End Semester Report on R&D Project (NU 302)

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on

VACCINES: LAB TO NEEDLE

A dissertation
Submitted in partial fulfillment of the requirements for the award of the degree
Bachelor of Technology

by

1. **Priyanshu Joshi**	**BT18GCS299**	**CSE**
2. **Richard Tony**	**BT18GEC091**	**ECE**
3. **Siddhi Lad**	**BT18GCS196**	**CSE**
4. **Yashas Grover**	**BT18GCS156**	**CSE**

Under supervision of
Prof. Debashis Sengupta

NIIT University, Neemrana, Rajasthan-301705

May 2021

DECLARATION BY STUDENT(S)

We hereby declare that the project report entitled **Vaccines: Lab to Needle** which is being submitted for the partial fulfilment of the Degree of Bachelor of Technology, at NIIT University, Neemrana, is an authentic record of our original work under the guidance of **Prof. Debashis Sengupta**. Due acknowledgements have been given in the project report to all other related work used. This has previously not formed the basis for the award of any degree, diploma, associate/fellowship or any other similar title or recognition in NIIT University or elsewhere.

Place: NIIT University, Neemrana

Date: May 16, 2021

Priyanshu Joshi	**BT18GCS299**	**CSE**
Richard Tony	**BT18GEC091**	**ECE**
Siddhi Lad	**BT18GCS196**	**CSE**
Yashas Grover	**BT18GCS156**	**CSE**

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CERTIFICATE BY SUPERVISOR(S)

This is to certify that the present R&D project entitled **Vaccines: Lab to Needle** being submitted to NIIT University, Neemrana, in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology, in the area of BT/CSE/ECE/GIS, embodies faithful record of original research carried out by **Priyanshu Joshi, Richard Tony, Siddhi Lad and Yashas Grover**. They have worked under my guidance and supervision and that work has not been submitted, in part or full, for any other degree or diploma of NIIT or any other University.

Place: NIIT University, Neemrana

Prof. Debashis Sengupta,

Date: May 16, 2021

Acknowledgement

We express our sincere gratitude towards Prof Debashis Sengupta for guiding us throughout the project and Dean Research for allowing us to conduct a project entitled Vaccines: Lab to Needle.

We ensure that the project is authentic and is not plagiarised.

Thank You,

Team:

Priyanshu Joshi	**BT18GCS299**	**CSE**
Richard Tony	**BT18GEC091**	**ECE**
Siddhi Lad	**BT18GCS196**	**CSE**
Yashas Grover	**BT18GCS156**	**CSE**

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Introduction

In the recent milieu of covid-19 pandemic, immunization becomes an utmost priority. However, the success of a large-scale immunization campaign is chiefly dependent on the obtainability of a methodical and operational system that counts for traceability and transparency in vaccine distribution which can also be audited by all the stakeholders involved. Further, vaccine distribution should also account for the physical conditions such as temperature, humidity etc. of the environment in which they're transported. Such a distribution system can be introduced within the pharmaceutical Supply Chain which makes use of Blockchain Technology and IoT Devices. Blockchain technology is defined as the technology that plays as a role of distributed ledger in which transactions are made in digital manner and at the same time these transactions are recorded, verified, and validated throughout the network of nodes without the approval of central authority [1]. Internet of Things (IoT) is a system that works over a network with uniquely identified machines, devices, animals, objects, and people, which are interrelated and they have the potential to transmit the data among themselves without any interaction between them [1]. With the integration of Blockchain and IoT, the sole problem of traceability and transparency is resolved.

Blockchain can increase the efficacy of the involved entities in the supply chain by providing the information in a secure and transparent manner such that all the stakeholders are duly informed in the due process and any modification with the falsified information is distinguished and held liable. Therefore, the data collected by the blockchain aids in efficient auditing as it becomes immutable in nature. Moreover, immutability also helps in prevention of counterfeit drugs entering the supply chain providing a safe transportation for the vaccines.

With the use of IoT devices, it becomes easier to monitor the temperature, humidity and location of the vaccine batches that are being transported. Any inconsistency in the data being collected is automatically alerted (displayed) in an entire blockchain network. Based on such alerts, the stakeholders involved in the process can take necessary actions.

To ensure the accuracy of the data generated in the entire process, use of digital signatures and other security algorithms can help to establish trustworthy transactions.

Thus, the use of blockchain technology and IoT devices in the traditional pharmaceutical supply chain helps to solve transparency, traceability and counterfeit detection problems that allows for optimal vaccine distribution.

Problem Statement

Most countries in the world face a lot of challenges in delivering vaccine doses to billions of people when pandemics like COVID-19 wreak havoc. Blockchain technology, combined with IoT can be a difference maker in this space.

The issues in the pharmaceutical supply chain are as follows:

- The lack of transparency within the supply chain system causes numerous problems such as fraud, violation of code of conduct etc.
- Lack of traceability of the vaccines in the supply chain which leads to counterfeiting.
- Tracking the temperature and humidity of vaccines all the way with trust among all parties in the supply chain is critical as the change in these parameters could render the vaccine useless.
- With many vaccines having multiple doses for patients, additional information regarding the batch number for the appropriate second dose is essential.

To overcome these issues, pharmaceutical companies are moving towards technologies like blockchain and Internet of things (IoT).

Our objective is to provide an optimal vaccine distribution system which ensures proper information flow for all the stakeholders right from supplier to the end user (i.e. patient).

We introduce Blockchain which will provide a decentralized ledger to all the participants involved in the supply chain and prevent the entry of counterfeit drugs along with IoT to monitor the physical parameters of the vaccines under which it will be transported on a real time basis. This will help to notify any change in the vaccine distribution process thus making the system more transparent and traceable.

Literature Review

A Review on Benefits of IoT Integrated Blockchain based Supply Chain Management Implementations across Different Sectors with Case Study [1]

Aich, Chakraborty and Sain in the cited paper provide a comprehensive review of blockchain technology that can be integrated with IoT to solve the traditional problems observed in Supply Chain Management. The paper outlines major issues faced by the Supply Chain Systems and can be summarized as follows:

(i) Lack of visibility in terms of fraud, violation in code of conduct, from upstream to downstream that involves the stakeholders from the start to the end of the chain.

(ii) Lack of flexibility during change/disruption in the chain.

(iii) Lack of trust among various stakeholders resulting in improper flow of information.

(iv) Ineffective risk management prediction and inability to adapt to corresponding changes produced.

Further, the paper elaborated on traceability, information continuity, and decrease in fraudulent activities brought about by the use of blockchain and gave a brief outline on the pharmaceutical supply chain handling using the proposed technology.

Drug Governance: IoT-based Blockchain Implementation in the Pharmaceutical Supply Chain [2]

The cited paper provides a discursive synopsis of the problems incurred in the supply chain of the pharmaceutical industry. It takes into consideration a broader perspective of the supply chain starting with the supplier of raw materials. The paper discusses the complexity of the supply chain when the production becomes global and identifies the lack of transparency in the process along with the involvement of unethical practices of substitution and corruption of drugs. It proposes use of blockchain technology and IoT based devices to track the transportation, theft and contamination in addition to providing the information concerning the contaminated and falsified drugs. RFID-enabled supply chain discussed here acts as a traceability system along with the blockchain providing a secure environment for transactions which aren't prone to be faked once validated. This concept also reduces the overhead of document exchange since a validated alternative of the paperwork is distributed all over the network in turn reducing the counterfeiting attempts.

Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention [3]

A standard supply chain in the pharmaceutical industry is riddled with the basic problem of information flow that can lead up to counterfeit drugs entering a genuine supply chain. Such an information flow not only requires data on various stakeholders engaged in the process but also takes into account the physical needs of the vaccines and drugs. Thus, an integration of IoT Devices with the ability to monitor the physical conditions like temperature, humidity and location in real time which can provide sufficient data on the vaccine and drug usability, with Blockchain Technology can help in tremendous progress of the supply chain management and can also reduce the substantial counterfeits entering the chain. This paper proposed by Singh, Dwivedi and Srivastava, includes (i) use of blockchain for traceability on different aspects of the supply chain right from the involvement of the manufacturer to the end-user, (ii) use of IoT devices in the supply chain and, (iii) security at every step of the supply chain to provide for a viable and trustworthy drug and vaccine distribution system.

The proposed framework by the authors makes use of a consortium blockchain to monitor interaction with all the participants. The decentralized ecosystem of the blockchain provides for an efficient traceability system which in turn helps to create trust among the stakeholders involved, preventing counterfeiting attempts. The use of IoT sensors to monitor the physical conditions in which the vaccines and drugs are transported are also taken into account. The security of such IoT based devices is ensured with the incorporation of digital signatures associated with each of these devices. Further, the problem of blockchain scalability to support fast transactions on the platform is supervised by the use of *bloXroute* and Raft Consensus Algorithm to make it suitable for IoT devices. The proposed framework also mentioned the rigorous performance evaluations conducted with detailed security analysis of the scalable blockchain network leaving the system flexible to changes that can be incorporated according to the needs.

TrustChain: Trust Management in Blockchain and IoT supported Supply Chains [4]

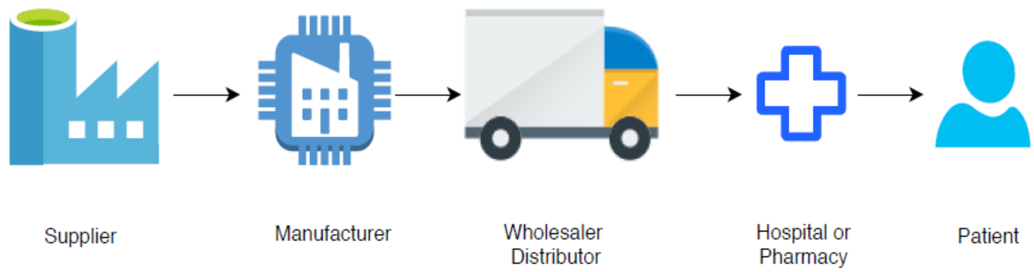
Malik, Dedeoglu, Kanhere, and Jurdak, proposed a three-layered Trust Management model, called TrustChain, that can be incorporated in the blockchain based supply chain to ensure that the data collected at each step is accurate and has not been falsified. TrustChain uses a consortium blockchain for tracking the interactions that take place with all the stakeholders involved in the supply chain and uses trust and reputation scores to evaluate their reputation. The model also evaluates the threats that can affect the reputation system which is both asset and agent-based.

The outlook of the model can be summarized on the basis of (i) Evaluation in terms of quality of the commodity and trustworthiness of the entities based on the observations of events in the supply chain. (ii) Reputation Scores being assigned to both the product and the stakeholder, separately so as to eliminate irresolute elements from the supply chain. (iii) Use of smart contracts for maintaining transparency in the entire process along with the calculation of reputation scores and, (iv) Blockchain overhead with respect to minimal throughput and latency when compared to different blockchain based supply chain models.

Proposed Methodology

With respect to the aforementioned problems, we propose a blockchain based IoT solution, which starts with the supplier from the supply chain and ends with the patient. Following stakeholders participate in our proposed vaccine distribution system:

1. Supplier: A supply chain starts from the supplier who delivers the raw materials to the manufacturer.
2. Manufacturer: The manufacturer receives orders from wholesalers or distributors and ships the finally produced pharmaceutical drugs in large quantities to distributor warehouses.
3. Distributor: The distributor propagates the process and distributes pharmaceutical drugs to pharmacies and hospitals. This saves time and effort of the manufacturer from the distribution of drugs.
4. Hospital: Pharmacies and hospitals purchase the pharmaceutical drugs from wholesalers. The drugs received by pharmacies and hospitals are given or sold to end-users or patients.
5. Patient: The patients are the end users who will be inoculated with the vaccines.



as illustrated in [3, Fig. 3]

Workflow

- Supplier initially, enters information regarding the raw materials into a new block which is then appended into the blockchain. The very first transaction takes place in the genesis block, the first block of the blockchain [3].

- When the raw materials reach the manufacturer, further information is updated in the new block. This block will contain data such as the temperature, humidity condition of the vaccine or drug, location based on the discrepancies in the temperature (if any), batch number of the vaccine, manufacturing date, expiry date, timestamp (out for delivery), source, destination. Same information is moved to the QR Code provided on the individual vaccines.
  But before such crucial information is added to the system, the manufacturer needs to perform a quality check that will ensure the credibility of the raw materials. If the materials match upto the specific standards, then they're processed and vaccines or drugs are manufactured. Otherwise they're discarded and accordingly a block is generated with the vaccine information or reject information. This helps in managing demand and supply for the stakeholders involved(as shown in figure.1).

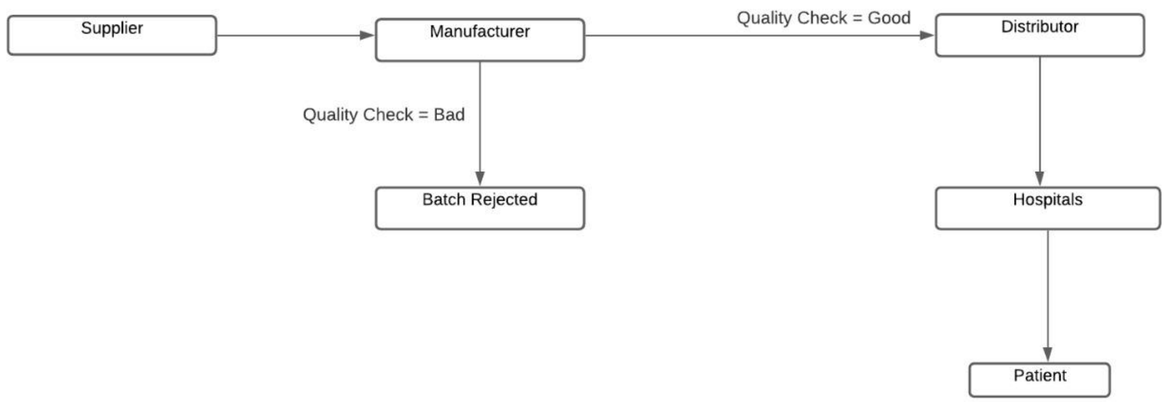


Figure.1 Generalised Pharmaceutical Supply Chain Model

- Next, the distributors involved add additional information from their end which includes physical conditions, batch number of the vaccine, source, destination and timestamp (out for delivery). Any discrepancies observed in the transportation of the vaccines will be registered in the blockchain as a transaction. With the use of GPS sensors, any temperature discrepancy registered will have corresponding location coordinates which will help in identifying where and what went wrong during the transportation. This in turn helps in identifying better routes from the source to the destination.

- Finally when the vaccines are delivered to the appropriate hospitals, the hospital authorities are required to append the delivery information such as physical conditions, batch number of the vaccine, source, timestamp (delivered). Two-dose vaccines are also stored in the hospital facility and with the batch information available they may schedule patient appointments accordingly.

- Patients can then scan the QR Codes on the vaccines and get all the details that have been previously appended onto the blockchain and view the journey of the vaccine.

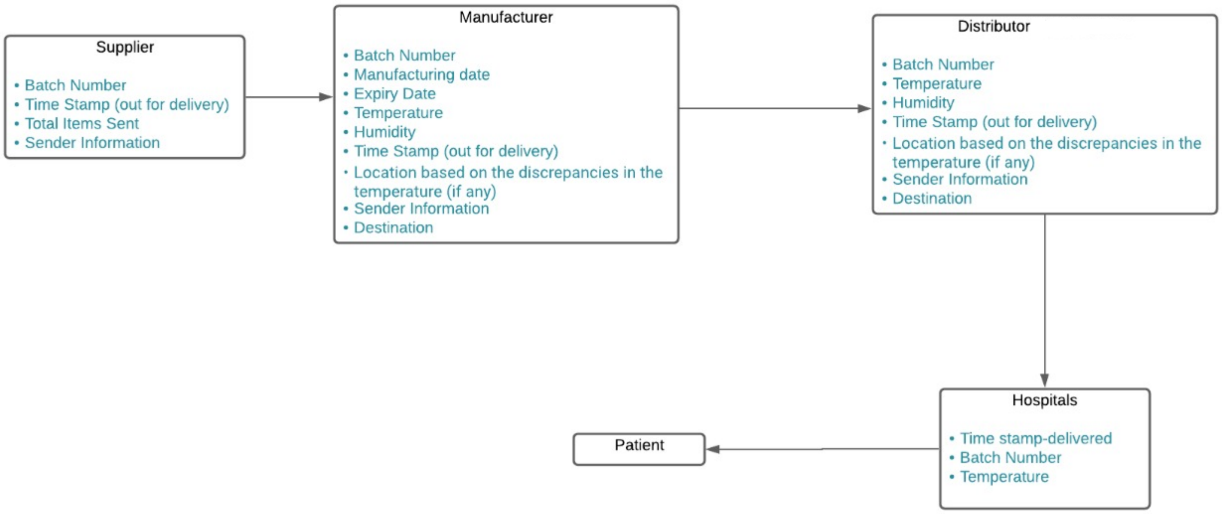


Figure.2 Data Flow Diagram

Technology

- *Ethereum:*

  Ethereum is an open-source software platform used for blockchain based decentralised applications. It allows SmartContracts and Distributed Applications (DApps) to be built with ease and run without any fraud, control, or interference from a third party.

- *Solidity*:

  Solidity is a syntactically-typed curly-braces programming language which is designed for developing smart contracts that would run on the Ethereum Virtual Machine. Smart contracts are the programs that are executed inside a peer-to-peer network where no-one has special authority over the execution, and allow to implement tokens of value, ownership, voting, and other kinds of logic.

- *Remix IDE*:

  Remix is a browser-based IDE that enables users to build Ethereum contracts with Solidity language and to debug transactions. It also has its own compiler.

- *Thingspeak*:

ThingSpeak is an IoT service provider that allows you to visualize, and analyze live data streams in the cloud. ThingSpeak provides instant visualizations of data posted by IoT devices and is often used for prototyping and in proof-of-concept IoT systems that require analytics.

Result & Analysis

To evaluate our IoT based Blockchain solution we considered a setup for a particular vaccine developed by an arbitrary vaccine manufacturing company. Considering that the vaccine manufacturing company already has a set of suppliers, manufacturers and distributors that take part in their vaccine distribution supply chain, our proposed system lays out a general model that can be adopted by individual vaccine developing companies to keep track of their vaccine demand and supply.

The model starts with deploying a smart contract on a blockchain that gathers information as illustrated in Figure 2. Starting with the supplier, raw material information is entered into the system and is available for the manufacturer. Manufacturer further updates with the additional details and the vaccines are sent to the distributor. Here, the concept of IoT is introduced with it being used to generate transportation details of the vaccines. Crucial information like vaccine temperature and other disruptions are recorded and are available on the blockchain. The model generates an alert in the form of a string that is included in the smart contract. Finally for the patients, the smart contract transaction details are available through the QR Code. This model takes care of the transparency and traceability of the vaccines. This is also in accordance with the TrustChain Model [4] to deal with the counterfeits in the medical supply chain. However, scalability of the blockchain and its sustainable nature needs to be taken care of. Moreover, the output generated by the given model can be used by individual stakeholders to collect data that can be used further for statistical analysis.

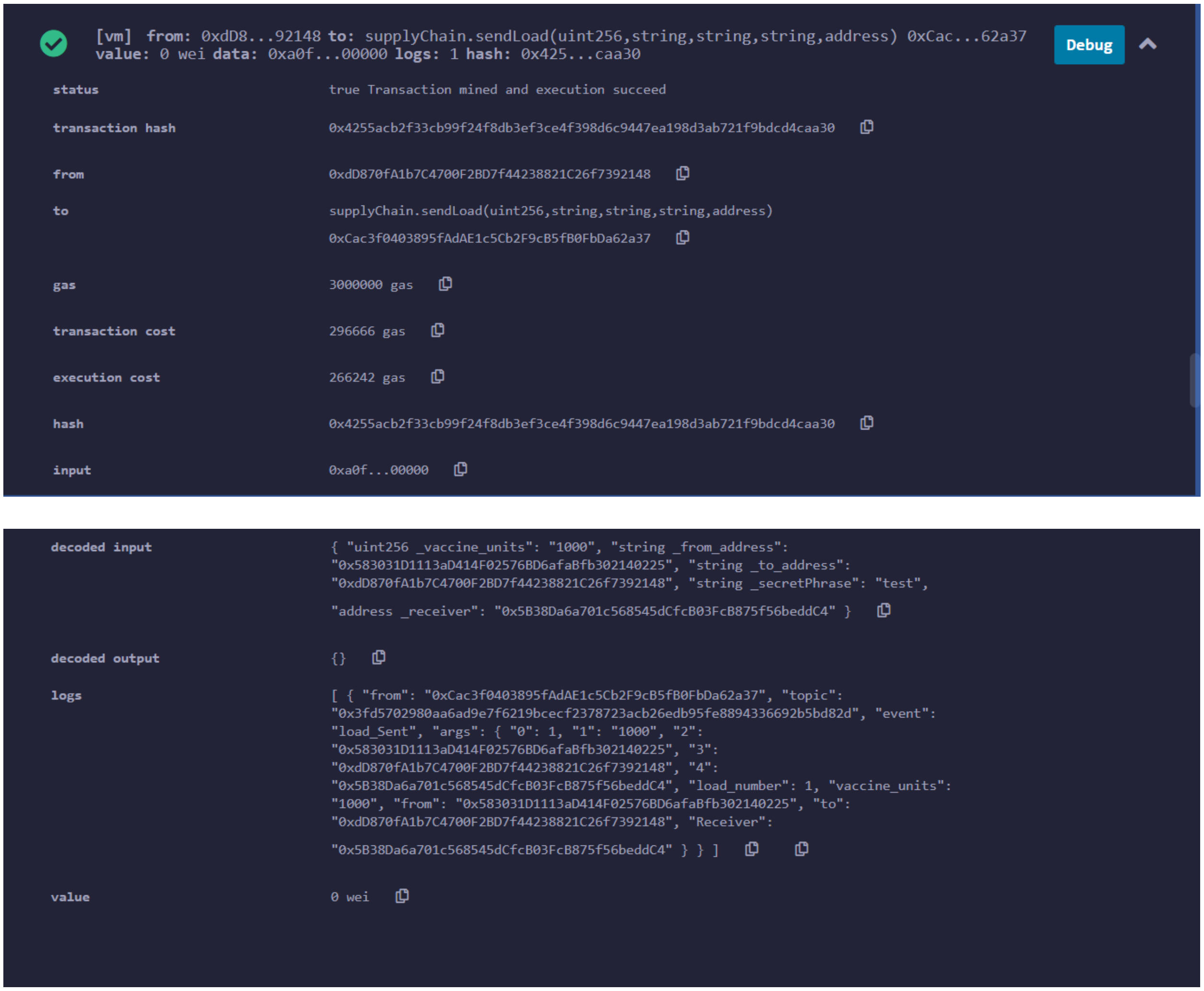


Figure.3 Transaction Details

Figure.4 Cloud Data showing temperature and humidity details

Conclusion & Future Scope:

In this report, we put forward a Blockchain based IoT Model that can be incorporated in the pharmaceutical supply chain. Blockchain being an essential part of this model, offers data immutability, transparency and efficient tracking of the vaccines. Integrating it with IoT produces a practical approach to handling vaccines which require utmost care in transportation with respect to temperature, humidity and other physical parameters. The proposed model takes care of traceability and transparency in vaccine distribution and also its sustainability in terms of preventing its counterfeiting attempts.

Shortcomings

The efficiency of the model is an aspect that can be improved upon. Additionally, the current model supports an efficient vaccine distribution for only one kind of vaccine manufactured by a single vaccine producer.

Scope for Improvement

Project output can further be analysed to aid in future research of vaccine supply and demand. Also, the collection of data through IoT devices can be improved by using more efficient IoT protocols. Additionally, support for multiple vaccine manufacturers can be developed in order to extend the scalability of the project such that information is available on how much of the population has been vaccinated.

Future Scope

With the recent backdrop of Covid-19 pandemic, multiple virus variants have been identified. In addition many countries have experienced multiple waves of infection and with that vaccine changes and its availability becomes an important aspect to be looked at. Vaccine preservation and the supply-demand ratio are also important constraints that can be incorporated in this model. With the model being open to changes in terms of information it can collect, statistical analysis can also be performed on the data collected as suited.

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[1] S. Aich, S. Chakraborty, M. Sain, H. Lee and H. Kim, "A Review on Benefits of IoT Integrated Blockchain based Supply Chain Management Implementations across Different Sectors with Case Study," *2019 21st International Conference on Advanced Communication*

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[4] S. Malik, V. Dedeoglu, S. S. Kanhere and R. Jurdak, "TrustChain: Trust Management in Blockchain and IoT Supported Supply Chains," *2019 IEEE International Conference on Blockchain (Blockchain)*, Atlanta, GA, USA, 2019, pp. 184-193, doi: 10.1109/Blockchain.2019.00032.

Annexure

Uploading temperature and humidity data to the cloud.

```
#include <ESP8266WiFi.h>
#include "ThingSpeak.h"
#include "DHT.h"

WiFiClient  client;
#define DHTPIN 4     // Digital pin connected to the DHT sensor

#define DHTTYPE DHT22  // DHT 22
unsigned long myChannelNumber = 1391230;  // Replace the 0 with your
channel number
const char * myWriteAPIKey = "M9U8OGBJFHEIX9EY";    // Paste your
ThingSpeak Write API Key between the quotes
const char * myReadAPIKey = "J0M0YVXACNDCXIO3";    // Paste your ThingSpeak
Read API Key between the quotes

DHT dht(DHTPIN, DHTTYPE);
void setup() {
  Serial.begin(115200);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port only
  }
```

```
  WiFi.begin("tony", "NNFHTP7TE3");
  Serial.print("Connecting");
  while(WiFi.status() != WL_CONNECTED){
    delay(500);
    Serial.print(".");
  }
  Serial.println();
  Serial.println("Connected, IP Address: ");
  Serial.print(WiFi.localIP());
  ThingSpeak.begin(client);

  dht.begin();

}

void loop() {
  // Reading temperature or humidity takes about 250 milliseconds!
  // Sensor readings may also be up to 2 seconds 'old' (its a very slow
sensor)
  float h = dht.readHumidity();
  // Read temperature as Celsius (the default)
  float t = dht.readTemperature();
  // Read temperature as Fahrenheit (isFahrenheit = true)
  float f = dht.readTemperature(true);

  // Check if any reads failed and exit early (to try again).
  if (isnan(h) || isnan(t) || isnan(f)) {
    Serial.println(F("Failed to read from DHT sensor!"));
    return;
  }

  // Compute heat index in Fahrenheit (the default)
  float hif = dht.computeHeatIndex(f, h);
  // Compute heat index in Celsius (isFahreheit = false)
  float hic = dht.computeHeatIndex(t, h, false);

  ThingSpeak.setField(1, h);
  ThingSpeak.setField(2, t);
  // Write to ThingSpeak. There are up to 8 fields in a channel, allowing
you to store up to 8 different
  // pieces of information in a channel.  Here, we write to field 1.
  int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
  float y = ThingSpeak.readLongField(myChannelNumber, 1, myReadAPIKey); //
Reads the humidity value from the cloud.
```

```
  float z = ThingSpeak.readLongField(myChannelNumber, 2, myReadAPIKey); //
Reads the temperature value from the cloud.

  Serial.print(y); // Prints the humidity
  Serial.println("%");
  Serial.print(z); // Prints the temperature
  Serial.println("°C ");

  // Check the return code
  if (x == 200) {
    Serial.println("Channel update successful.");
  }
  else {
    Serial.println("Problem updating channel. HTTP error code " +
String(x));
  }

  delay(15000);// Wait a few seconds between measurements.
}
```

Solidity code for Smart Contract

```
pragma solidity 0.6.7;

contract supplyChain{
    uint32 public loads_sent=0;
    uint32 public loads_received=0;
    address public admin;
    struct Load{
        uint256 vaccine_units;
        string address_from;
        string address_to;
        bool Load_Received;
        string secretPhrase;
        address sender_address;
        address receiver_address;
    }
    mapping(uint32=>Load) private load;
    uint32[] private vaccine_loads;
    address[] public distributers;
    address[] public receivers;

/**
 *
```

```
 */
    constructor() public{
        admin=msg.sender;
    }
    modifier onlyAdmin(){
        require(msg.sender==admin,"Only Admin has access to this
function");_;
    }

    event load_Sent(
        uint32 load_number,
        uint256 vaccine_units,
        string from,
        string to,
        address Receiver
        );

    event distributer_Set(
        address distributer
        );

    event receiver_Set(
        address receiver);

    event load_Received(
        uint32 load_number
        );


/**
 *
 * @param  _vaccine_units :  Number of Vaccine Units being loads_sent
 * @param _from_address :  The Address of Origin
 * @param _to_address :  The Address of Destination
 * @param _secretPhrase :  The secret phrase attached to the Load of
Vaccine
 * @param _receiver :  Ethereum address of the receiver
 */
    function sendLoad(uint256 _vaccine_units, string memory _from_address,
string memory _to_address,string memory _secretPhrase,address _receiver)
public
    {
        require(checkDistributer(msg.sender),"Only distributers have access
to this function");
        loads_sent++;
```

```
        Load storage Vaccine=load[loads_sent];
        Vaccine.vaccine_units=_vaccine_units;
        Vaccine.address_from=_from_address;
        Vaccine.address_to=_to_address;
        Vaccine.secretPhrase=_secretPhrase;
        Vaccine.sender_address=msg.sender;
        Vaccine.receiver_address=_receiver;
        vaccine_loads.push(loads_sent);
        emit
load_Sent(loads_sent,_vaccine_units,_from_address,_to_address,_receiver);
    }
/**
 *
 * @param  _load_number :  Load Number of the Vaccine Load
 * @param _secretPhrase :  secret phrase to match with that of the secret
phrase of the load
 * @return :
 */
    function confirmLoadReceived(uint32 _load_number,string memory
_secretPhrase) public returns(bool)
    {
        require(checkReceiver(msg.sender),"Only receivers have access to
this function");

require(hashCompareWithLengthCheck(_secretPhrase,load[_load_number].secretP
hrase),"Incorrect Secret Phrase");
     //
require(keccak256(abi.encodePacked(_secretPhrase))==keccak256(abi.encodePac
ked(load[_load_number].secretPhrase)),"Incorrect Secret Phrase");
        require(_load_number>0,"Invalid Load Number");
        require(msg.sender==load[_load_number].receiver_address,"Invalid
Receiver");
        load[_load_number].Load_Received=true;
        loads_received++;
        emit load_Received(_load_number);
        return(load[_load_number].Load_Received);

    }
/**
 *
 * @param  _address :  Ethereum Address of distributer
 */
    function setDistributer(address _address) onlyAdmin() public{
        distributers.push(_address);
        emit distributer_Set(_address);
```

```
    }
/**
 *
 * @param  _address :  Ethereum Address of Receiver
 */
    function setReceiver(address _address) onlyAdmin() public{
        receivers.push(_address);
        emit receiver_Set(_address);
    }
/**
 *
 * @param  _address : Ethereum Address of distributer
 * @return : true/false depending on the nature of given address
 */
    function checkDistributer(address _address) public view returns(bool){
        bool c=false;
        for(uint32 i=0;i<distributers.length;i++){
            if(_address==distributers[i])
              c=true;
        }
        return(c);
    }
/**
 *
 * @param  _address :  Ethereum Address of receiver
 * @return : true/false depending on the nature of given address
 */
    function checkReceiver(address _address) public view returns(bool){
        bool c=false;
        for(uint32 i=0;i<receivers.length;i++){
            if(_address==receivers[i])
              c=true;
        }
        return(c);
    }
/**
 *
 * @param a :  Input Secret phrase
 * @param b :  Secret Phrase attached to load
 * @return :
 */
    function hashCompareWithLengthCheck(string memory a,string memory b)
private pure returns(bool){
    if(bytes(a).length != bytes(b).length) {
        return false;
```

```
    } else {
        return keccak256(abi.encodePacked(a)) ==
keccak256(abi.encodePacked(b));
    }
}
}
```