Efficient Vaccine Distribution Planning using IoT

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ABSTRACT

Vaccine distribution planning and its efficiency plays a crucial role in prevention of infectious diseases from spreading. Vaccines are required for children's proper as well as regular immunization and effective vaccine distribution planning is very necessary for providing efficient immunization and public health care. For efficient planning of vaccine delivery, things that need to be considered are demand fulfillment of the customers, cold chain constraints, the number and capacity of the vehicles needed for the distribution. There is a need for a proper supply chain mechanism to supply vaccines to various customers in a well optimized way so as to reduce any further wastage and cost of transporting the vaccines. In this paper, we address the problem vaccines distribution planning; formulate the problem as mixed integer programming problem and propose algorithms to solve the problem. We also discuss the role of IoT to improve the vaccine supply chain efficiency.

1. INTRODUCTION

Vaccines are one of the most successful interventions in medical history that could uplift health conditions of the population by significantly reducing infectious diseases. India's Universal Immunization Program (UIP) is the largest in the world when it comes to the amount of vaccines used; number of people immunized annually, number of immunization programs and wide geographical coverage (National Health Portal, 2015). The main aim of UIP is to minimize morbidity and mortality caused by Vaccine Preventable Diseases. There are many immunization programs incorporated by the Government of India, Immunization Strengthening Project (ISP) was one of them which focused on eradication of polio, strengthening the routine immunization and developing strategic framework (Khera et al, 2012). In 1985, India introduced its first oral polio vaccine and in 1995 India's first polio immunization campaign was held (UNICEF, 2014). Since then every year various campaigns are held for children up to 5 years of age and have gained remarkable success. As reported in 2014, India completed three years without any report of polio disease in the country (UNICEF, 2014). Along with polio, the Table 1 shows the necessary vaccines for babies up to 2 years of age with their storage temperature.

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Achieving maximum immunization in a country like India which continuously struggle with the growing population is a difficult task. Therefore, there needs to be an adequate system present to manage the supply of vaccines to various health care centers. The World Health Organization (WHO) reports that in some countries the wastage of vaccines is almost 50 percent. Also, the cost of new vaccines is increasing day by day. Thus, there is need for an efficient and optimized distribution plan, for reducing the wastages.

Challenges: There are many challenges which need to be considered while transporting vaccines such as vaccines need to be stored and transported in a strict cold chain conditions where the temperature must be maintained within the specified range, exposure to sunlight and fluorescent light must be avoided and vaccine perishability must be taken into consideration as each vaccine has different expiry date (Immunization Program Guide, 2012).

Internet of Things: IoT can provide much needed technological development and support to the vaccine distribution system. The impact of IoT will affect how vaccine supply chain leaders' access information needed to improve the service. The IoT revolution can enhance the supply chain management by intelligently connecting people, processes, data, and things via devices and sensors (Shankar, 2015).

Our goal is to optimize the supply routes of vaccines distribution to various Primary Health Centre's (PHC's) by minimizing the distance travelled and maximize the demand fulfilment at various center's keeping into consideration the various constraints. We have used various heuristics along with exact method to find the most optimized solution and compared to those heuristic solutions. Along with this, we have discussed various ways by which we can use IoT devices to efficiently manage vaccine distribution.

Table 1. Vaccines with dosage, timing and temperature

	Vaccine Type	Dosage & Timings	Storage Temp.
1.	Hepatitis B	3 doses; Recommended at birth	2° C to 8°C
2.	MMR	2 doses; first dose at 12 to 15 months of age	2° C to 8°C
3.	Haemophilus Influenzae B (HiB)	2 – 3 doses; at 2 – 6 months of age and then booster dose at 12 to 15 months of age	2° C to 8°C
4.	DTaP	5 doses; first 3 doses at 2,4 and 6 months of age, 4th at 15th to 18th month, and 5th at 4 – 6 years.	2° C to 8°C
5.	IPV	3 doses of 0.5ml and one booster dosage of 0.5ml, first dose at 6 weeks of age and following at the interval of at least 4 weeks.	2° C to 8°C
6.	Pneumococcal	4 doses, at age of 2, 4, 6 and 12 – 15 months	2° C to 8°C
7.	Varicella	2 doses, first at 12 – 18 months of age and second at 4 to 6 years of age	-50°C to -15°C

1.1 Challenges in Vaccine Distribution Planning

Vaccine distribution is challenging compared to other goods supply chain planning because of different constraints which need to be considered while supplying the vaccines. The constraints are:

Refrigerator: All vaccines are supposed to be stored strictly under certain temperature range which is usually between 2° to 8° Celsius but can vary for different vaccines (UNICEF, 2008). Normal refrigerators are not designed to maintain such precise temperature and therefore can't be used. A purpose-built refrigerator is required to transport the vaccines which along with maintaining the temperature should be spacious enough to store maximum volume of vaccines at any given time as well as allow proper air circulation around vaccine packages. Refrigerator should be connected to the back-up power source so that the vaccines should not lose its potency in case of power failure. For this purpose, Internet of Things (IOT) can be used to collect information about vaccine temperature, how many times there was a cold-chain breach and report it to the administrator in charge to take preventive measures.

Along with maintaining the temperature, the vaccines should be protected against the exposure to sunlight or fluorescent light (Immunization Program Guide, 2012).

To prevent the wastage of vaccines, vaccines with early expiry date should be used early.

While these constraints are vital for efficient vaccine distribution, people responsible for managing and maintaining these vaccines while they are being stored or transported need to be well trained.

Trained Personnel: Though this paper does not cover use of trained personnel, it is a very important constraint which needs to be considered to improve the vaccine distribution plan. People involved in transportation and supply of vaccines need to be trained and have knowledge of cold chain and how to handle breakage of cold chain. Without pre-requisite knowledge of how to handle vaccines being transported can seriously affect the vaccine potency which in turn can result in wastage of vaccines and thus, increase in their price (Immunization Program Guide, 2012).

In this paper, we have tried to tackle the above mentioned challenges in our formulation along with generating optimized supply route of vaccines using different heuristics and methods.

2. LITERATURE REVIEW

Now a days there are number of vaccines available and inventions of new vaccines have generated serious challenges in their vaccine supply and logistic systems. Storage capacity bottlenecks and system inefficiencies threatens the access, availability and quality of vaccines. In advent of new and improved vaccines introduced daily, the logistics systems must be strengthened and optimized.

Elodie et al. (2013) mentioned the two main reasons of why it is difficult to reach optimum level of vaccine coverage (i) emergence of operational issues on the supply side (ii) negative network effects on consumption side. These two reasons are needed to be dealt with to achieve the optimized solution for vaccine supply.

There are many constraints which need to be considered in vaccine distribution planning like Michel Zaffran et al. (2013) mentioned some current issues:

- Impact of vaccine schedules and presentations on cold chain volume requirements.
- What can be used for transporting vaccines to maintain cold chain constraints?
- Immunization related information systems.
- Human resources for vaccine supply chain.
- Vaccine cost and wastage.

These issues need to be addressed in order to keep logistic systems with pace with growing immunization programs. According to the researchers from the World Health Organization (WHO) and PATH, the vaccine volume requirements compared to the available capacity exceeds by 25 percent.

As mentioned in Immunization Program Guide (2012), there are three elements required for safe storage and transportation of vaccines: Trained personnel, Equipment to store and transport vaccines.

Maintaining cold chain is a very important constraint which need to be handled while storing or transporting vaccines. In most of the prior work this important constraint is either neglected or not given much importance while generating the optimized supply route.

2.1 Research Gap

From our limited literature study, we found that there are ample of research opportunities in vaccine supply chain planning. In this paper, we not focus on the implementation of optimize route generation or importance of inventory management.

In this paper, we address the issues of vaccine distribution planning while considering the cold chain constraint. Following are the issues which we address in this paper:

- Effective Distribution of Vaccines with minimum transportation cost, Inventory cost and penalty cost for unsatisfied demand.
- Reducing the wastage cost of vaccines by first using vaccines with nearby expiry dates and by reducing as much wastage of vaccine as possible due to cold chain breakage.
- Designing the Vaccine immunization related Centralized Information System, so that the managers would get accurate data and timely information from any remote location.

At last, this paper discusses the importance of Internet of Things (IOT) in vaccine distribution planning. Research firm Gartner released a write up saying that by the year 2020 there will be a thirty-fold increase in internet-connected physical devices which will change how the supply chain operates (Shankar, 2015).

Our result generated can provide optimized solution along with keeping into consideration all the important constraints that affect vaccine supply.

3. PROBLEM DESCRIPTION

There is a District Health Centre in every district of India and all the PHC's order their vaccines to the DHC. According to their demands, vehicle allocation takes place and the demand is fulfilled by DHC. In this model, we have focused on the vaccine supply chain of Pune district.

The task is to fulfill the weekly demands of all the PHC's in Pune district along with finding the most optimized route to supply those vaccines using different heuristics. There is a DHC which supplies vaccines to all the PHC's in that district depending on their weekly demands. There are total 96 PHC's in Pune District, each having their own set of weekly demands. The demand consists of different types of vaccines and their quantity needed. Types of vaccines considered are mainly for the babies within the age 0-2 years but can be increased further. Depending on the demands and the capacity of fleet of vehicles used, routes with minimum distance travelled is generated.

The main objective is to generate the route to supply vaccines to all PHCs with minimum total distance travelled by each vehicle and minimize the unfulfilled demands of each PHC. The challenges mentioned above play a vital role in determining the important constraints which need to be considered while achieving the objective, such as, to maintain the cold chain breakage, we have assumed that a vehicle can travel maximum 300 km without affecting the vaccine potency due to cold chain breach, therefore, adding it as a constraint while formulating the problem.

The solutions obtained by different methods can then be used to compare these methods on the basis of various factors such as computation time, demand fulfilment, distance travelled.

Figure 1 shows a map of Pune district in which all the PHC's are marked (Pune District Map, Accessed on 21-07-2014).

3.1 Mathematical Formulation

The objectives are as follows:

- To minimize the total time of supplying the vaccines.
- To minimize the unfulfilled demands.

To achieve the first objective we minimize the total distance travelled by all the vehicles. This can be done because total travel time of vehicles is directly proportional to the total distance travelled by them. The second objective is achieved by supplying as many vaccines as equal to the maximum capacity of each vehicle.

There are suppose n PHC's (in our case n=96). Each PHC is located at a different location. So there is a distance (d_{ij}) between them and travel time (t_{ij}) associated with each pair of PHC's (i, j). The distance and time matrices are symmetrical matrices. DHC is denoted by 0. q_i is used to denote weekly demands of each PHC where $i = 1,2,..,n$.

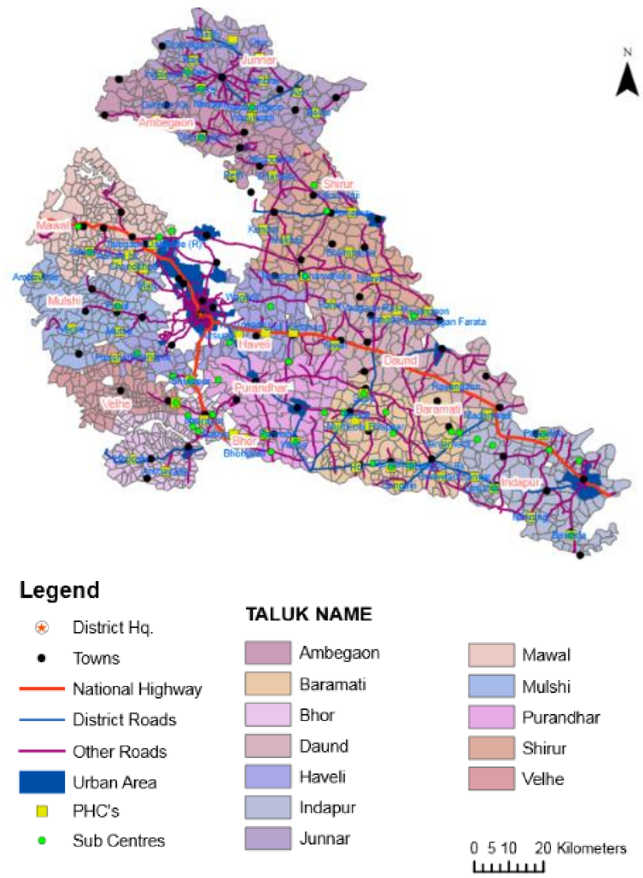

Figure 1. Map of Pune District Showing all the PHC's

DHC has in total of m vehicles. Each vehicle may have same or different capacities. Capacity of each vehicle is denoted by a_k where $k = 1, 2,..,m$.

Each PHC has a time window. It is an interval [e_i, l_i], where $e_i \leq l_i$ in which:

- e_i corresponds to the earliest time to start to reach PHC i
- l_i corresponds to the latest time to start to reach PHC i

Let s_i be the time duration for which a vehicle will halt at PHC i.

3.1.1 Variables:

x_{ijk} = 1 if PHC j is supplied after PHC i by vehicle k

= 0 otherwise

y_i^k = fraction of PHC i's demand supplied by vehicle k

b_i^k = moment at which vehicle k arrives at PHC i

3.1.2 Objective Functions:

1. To minimize the distance travelled by each vehicle

$$min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{m} d_{ij}.x_{ijk}$$

2. To minimize unfulfilled demand of each PHC

$$min \sum_{i=1}^{n} (1 - \sum_{k=1}^{m} y_i^k)$$

3.1.3 Constraints:

1. Every vehicle must leave from DHC and arrive at some PHC

$$\sum_{j=1}^{n} x_{0j}^k = 1 \qquad k = 1,2, \dots, m$$

2. Each vehicle must leave from every PHC it visits and finally arrive back at the DHC

$$\sum_{i=0}^{n} x_{ip}^k - \sum_{j=0}^{n} x_{pj}^k = 0 \ \forall k \ and \ p = 0,1, \dots, n$$

3. Total quantity supplied by each vehicle should be less the its capacity

$$\sum_{i=1}^{n} q_i y_i^k \leq a_k \qquad k = 1,2, \dots, m$$

4. Any vehicle should supply at a PHC only if it visits that PHC

$$y_i^k \leq \sum_{j=0}^{n} x_{ji}^k \qquad \forall k, i$$

5. Every PHC must be visited at least once

$$\sum_{k=1}^{m} \sum_{i=0}^{n} x_{ij}^k \geq 1 \qquad j = 1,2, \dots, n$$

6. Total fraction of supply of each PHC should be less than or equal to 1

$$\sum_{k=1}^{m} y_i^k \leq 1 \qquad i = 1,2, \dots, n$$

7. Distance travelled by each vehicle should not be more than 300km

$$\sum_{i=0}^{n} \sum_{j=0}^{n} d_{ij} x_{ij}^k \leq 300 \qquad k = 1,2, \dots, m$$

8. Sets a minimum time for arriving at PHC j in a determined route and also guarantees that there will be no sub tours

$$b_i^k + s_i + t_{ij} - M_{ij}(1 - x_{ij}^k) \leq b_j^k \qquad k = 1,2, \dots, m; \ i = 1,2, \dots, n; \ j = 1,2, \dots, n$$

The constant M_{ij} is a large enough number, for instance, $M_{ij} = l_i + t_{ij} - e_j$

9. Vehicles should serve the PHC's within time windows

$$e_i \leq b_i^k \leq l_i \qquad i = 1,2, \dots, n$$

3.1.4 Variable Bounds:

1. Variable b should be non-negative

$$b_i^k \geq 0 \qquad k = 1,2, \dots, m; \ i = 1,2, \dots, n$$

2. Variable y should be non-negative

$$y_i^k \geq 0 \qquad k = 1,2, \dots, m; \ i = 1,2, \dots, n$$

3. Variable x should be binary

$$x_{ij}^k \ \varepsilon \ \{0,1\} \qquad k = 1,2, \dots, m; \ i = 0,1, \dots, n; \ j = 0,1, \dots, n$$

3.1.5 Assumptions:

- We need a weekly schedule of routes for each vehicle. With the introduction of time variant, the problem becomes complex. So to simplify the model and generate weekly schedule, we multiply number of days by number of vehicles. For example, if DHC has 3 vehicles available daily, so for a weekly (6 days a week) schedule, we consider that the DHC has 18 vehicles available (3*6=18) and give k = 18 as input. As output we will get 18 individual routes. Out of these 18 routes first 6 routes by of vehicle 1, next 6 routes of vehicle 2 and last 6 routes of vehicle 3.
- We also assume that the battery life of the refrigerators in the vehicles will not last for more than the time taken by the vehicle to travel 300km. Therefore, we have included constraint no. 7.
- As we do not know the actual demands of the PHC's, we have assumed that demands follows uniform distribution between the range of [0, 100].
- We have also assumed that every vehicle travels at a uniform speed of 40km/hour to calculate the time matrix from the distance matrix.
- Also in the formulation we have used time window, which allows us to eliminate the sub tour elimination constraints. Otherwise, the number of constraints grows exponentially.
- Currently we have limited the mathematical model for only one type of vaccine.

3.2 Problem Complexity

Table 2. Problem Size

Problem Size	No. of Variables	No. of Constraints	Time Taken (in seconds)
5 PHC's and 1 Vehicle	240	243	250.69
5 PHC's and 2 Vehicles	480	471	2469.64
10 PHC's and 2 Vehicles	1560	1518	Unknown
50 PHC's and 3 Vehicles	47700	47022	Unknown
96 PHC's and 5 Vehicles	285120	282648	Unknown

As we know that Vehicle routing problem with split deliveries and time windows is a NP-HARD Problem (Tonci Caric, 2008) and as the size of our input (no. of variables and constraints) was increasing, it was taking huge amount of time to solve the formulation. Hence, we are solving the same problem using approximation algorithms.

3.3 Methodology

Heuristic for Vehicle Routing Problem is a two-phased method. The two phases of the algorithm are:

- Clustering
- TSP solving

In the first stage of the algorithm, we decompose the input and form cluster of nearby PHC's and in the second stage we solve TSP problem in each cluster to form routes. Figure 2 shows the flow of heuristics.

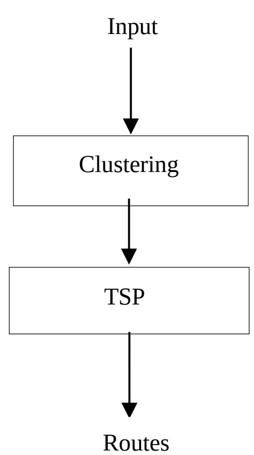

Figure 2. Flow diagram of Heuristic

3.3.1 Clustering using Sweep Algorithm

We already know the location of every PHC. We use this location and find out the (x, y) co-ordinates of every PHC keeping the DHC as the origin. Once we have the co-ordinates of all the PHC's, we start forming clusters of nearby PHC's. But there are two criteria's for including a PHC in any particular cluster. They are:

- All PHC's within a cluster have minimal angle amongst them.
- Capacity of the vehicle assigned to a cluster should not be exceeded. This means that all the PHC's in that cluster should have a total demand less than or equal to the capacity of the cluster.

There are two types of Sweep algorithm:

- Forward Sweep: In forward Sweep, we consider PHC's for clustering in clockwise direction.
- Backward Sweep: In backward Sweep, we consider PHC's for clustering in anti-clockwise direction.

We start from an arbitrary PHC. Then we join the closet PHC to the chosen PHC. The closest PHC is the one with the smallest angle between them. Then the next closest is taken and so on. This process continues till the constraints are satisfied. Figure 3 below show an example of clusters formed using sweep algorithm (Gunadi W. Nurcahyo, 2002). This is how one cluster is formed. We continue the entire process to form as many clusters as equal to the no. of vehicles multiplied by 6(no. of days each vehicle will travel as we need weekly schedule).

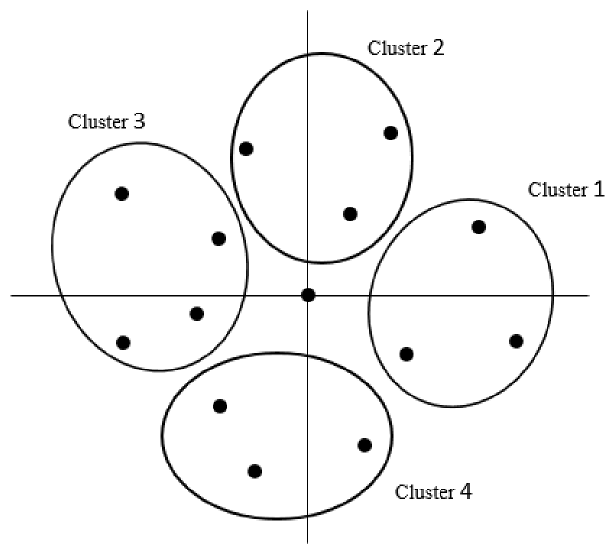

Figure 3. Example of Sweep Algorithm

In the next stage, we need to link all the PHC's in a cluster to form a route. The route should start and end at the DHC. The route generated should be the shortest path connecting all the PHC's in the cluster. For this purpose we have used two algorithm. They are:

- Nearest Neighbor
- Greedy

3.3.2 TSP using Nearest Neighbor

We already know the distance between each pair of PHC's. The basic idea of nearest neighbor algorithm is to add the nearest neighbor of the last added PHC to the route. Nearest Neighbor is the one which has least distance from it. We start at the DHC. Next we add the PHC which is the nearest to the DHC to the route. Then we continue adding PHC's nearest to the last added PHC to the route till all the PHC's in the clusters have been added to the route. Only PHC's which have not already been added are added to the route.

3.3.3 TSP using Greedy

Even for greedy algorithm, we require the distance between each pair of PHC's which is already known. The basic idea of greedy algorithm is to add that pair of PHC's to the route which have the shortest distance amongst them. We start by selecting a PHC pair which has the minimum distance between them. Add this pair to the route. Then select the next minimum distance and add this to the route and keep on doing this till all the PHC's in that particular cluster have been added to the route.

But before adding any PHC pair to the route, we need to check if by adding this pair, a sub-tour is being generated? If yes, then ignore the pair selected and if not, only then add it to the route. A sub-tour is generated if degree of all the connected PHC's become 2 after adding this pair. At all times at least 2 PHC's should have degree 1 unless we are adding the last edge to the route.

Figure 4 shows sample routes that are generated from nearest neighbor algorithm and greedy algorithm.

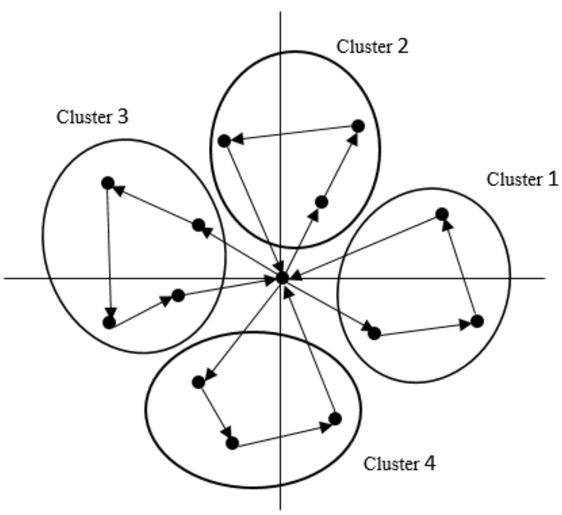

Figure 4. Sample Routes

3.4 Implementation

The objective is to build a system that is capable of generating/planning/scheduling of vaccine distribution efficiently. Based on this objective, we build a system with following features:

- System is capable of generating and displaying efficient routes and amount of vaccines to be delivered to PHC's for each day in a week (based on demands).
- The system gives the delivery details of vaccines to the respective PHC's.
- The system keeps the record of all the Inventory details of PHC's.
- Each PHC is capable of placing the demand order of vaccines to DHC.

There are two types of user's in our system:

1. DHC (District Health Center)
2. PHC (Public Health Center)

The DHC is (Sassoon Hospital, Pune in our case) responsible for distribution of vaccines over PHC's in order to full the demand. It will generate and keep track of all Vaccine Distribution Plans on weekly basis. The DHC administrator will receive demands (from PHC's) generate schedule, allocate vehicles to each route and manage supply of vaccines as per the demands of the PHC's from the previous week in such a way that it minimize cost and time of vaccine supply. The Demands of each PHC's will be fulfilled on weekly basis only. The PHC users will be the end users to the system. They will provide the demand detail of vaccines to the DHC. The PHC users can view its Inventory details and can update its stock (Vaccine) details.

System is built in J2EE, where Java Server Faces (JSF 2.0) along with HTML 5 and CSS 3.0 are used for user interface and Java Script for client side validations. Backend is implemented in Java. For maintaining Inventory details we are using Oracle 11g database. Along with this, for solving our mathematical formulation, we are using the IBM ILOG CPLEX Version 12.4 tool. Apache Tomcat 7.0 is used as application server for development of system. Following figure 5 shows the implementation flow of the system.

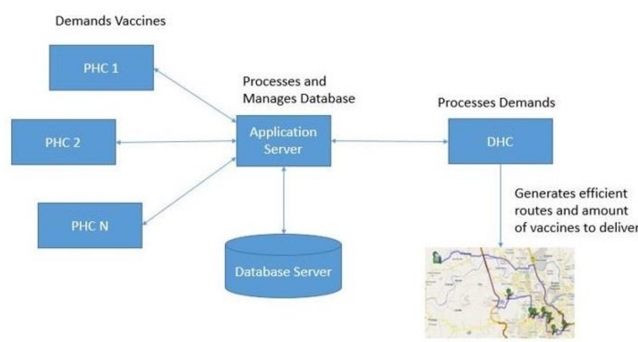

Figure 5. Implementation Flow

3.5 Results

Figure 6 shows Latitude and Longitude of DHC and few PHC's (Latitude Longitude Coordinates, Accessed 04-08-2014).

	A	B	C	D
1		Sasson Hospital	18.523244	73.868769
2				
3	Taluka	PHC	Latitude	Longitude
4	Ambegaon	Adiware	19.14827	73.693927
5	Ambegaon	Dhamani	18.915533	74.063793
6	Ambegaon	Dimbha	19.084446	73.745191
7	Ambegaon	Mahalunge Padwal	19.113234	73.732678
8	Ambegaon	Nirgudsar	18.975906	74.0447
9	Ambegaon	Peth	18.9304	73.921286
10	Ambegaon	Taleghar	19.070022	73.663485
11	Baramati	Dorlewadi	18.098258	74.610031
12	Baramati	Hol	18.105279	74.352882
13	Baramati	katewadi	18.130247	74.657609
14	Baramati	Lonibhapkar	18.234047	74.376341
15	Baramati	Morgaon	18.272648	74.320621

Figure 6. Latitudes and Longitudes

Figure 7 shows (x, y) co-ordinates of DHC and few PHC's (Calculating XY Coordinates", 12-12-2014).

Here are the screenshots of an example. For input, we have given PHC details including their angle w.r.t. positive x axis and their individual demands, no of vehicles is equal to 5 and their capacity is suppose 150. So all the vehicles will travel on all 6 days. So we assume that it is equivalent to 30 vehicles, and therefore no. of clusters that will be formed will be 30. Figure 8 below shows the input.

	A	B	C	D
1		Sasson Hospital	0	0
2				
3	Taluka	PHC	x	y
4	Ambegaon	Adiware	-18461.5	69178.3
5	Ambegaon	Dhamani	20592.5	43418.8
6	Ambegaon	Dimbha	-13048.6	62114.2
7	Ambegaon	Mahalunge Padwal	-14369.8	65300.5
8	Ambegaon	Nirgudsar	18576.5	50100.9
9	Ambegaon	Peth	5545.3	45064.3
10	Ambegaon	Taleghar	-21675.9	60517.7
11	Baramati	Dorlewadi	78269.7	-47037.7
12	Baramati	Hol	51117.4	-46260.6
13	Baramati	katewadi	83293.4	-43497.2
14	Baramati	Lonibhapkar	53594.4	-32008.5
15	Baramati	Morgaon	47711	-27736.1

Figure 7. (x, y) co-ordinates

```
PHC Details:
PHC No: 24.0  Angle: 355.0883218936547  Demand: 96.0
PHC No: 23.0  Angle: 354.92297994503184  Demand: 32.0
PHC No: 22.0  Angle: 354.15491668040164  Demand: 33.0
                    .
                    .
                    .
PHC No: 74.0  Angle: 222.6313742772998  Demand: 58.0
PHC No: 38.0  Angle: 214.07434461347523  Demand: 19.0
PHC No: 81.0  Angle: 196.0967164687789  Demand: 50.0
                    .
                    .
                    .
PHC No: 27.0  Angle: 7.123520299594099  Demand: 91.0
PHC No: 89.0  Angle: 2.2919136939194216  Demand: 68.0
PHC No: 26.0  Angle: 2.0145812681902484  Demand: 100.0
```

Figure 8. Sample Input

```
Cluster details:
Cluster No.: 1.0  PHC No.: 24.0  Supply Amount: 96.0
Cluster No.: 1.0  PHC No.: 23.0  Supply Amount: 32.0
Cluster No.: 1.0  PHC No.: 22.0  Supply Amount: 22.0
                    .
                    .
                    .
Cluster No.: 15.0  PHC No.: 74.0  Supply Amount: 43.0
Cluster No.: 15.0  PHC No.: 38.0  Supply Amount: 19.0
Cluster No.: 15.0  PHC No.: 81.0  Supply Amount: 50.0
Cluster No.: 15.0  PHC No.: 37.0  Supply Amount: 38.0
                    .
                    .
                    .
Cluster No.: 30.0  PHC No.: 27.0  Supply Amount: 76.0
Cluster No.: 30.0  PHC No.: 89.0  Supply Amount: 68.0
Cluster No.: 30.0  PHC No.: 26.0  Supply Amount: 6.0
```

Figure 9. Clusters Formed

Figure 9 above shows the clusters formed using the sweep algorithm and figure 10 below shows the routes generated. Total travel distance including all the routes is 4805.75kms which is equal to 120.14hrs considering uniform speed of 40km/hr. In this case unfulfilled demand = 94 units.

```
The Routes:
For Vehicle 1 Day 1
DHC 0  -> PHC 24 -> PHC 23 -> PHC 22 -> DHC 0
For Vehicle 1 Day 2
DHC 0  -> PHC 39 -> PHC 29 -> PHC 22 -> DHC 0
For Vehicle 1 Day 3
DHC 0  -> PHC 35 -> PHC 29 -> PHC 25 -> DHC 0
                    .
                    .
                    .
For Vehicle 3 Day 4
DHC 0  -> PHC 37 -> PHC 80 -> PHC 78 -> PHC 77 -> DHC 0
For Vehicle 3 Day 5
DHC 0  -> PHC 76 -> PHC 72 -> PHC 77 -> PHC 73 -> PHC 75 -> DHC 0
For Vehicle 3 Day 6
DHC 0  -> PHC 30 -> PHC 76 -> PHC 68 -> PHC 67 -> PHC 62 -> PHC 53 -> PHC 64 -> DHC 0
                    .
                    .
                    .
For Vehicle 5 Day 4
DHC 0  -> PHC 88 -> PHC 91 -> PHC 93 -> DHC 0
For Vehicle 5 Day 5
DHC 0  -> PHC 87 -> PHC 41 -> PHC 40 -> PHC 94 -> PHC 91 -> PHC 92 -> PHC 90 -> PHC 27 -> DHC 0
For Vehicle 5 Day 6
DHC 0  -> PHC 27 -> PHC 26 -> PHC 89 -> DHC 0
```

Figure 10. Route generated

3.5 Comparison between naïve approach and our heuristic approach

In naïve approach, we add clusters randomly until the capacity of the vehicle assigned to the cluster is exhausted. For examples, keeping the demands same as the previous example cluster 1 contained PHC 1 and 2, in cluster 2 PHC 2, 3 and 4 are there and so on as shown in the figure 11 below.

```
Cluster details:
Cluster No.: 1.0  PHC No.: 1.0  Supply Amount: 97.0
Cluster No.: 1.0  PHC No.: 2.0  Supply Amount: 53.0
                        .
                        .
                        .
Cluster No.: 15.0  PHC No.: 43.0  Supply Amount: 29.0
Cluster No.: 15.0  PHC No.: 44.0  Supply Amount: 82.0
Cluster No.: 15.0  PHC No.: 45.0  Supply Amount: 32.0
Cluster No.: 15.0  PHC No.: 46.0  Supply Amount: 7.0
                        .
                        .
                        .
Cluster No.: 30.0  PHC No.: 90.0  Supply Amount: 36.0
Cluster No.: 30.0  PHC No.: 91.0  Supply Amount: 66.0
Cluster No.: 30.0  PHC No.: 92.0  Supply Amount: 6.0
Cluster No.: 30.0  PHC No.: 93.0  Supply Amount: 42.0
```

Figure 11. Clusters formed by sequentially adding PHC's

Once the clusters are formed, next task is route generation. To form routes, PHC's are connected again in linear fashion. For example, cluster 1 has PHC 1 and 2 in it. So the vehicle will start at DHC, visit PHC 1 then PHC 2 and return back to DHC. Figure 12 shows the routes.

```
The Routes:
For Vehicle 1 Day 1
DHC 0  -> PHC 1 -> PHC 2 -> DHC 0
For Vehicle 1 Day 2
DHC 0  -> PHC 2 -> PHC 3 -> PHC 4 -> DHC 0
For Vehicle 1 Day 3
DHC 0  -> PHC 4 -> PHC 5 -> PHC 6 -> PHC 7 -> PHC 8 -> PHC 9 -> PHC 10 -> DHC 0
                        .
                        .
                        .
For Vehicle 3 Day 4
DHC 0  -> PHC 46 -> PHC 47 -> PHC 48 -> PHC 49 -> PHC 50 -> DHC 0
For Vehicle 3 Day 5
DHC 0  -> PHC 50 -> PHC 51 -> PHC 52 -> PHC 53 -> DHC 0
For Vehicle 3 Day 6
DHC 0  -> PHC 53 -> PHC 54 -> PHC 55 -> DHC 0
                        .
                        .
                        .
For Vehicle 5 Day 4
DHC 0  -> PHC 84 -> PHC 85 -> PHC 86 -> DHC 0
For Vehicle 5 Day 5
DHC 0  -> PHC 86 -> PHC 87 -> PHC 88 -> PHC 89 -> PHC 90 -> DHC 0
For Vehicle 5 Day 6
DHC 0  -> PHC 90 -> PHC 91 -> PHC 92 -> PHC 93 -> DHC 0
```

Figure 12. Routes

Total travel distance including all the routes comes out to be 6219.43kms which is equal to 155.48hrs considering uniform speed of 40kn/hr.

Our Solution gives total travel of 120.14hrs which is much less than 155.48hrs given by the naïve approach. There is a difference of 35.34hrs. This shows how the solution we present gives us quite efficient routes.

4. ROLE OF IoT IN VACCINE DISTRIBUTION PLANNING

So how IoT can benefit in vaccine supply chain?

In Internet of Things (IOT), various objects, places and animals are provided with unique identifiers and the data is transferred over a network without any human-to-human or human-to-machine interaction (Internet of Things definition, 2015). It therefore, intelligently connects people, processes or data via some sort of device or sensor. A thing in Internet of Things can be either a heart monitor implant on a person or a biochip transponder on a farm animal or a vehicle with built in sensors to alert the driver whenever the tire pressure is low. Basically, it can be any man-made or natural thing which can have an IP address and has the ability to transfer the data over a network.

WHO provide a guide lines for electronic monitoring devices such as temperature monitoring devices and other control devices in vaccine supply (Daskalopoulos, 2014). Temperature monitoring devices includes sensors and controllers that should attach to refrigerators for maintaining and controlling temperature of refrigerator carrying vaccines. Other devices such as cloud based GPS or Radio frequency Identification (RFID) to provide identity, location and other tracking information related to current vaccine distribution.

The goal is to develop a system using IoT of things that will make vaccine supply chain more flexible and adaptive. We propose a system that will assist in real time decision making with use of ioT. System is as follows:

An intelligent device, which contains controllers and sensors (as suggested above), will be attached to each vehicle. This device will control and observe these controllers and sensors. Also this device will have information about real time vaccine transportation like name of PHCs, vaccine type, vehicle information, route followed, vaccine demand etc. Each of these devices will directly connect to main dedicated server on which the system will be deployed. This device will provide real time information of particular vaccine distribution (like PHCs covered, vaccines supplied etc.) to the system. With the help of it, the system can keep track of each vaccine distribution. While being connected to server, these devices will also connect to each other through server and form internet of these intelligent devices. In this way each device will have current information/status of other vaccine transportations along with its own. These devices will assist managers in efficient decision making in transportation of vaccines and predicting outcomes (like estimate time of delivery etc.) of distribution. Also allow system to reschedule/change the transport on the basis of current conditions and status like the GPS co-ordinates of the vehicles, temperature range, traffic conditions, and driver-specific information.

This device will be very helpful and effective in many stimuli as well as in adverse situations such as:

1. **Temperature Control:** A sensor can be attached to all the refrigerators/vehicles carrying vaccines. This sensor will connect to this device in order to monitor the temperature maintained in the refrigerator and alert the personnel in charge and system whenever there is a cold chain breach.
2. **Conjunction in route:** IoT will be very help full in monitoring traffic in the route in real world situations. It will keep track of the current traffic situation in the route that vehicle is following for transportation of vaccines. If there any heavy traffic situation will build in the route then devices will help in finding new optimize route over pre-selected route and update system with this new route.
3. **Inventory Management:** By using IOT we can check how much stock is left in the inventory of each PHC without any

manual interference and get how much have been supplied at any point of time to PHC.

4. **Unexpected increase in demand:** If there any sudden increase in demand of vaccine in some PHCs (in case of any epidemic etc.) then large amount of particular vaccine will be required. In such scenario the system will first identify vehicles which are currently carrying required vaccine. Then recalculate and reschedule the transportation and guide/redirect these vehicles from low priorities PHCs to a high priority PHCs.
5. **Vehicle Failure:** If some damage happens to vehicle during transportation of vaccines, this device will update system with current conditions of vehicle and supply. As soon as system gets this information it starts updating other devices which are on the way to supply. Then it will find and redirect nearest vehicle to damaged vehicle in order to prevent damages to vaccines.

By introducing IOT in vaccine supply chain management, we can allow stakeholders to make efficient decision by offering information well before any supply happens. Involvement of IOT in vaccine supply chain management is still nascent. And hence need to start considering its potential for intelligent decision making.

5. SUMMARY

Infectious diseases are a worldwide threat to public health and vaccines provide a safe and efficient solution to this problem. Optimizing the supply route of vaccines can reduce the cost of transporting the vaccines thus reducing the overall cost. The optimization and management of vaccine supply chain at present is much focused research area. Thus there is a need for better and optimized system which can cater the needs of increasing demands of vaccines and can solve the problems which earlier systems couldn’t solve. In this paper, different heuristics and models are used in an attempt to find the most optimized solution for supply route of vaccines while considering all the constraints. This paper also looked into the role of Internet of Things in vaccine distribution system and how it can help to improve the supply chain efficiency.

In future, this model can be expanded for multiple types of vaccines. We can also include vaccines other than compulsory vaccines for babies. Demand forecasting is an important issue and with the digitization and IoT, the accuracy of demand estimation could increase. This model can also be used as a platform to supply different goods which can get easily perishable by altering few constraints.

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