Institute Vaccine Management Solution

A software solution to aid in institute vaccine management

Arihanth Srikar Tadanki
2019113005
International Institute of Information Technology
Hyderabad, India
arihanth.srikar@research.iiit.ac.in

***Abstract*—A major problem across large organisations is the management of vaccination of the population. A novel software solution tackles the problem by eliminating majority of the laborious process by automating everything from start to end.**

I. Introduction

The problem of managing the vaccination is due to a fairly large population to cater to. A manual method of processing each request and maintaining of logs would be laborious and strenuous. A novel software solution will help automate the entire process of maintaining logs, keeping track of vaccinated population, scheduling and rescheduling of appointments. This eliminates the need for physical book-keeping and human errors.

II. Literature Review

Our goal is to achieve an optimal solution for managing the vaccination of people in our institute. However, there are several factors that will affect or influence the solution we come up with. In order to understand these factors, we need to take a look at the bigger picture. There are broadly two ways of treating a disease - cure or prevent. The famous saying "Prevention is better than cure" stands strong till date.

A. Vaccine management

Vaccinations are well known methods of prevention. In the case of an outbreak, catering to a nation's population isn't easy. The country must devise a model for fair vaccination of the citizen. Some of the factors that need to be thought of or designed are the vaccine arrival, shipment and transport, monitoring physicals conditions of the vaccine's surroundings like temperature, pH, etc, storing the vials (may it me cold storage, dry storage, away from exposure to sunlight), managing the stock and distribution of the vaccine, tracking systems to make keep an eye on how things are moving [1].

B. Allocation of resources

"One of the most crucial ethical issues in vaccine allocation is the fact that equity and efficiency are often competing objectives" [3]. Resources will be divided according to criteria of higher need and availability. In the case of vaccination, studies and data gathering will split the population in categories based on certain criteria. This could be age, prior medical conditions (heart complications, diabetes, etc), line of occupation, etc data on death rate, recovery rate. Models like Monte Carlo Simulations, optimization algorithms, machine learning algorithms, or neural networks can be used to find optimal ordering of decisions.

C. COVID-19 Transmission

We will look at how to model the transmission of COVID-19 to better be able to strategize a vaccination scheme. We will divide the population in to eight bands based on their age, them being 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, and $\geq$70. We will further consider six criteria that will apply to each age band, them being S, E, A, I, Q, R. S is the susceptibility of the subject. E is the exposure to the virus. A means the subject shows symptoms and I means he/she is asymptomatic. Q is the rate at which subjects are either hospitalized or self-isolated. R means the subject recovers. D means the subject dies. We make a few assumptions here based on whether or not the subject shows symptoms once infected. If the subject is asyptomatic, then it is assumed to have a zero risk of mortality and would recover at a steady rate. If they were symptomatic, then they are assumed to be susceptible to the virus again at a a given rate. This demonstrates the temporary attainment of immunity. We also take into account the various situations that may arise and divide them into two simulations.

Simulation 1

- A vaccinated subject is completely protected against the virus and can't be a vector of transmission.
- Sterilizing immunity

Simulation 2

- A vaccinated subject is not completely protected against the virus and can be a vector of transmission.
- Non-sterilizing immunity

We will now model the susceptibility S_i for every age group i using the following differential equations where, $\frac{1}{\mu}$ is the average length of immunity, β_1 is the force of infection, N is the total population size, $\frac{1}{\sigma}$ is the average latent period, p is the proportion of infections which are symptomatic, $\frac{1}{\gamma}$ is the average asymptomatic recovery time, $\frac{1}{\omega}$ is the average time from isolation to recovery for a symptomatic infection, $\frac{1}{\alpha}$ is the average time until a symptomatically infectious subject self-quarantines or is hospitalized, and δ is the likelihood of death given symptomatic infection. C_{ij} is the relative frequency of contact between age group i and age group j.

In simulation 1, $\beta_2 = 0$

In simulation 2, $\beta_2 = \beta_1$. E^V are subjects who are exposed. A^V are subjects who are asymptomatic. R^V are subjects who are recovered.

In both cases, M doses of vaccines of an efficacy of ϵ are assumed to be available each day. We also assume that the vaccinated subjects have received the total required doses.

$$\frac{dS_i}{dt} = \mu R_i - \varepsilon M - \frac{\beta_1}{N}\sum_{j=1}^{K} C_{ij} S_i \left(A_j + A_j^v + I_j\right),$$

$$\frac{dV_i}{dt} = \mu R_i^v + \varepsilon M - \frac{\beta_2}{N}\sum_{j=1}^{K} C_{ij} V_i \left(A_j + A_j^v + I_j\right),$$

$$\frac{dE_i}{dt} = -\sigma E_i + \frac{\beta_1}{N}\sum_{j=1}^{K} C_{ij} S_i \left(A_j + A_j^v + I_j\right),$$

$$\frac{dE_i^v}{dt} = -\sigma E_i^v + \frac{\beta_2}{N}\sum_{j=1}^{K} C_{ij} V_i \left(A_j + A_j^v + I_j\right)$$

$$\frac{dA_i}{dt} = (1 - p_i)\sigma E_i - \gamma A_i,$$

$$\frac{dA_i^v}{dt} = \sigma E_i^v - \gamma A_i^v$$

$$\frac{dI_i}{dt} = p_i \sigma E_i - \alpha I_i,$$

$$\frac{dQ_i}{dt} = \alpha I_i - \omega Q_i,$$

$$\frac{dR_i}{dt} = \gamma A_i + (1 - \delta_i)\omega Q_i - \mu R_i,$$

$$\frac{dR_i^v}{dt} = \gamma A_i^v - \mu R_i^v,$$

$$\frac{dD_i}{dt} = \delta_i \gamma_2 Q_i,$$

Fig. 1. Differential equations modelling the susceptibility of each age group.

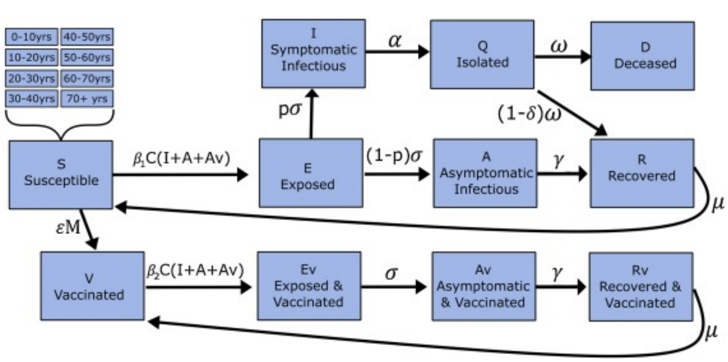

Fig. 2. Schematic of model transmission dynamics.

D. *Current vaccine distribution*

The life of a single vial of COVID-19 vaccination upon usage is just four hours. Each vial would serve up to ten vaccinations. Hence one of the limitations is to have ten subjects lined up within a span of four hours to minimize wastage. In India, vaccinations are being provided to all the front-line workers, senior citizen and people aged forty-five and above as of April 2021. From the 1st of May 2021, they plan to make it available for any individual above the age of eighteen.

E. *Solutions to management of vaccination*

Several product management techniques following the order:

- Functional analysis
- Technical analysis
- Development
- Parameterization
- Testing
- Training and change management
- Data migration and deployment
- Maintenance and stabilization

can be used to develop a software tracking and scheduling system.

III. System Architecture

The above literature review is crucial in building a software system that manages the vaccination of the entire institute since we would better consider relevant factors. We must plan for the time when the government allows for independent procurement of vaccines for all age groups. Thus all the above points are still relevant as our system has simply changed from country to institute.

If we have enough vaccines to provide for all the residents on campus at one shot then we can being to schedule based on an individuals convenience and allot slots. If we were to assume a constant rate of supply of the vaccine, then we could follow the above model which takes into account the susceptibility of various age groups and prioritize accordingly.

The software solution will consist of four components.

- Setting up accounts of all residents (registration). This can be done via CAS but might leave out some staff such as the ones that run the canteens, take care of hostels, etc. A simple fix would be to assign an email to them too (if not present already) and centralize the information for ease of tracking.
- The software will run algorithms that prioritize the distribution of vaccine among the population. We will consider this as a black box going forward.
- Based on the selection of a pool of people, the software will set time slots that users can then apply for. Basically scheduling of vaccination.
- Provide statistics, updates the model based on completed vaccination shots and provides different views/access to the software based on their role.

A few points to note are, while registering the user is expected to provide medical conditions, other relevant information such as health disorders, pregnancy at the time of scheduled vaccination, etc. Each vial of vaccine would serve up to ten people within the span of four hours. Thus the scheduling of vaccination will only take place if multiple of ten number of people apply for a slot. These slots would be decided by the software based on the availability of the vaccine.

The advantages of implementing a solution in this manner is that no extra registration is required by the user. They are simply required to login via CAS. Mailing lists, basic information regarding each user, contact information, etc is already present in the database. This would also not duplicate the storage of information and make it easier to review the statistics.

A. Diving into specifics

We have broadly determined what our software system does. Let us define the parameters, input and output of every phase.

Component-1 is fairly clear. It requires an integration of CAS and our software system.

Component-2 is going to take age, health conditions, medical conditions and whether the person is already vaccinated (taken all doses or not) as input. It will run its algorithms on it and output an order in which people should be vaccinated. We will consider the algorithm to be a black box for now (we could use the model described in the literature review).

Component-3 consists of two sub-Component 3.1 and 3.2. 3.1 is maintaining the availability of the vaccine and its distribution. 3.2 is the scheduling of vaccinations. The reason these two aren't separate components is because they are highly dependant on one another. The software has no control over the availability of the vaccine and hence considers it as a variable and takes it as the input to prepare a schedule. The software will let you schedule as early as a month or as late as a day before the slot based on the availability of the vaccine. One can't cancel an appointment within 24h of their scheduled slot. Upon receiving their vaccination, they will have to scan a QR code that will update the database on how many shots they have received. Not only does it schedule the residents vaccination slot but also the doctors/nurses that would deliver the vaccine.

Component-4 is the interactive part of the solution. It generates reports that can be viewed by the CHMC administrators, updates the database and re-runs the algorithm to update the order of people. The software will maintain three lists, those that are yet to be vaccinated, those that received the first shot of vaccination and those who are completely vaccinated.

The advantage of dividing them into components is that, a change in component C_i will only affect components C_j such that $j \geq i$. For example a change in C_3, say a person backed out from vaccination. In that case the effect is observed only at C_4 and itself. A change in C_1, say an addition of a resident will affect all the consecutive components.

B. Various roles

We would divide it into five views:

- Resident - he/she will be able to upload medical reports, provide health condition information, and apply for vaccination. She will also be able to view only her profile on the software and some basic statistics such as total number of vaccinated people, etc.
- Healthcare staff - they will be able to set their schedule according to which slots will be chosen by the software. They will be able to view the profiles of all the patients registered to get vaccinated by them during their slot. Higher members can also view all profiles to make sure certain health complications are taken into account. They can also view the basic statistics such as total number of vaccinated people, etc.
- CHMC administrators - they can view the logs of all scheduled and completed vaccinations. They can view the profiles of all residents and healthcare staff. They also have access to all statistics such as inflow rate of vaccines, consumption rate, wastage rate, etc.
- Data providers - they will update the availability of vaccine, public holidays, etc. They have access to most of the inputs that aren't abstracted from the user.
- App developers - there will be a hierarchy but the highest position will have access to everything. They can make changes to the any part of the software.

C. Use Cases

- Resident can login/register
- Residents can update and modify their dashboard
- Residents can pick slots that are available in
- Residents can view their profile
- Residents can upload documents
- Residents can update their calendars
- Residents can sync their calendars
- Residents can view healthcare availability
- Healthcare staff can login/register
- Healthcare staff can update and modify their dashboard
- Healthcare staff can pick slots that are available in
- Healthcare staff can view their profile
- Healthcare staff can sync their calendars
- Healthcare staff can update their calendars
- Healthcare staff can view all resident profiles
- CMHC staff can login/register
- CMHC staff can update and modify their dashboard
- CMHC staff can view all resident profiles
- CMHC staff can view all healthcare staff profiles
- CMHC staff can view statistics of the operation
- Admins can login/register
- Admins can update any working of the system
- Admins can modify any working of the system
- Admins can delete any working of the system
- Admins maintain the system
- Data providers can login/register
- Data providers can update the inventory

D. UML Sequence Diagram

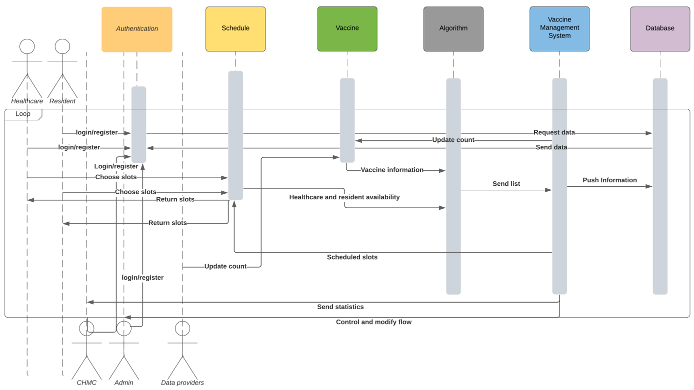

Fig. 3. UML Sequence Diagram.

E. UML Class Diagram

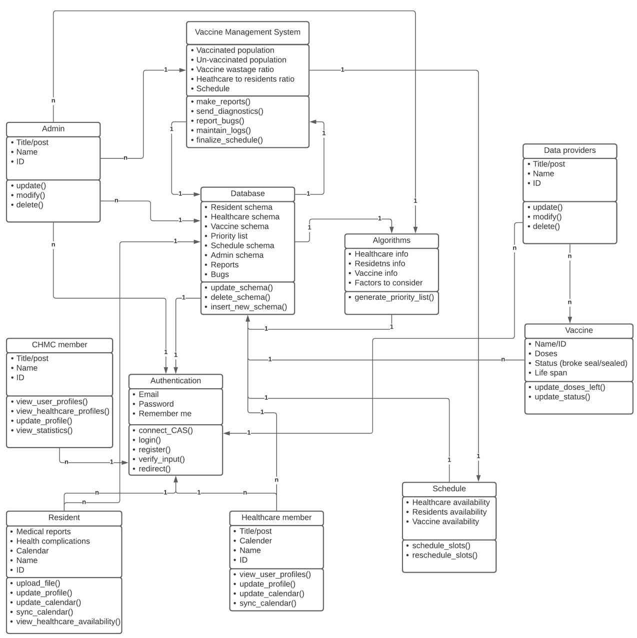

Fig. 4. UML Class Diagram.

Conclusion

The software system should be able to minimize the wastage of the vaccine while delivering to as many residents as possible. In the future we could potentially introduce new algorithms based on the performance of the current one. This model could be scaled up and used to very large organizations by tweaking or adding or removing some of the use cases.

Technology is always evolving and better mathematical models are always coming up. This software system isn't limited to vaccine management and can be applied to other fields such as preservation of wildlife, supply of water/food/resources, etc.

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