applicability of the existing technologies	4	4

Table A.2: Mapping between research aims and publication year

Ser	Aims/ Year		2007	2009	2010	2011	2012	2013	2015	2016	2017	2018	2019	2020	2021	Freq	Total
	Name of the textbfcategory	**Research Aims**															
1	Prevent medicine counterfeit	Authenticate a medicine/ identify counterfeit drug	1	1	-	6	2	1	1	4	2	2	4	2	1	28	29
		Determine the concentration of a drug	-	-	-	-	-	-	-	1	-	-	-	-	-	1	
2	Performance and security	Add traceability for real time surveillance	1	1	1	-	-	1	-	-	2	3	3	5	1	18	39
		Ensure secured logistic supply chain	1	-	-	2	-	-	-	-	1	3	2	2	-	11	
		Enhance transparency	-	-	-	-	-	-	-	-	-	1	-	3	-	4	
		Increase trust	-	-	-	1	-	-	-	-	-	1	-	-	-	2	
		Protect privacy	-	-	-	-	-	-	-	-	-	2	-	-	-	2	
		Balance between security and performance	-	-	-	1	-	-	-	-	-	-	-	1	-	2	
3	Smart health care	Store and encode large amount of medicine data easily	-	-	-	-	1	1	-	-	-	-	-	2	-	4	11
		Develop a central pharmaceutical turnover control system	-	-	-	-	-	1	-	-	-	-	1	-	-	2	
		Enable a viable and resilient smart electronic healthcare ecosystem	-	-	-	-	-	-	-	-	-	-	1	2	-	3	
		Reduce the cost of medication	-	-	-	-	-	-	-	-	-	-	1	-	-	1	
		Ensure proper medication to the patients	-	-	-	-	-	1	-	-	-	-	-	-	-	1	
4	Public health and awareness	Protect public fitness	-	-	-	-	-	-	-	1	-	-	-	1	-	2	5
		Raise awareness	-	-	-	-	-	-	-	1	-	-	-	1	-	2	
		Eliminate the development of unusual information resources and tools	-	-	-	-	-	-	-	-	-	-	-	1	-	1	
5	Technology acceptance	Explore the applicability of the existing technologies	-	-	1	1	-	-	-	-	-	-	1	-	-	4	4

Table A.3: Research focus of the articles

Ser	Research focus	Freq
1	Supply chain	30
2	Authentication	26
3	Medicine ingredients	3
4	Medicine appearance	2
5	Medicine ownership	1

Table A.4: Technologies and techniques used to conduct research

Ser	Name of Technology/ Technique	Ref	Freq
1	Blockchain	Adsul and Kosbatwar (2020), Alzahrani and Bulusu (2018), Anand et al. (2020), Archa et al. (2018), Bryatov and Borodinov (2019), Haq and Esuka (2018), Y. Huang et al. (2018), Kamble et al. (2020), Kumar and Tripathi (2019), Kumari and Saini (2020), Nørfeldt et al. (2019), Pandey and Litoriya (2020), Pham et al. (2019), Sahoo et al. (2020), Saxena et al. (2020), Schöner et al. (2017), Shrikant et al. (2019), Singh et al. (2020), Sylim et al. (2018), Tseng et al. (2018), Wang et al. (2021), and Zhu et al. (2020)	22
2	RFID	Bansal et al. (2013), G. Q. Huang et al. (2010), Kaul and Awasthi (2013), Koster (2013), Nilsson et al. (2011), Nørfeldt et al. (2019), Schapranow et al. (2011), Ting et al. (2010), and Wigand et al. (2011)	10
3	Image processing	C. R. Jung et al. (2012) Bansal et al. (2013), R. Chen et al. (2020), Han et al. (2012), Koster (2013), Kumar and Tripathi (2019), B. Naughton et al. (2016), Rehman et al. (2011), Shaik (2021), Shuaib (2013), and Trenfield et al. (2019)	11
4	Mobile phone technology	Paik et al. (2009), Rehman et al. (2011), Trenfield et al. (2019), Yu, Le, et al. (2016), and Yu, Le, et al. (2016)	5
5	IoT	Archa et al. (2018), R. Chen et al. (2020), Nørfeldt et al. (2019), Ting et al. (2010), and Wazid et al. (2017)	5
6	Pattern Recognition	Abbasi et al. (2012), Banerjee et al. (2016), Corona et al. (2015), and Kalyanam and Mackey (2017)	4
7	NFC	Alzahrani and Bulusu (2018), Alzahrani and Bulusu (2016), and Wazid et al. (2017)	3
8	TLC analyzer	Yu, Le, et al. (2016) and Yu, Le, et al. (2016)	2
9	Cryptography	Alzahrani and Bulusu (2016) and Shaik (2021)	2
10	2D Data Matrix	B. Naughton et al. (2016) and B. D. Naughton (2019)	2
11	Statistical Analysis	C. R. Jung et al. (2012)	1
12	3D Printing	Trenfield et al. (2019)	1

Table A.5: Number of articles with more than one technologies used to conduct research

Ser	Name of Technologies	Blockchain	RFID	Image processing	Mobile phone technology	Pattern Recognition	NFC
1	RFID	1	-	-	-	-	-
2	Image processing	1	2	-	1	2	-
3	IoT	2	1	1	-	1	-
4	NFC	1	-	-	-	-	-
5	TLC analyzer	-	-	-	2	-	-
6	Cryptography	-	-	1	-	-	1
7	2D Data Matrix	-	-	1	-	-	-
8	Statistical Analysis	-	-	1	-	-	-
9	3D Printing	-	-	1	1	-	-

Table A.6: Mapping between technology used and publication year

Ser	Name of Technologies	2007	2009	2010	2011	2012	2013	2015	2016	2017	2018	2019	2020	2021	Freq
1	Blockchain	-	-	-	-	-	-	-	-	2	5	6	8	1	22
2	RFID	1	-	2	4	-	2	-	-	-	-	1	-	-	9
3	Image processing	1	-	-	1	2	2	-	1	-	-	2	1	1	9
4	Mobile phone technology	-	1	-	1	-	-	-	2	-	-	1	-	-	5
5	IoT	-	-	1	-	-	-	-	-	2	-	1	1	-	5
6	Pattern Recognition	-	-	-	-	1	-	1	1	1	-	-	-	-	4
7	NFC	-	-	-	-	-	-	-	1	-	1	-	-	-	2
8	TLC analyzer	-	-	-	-	-	-	-	2	-	-	-	-	-	2
9	Cryptography	-	-	-	-	-	-	-	1	-	-	-	-	-	1
10	2D Data Matrix	-	-	-	-	-	-	-	1	-	-	1	-	-	1
11	Statistical Analysis	-	-	-	-	1	-	-	-	-	-	-	-	-	1
12	3D Printing	1	-	-	-	-	-	-	-	-	-	-	-	-	1

Table A.7: Mapping between research aims and outcomes

Ser	Name of the category	Architectural framework	Conceptual idea	Software	Quantitative analysis	Algorithm	Edible element	Total
1	Prevent medicine counterfeit	11	9	4	3	1	1	29
2	Performance and security	19	10	9	1	-	-	39
3	Smart health care	4	2	3	1	-	1	11
4	Public health and awareness	3	-	-	2	-	-	5
5	Technology acceptance	2	2	-	-	-	-	4

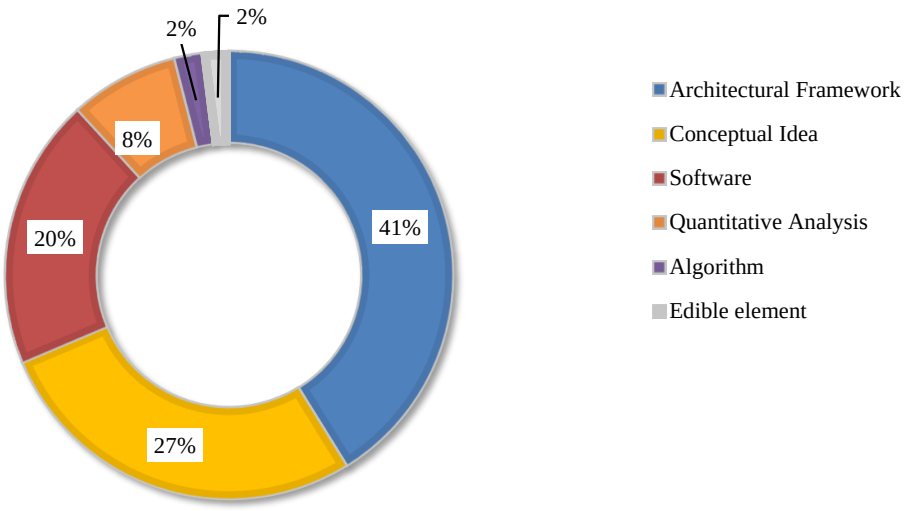

Fig. A.7. Number of articles according to the type of research outcome

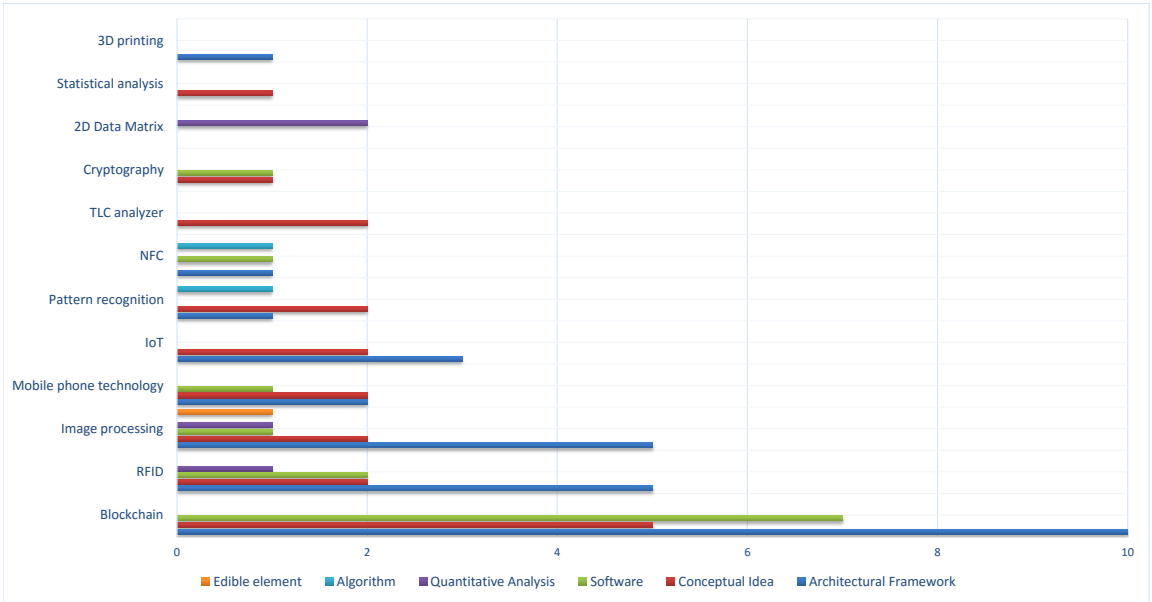

Fig. A.8. Relation between the research outcome with technology used

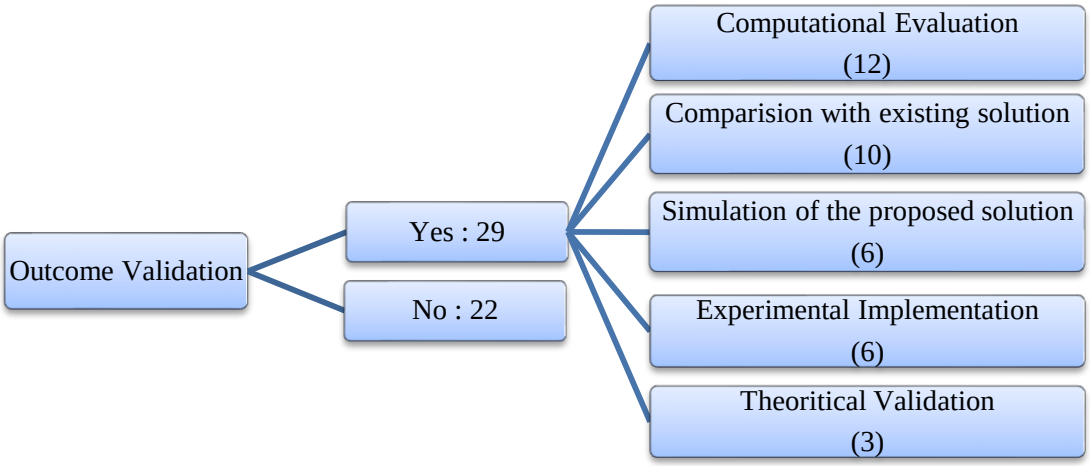

Fig. A.9. Number of articles pursued outcome validation

Table A.8: Mapping between research outcome and the method of outcome validation

Ser	Method	Architectural framework	Conceptual idea	Software	Quantitative analysis	Algorithm	Edible element
1	Comparison	Nilsson et al. (2011), Pham et al. (2019), Rehman et al. (2011), Singh et al. (2020), Wang et al. (2021), and Wazid et al. (2017)	Rehman et al. (2011)	Pandey and Litoriya (2020) and Saxena et al. (2020)	-	Abbasi et al. (2012)	-
2	Simulation	Adsul and Kosbatwar (2020), Wang et al. (2021), and Zhu et al. (2020)	-	Alzahrani and Bulusu (2016) and Shaik (2021)	-	-	Han et al. (2012)
3	Computational evaluation	Corona et al. (2015), Kamble et al. (2020), Kaul and Awasthi (2013), Pham et al. (2019), Rehman et al. (2011), Shaik (2021), Wazid et al. (2017), and Zhu et al. (2020)	Alzahrani and Bulusu (2016)	Y. Huang et al. (2018), Paik et al. (2009), and Singh et al. (2020)	-	-	-
4	Theoretical validation	Nilsson et al. (2011) and Schapranow et al. (2011)	Nilsson et al. (2011)	-	-	-	-
5	Experimental implementation	R. Chen et al. (2020)	Banerjee et al. (2016), C. R. Jung et al. (2012), Kalyanam and Mackey (2017), Yu, Le, et al. (2016), and Yu, Le, et al. (2016)	-	-	-	-
6	No	9	6	3	4	-	-

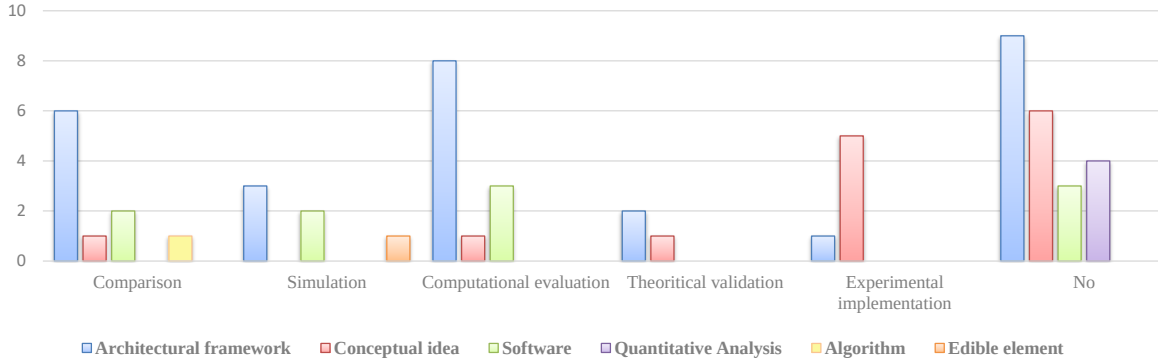

Fig. A.10. Relation between the type of research outcome with outcome validation

Table A.9: Benefits Achieved

Ser	Benefits	Freq
1	Enhanced trust, security and transparency in drug supply chain	20
2	Increased performance (increased efficiency, throughput or reduced latency) of supply chain	17
3	Monitoring the supply chain easily	10
4	Authenticated manufacturer	8
5	Tracking any event of disputes	6
6	Low cost operations of counterfeit unit	4
7	Maintaining patient data privacy	4
8	Facilitate medication to the patients	3
9	Tracing back a medicine with expired date to the real source	2
10	Locate/ trace any product over the supply chain	1
11	Reduced loss related to counterfeit drugs	1

APPENDIX B

DATA EXTRACTION TABLE OF SLR

A sample table for data extraction while performing the SLR is as follows:

Table B.1: Sample data extraction

Ser	Title	Keyword	Aim	Main findings	Outcome Validation	How	Benefits	Article Type	Outcome	Country	Year	Publisher	Prototype	Technology
1	A Blockchain Based Solution for Medication Anti-Counterfeiting and Traceability Zhu et al., 2020	Medication anti-counterfeiting, traceability, blockchain, PBFT consensus, supply chain	to propose a blockchain based method for medication information storage, inquiry, and anti-counterfeiting along a medication supply chain	the proposed method can assure the transparency and openness of medication supply chains	Yes	simulation in terms of enhanced security and performance analysis (transaction delay comparison, throughput comparison, operational efficiency verification, storage space occupancy, and energy cost evaluation)	eliminates centralized institutions and third-party organizations, provides a full record of the medication circulation process.	Journal	Architec-tural Framework	China	2020	IEEE Access	No	Blockchain
2	PharmaCrypt: Blockchain for Critical Pharmaceutical Industry to Counterfeit Drugs Saxena et al., 2020	Blockchain, Counterfeit drugs, Pharmaceutical industry, Security, Amazon web service	to create a blockchain driven tool to record and timestamp the transfer of goods at each point in the medicine supply chain	a tool to track and trace drugs over the supply chain, uploading medicine data to the Blockchain after drug au-thentication.	Yes	evaluation of effectiveness through comparison with existing solution	record and timestamp the transfer of goods at each point in the pharmaceutical supply chain	Journal	Software	UK	2019	IEEE Computer Society	Yes	Blockchain
3	Information Management and Tracking of Drugs in Supply Chains within the Pharmaceutical Industry Wigand et al., 2011	Drug Safety, Pharmaceutical Industry, Tracking, Radio Frequency Identification, RFID, Supply Chain Management	to authenticate pharmaceutical products using RFID to reduce the distribution of counterfeit pharmaceutical products	Product Code Information Services and RFID imple-mentation facilitate to track and trace uniquely identifiable, i.e. mass-serialized, products over the supply chain.	No	-	provide a suitable infrastructure for the tracking and tracing of uniquely identifiable visibility, transparency and control detect counterfeit drug	Confer-ence Paper	Architec-tural Framework	USA	2011	IEEE	No	RFID
4	PharmaGuard: automatic identification of illegal search-indexed online pharmacies Corona et al., 2015	Detection of Illegal Pharmacies, Search Engines, Pattern Classification, Human-Machine Interaction	to develop a system to automatically discover illegal online pharmacies, assist law-enforcement toward their early identification, blacklisting, and shutdown.	detect illegal online pharmacy	Yes	theoretical validation in terms of accuracy, learning time, and throughput with respect to state-of-the-art tools	effectively detect online illegal pharmacy	Confer-ence Paper	Architec-tural Framework	Denmark	2015	IEEE	No	Pattern Recognition

APPENDIX C

QUESTIONNAIRES AND RESPONSE OF THE USER STUDY

a. Interview procedure and questionnaires for Customer/ medicine user:

- The purpose of this interview as well as research was explained briefly.
- Their biographical information (e.g.: age, experience of consuming medicine regularly, type of medicine, etc.) were collected.
- They were asked:
  - If they had experienced any incident related to medicine counterfeit.
  - If yes, then how they identified it as a fake one.
  - What type of medicines were suspected as counterfeit.
  - In case of any counterfeit medicine, whom they informed.
  - How many times they experienced these type of incident.
  - What was their opinion to prevent medicine counterfeit.
- If anyone didn't face any incident regarding medicine counterfeit, he/ she was asked only his/ her opinion about prevention of medicine counterfeit.

b. Interview procedure and questionnaires for Retailer:

- The purpose of this interview as well as research was explained briefly to each of them at first.
- Their biographical information (e.g.: age, experience of working in a retailer shop, etc.) was collected.
- They were asked:
  - If they had experienced any incident related to medicine counterfeit.

- If yes, then how they were informed?
- What action was taken against the incident.
- Which products are reported as counterfeit in most of the cases.
- In case of any counterfeit medicine, whom they informed.
- How frequent they face any incident of drug counterfeit.
- What was their opinion to prevent medicine counterfeit.

- If anyone didn't face any incident regarding medicine counterfeit, he/ she was asked only his/ her opinion about prevention of medicine counterfeit.

c. Interview procedure and questionnaires for Distributor:

- The purpose of this interview as well as research was explained briefly to each of them at first.
- Their biographical information (e.g.: age, experience of working in a wholesaler shop, etc.) was collected.
- They were asked:
  - If they had experienced any incident related to medicine counterfeit.
  - If yes, then how they were informed?
  - What action was taken against the incident.
  - Which products are reported as counterfeit in most of the cases.
  - In case of any counterfeit medicine, whom they informed.
  - How frequent they face any incident of drug counterfeit.
  - What was their opinion to prevent medicine counterfeit.
- If anyone didn't face any incident regarding medicine counterfeit, he/ she was asked only his/ her opinion about prevention of medicine counterfeit.

d. Interview procedure and questionnaires for Manufacturer:

- The purpose of this interview as well as research was explained briefly to each of them at first.
- Their biographical information (e.g.: age, experience of working in a retailer shop, etc.) was collected.
- They were asked:
  - If they had experienced any incident related to medicine counterfeit.
  - If yes, then how they were informed? Which node reported the incident.
  - What measures were taken against the incident.
  - How a product can be identified as counterfeit.
  - Which products are selected for counterfeiting in most of the cases.
  - In case of any counterfeit medicine, whom they informed.
  - How frequent they face any incident of drug counterfeit.
  - What measures are taken by their company to prevent medicine counterfeit.
- If anyone didn't face any incident regarding medicine counterfeit, he/ she was asked about the company policies about prevention of medicine counterfeit in future.

e. Transcribed response from a participant:

Table C.1: An example interview response.

Biography	**Participant Type:** Manufacturer
	Age: 35 years
	Gender: Male
	Experience: 8 years in quality assurance department in a pharmaceutical industry
Questionnaires	**Q1:** Did you company ever experience any incident related to medicine counterfeit?
	Response: "Yes but typically we are informed about these incidents not that much frequent."
	Q2: Who generally informs you about these issue?
	Response: "In case of our company, we employ our medical representatives to investigate in the market. They report us that some medicines seems to be fake. Sometimes shopkeepers also report about fake medicines after getting a complaint from a customer."
	Q3: What actions do you take in these cases?
	Response: "We instruct our representatives to bring all these medicines to the company for further checking."
	Q4: How do you identify a fake medicine?
	Response: "Well, we check several aspects like spelling of the product name, batch number, manufacturing date, expired date, date format, leaflet, barcode, and blister. We also check the foil by noticing the hologram in UV light) Sometimes, we also perform chemical analysis to identify the ingredients."
	Q5: Which measures have you taken to prevent fake medicines?
	Response: "We have taken a number of measures like printing barcode or QR code for the costly and mostly counterfeited products, employing medical representatives to monitor local markets, modifying the appearance of a medicine in a interval of few months."
	Q6: Which medicines are mostly reported as counterfeit?
	Response:"Over the years, it has been seen that popular and mostly sold products are targeted for counterfeiting."
	Q7: How frequent do you know about falsified medicines?
	Response:"In 2020, 18 cases were reported. In 2021, 10 to 12 cases were found. On average, we recieve annually 12-15 cases on average."