A feasibility study proposal of the predictive model to enable the prediction of population susceptibility to COVID-19 by analysis of vaccine utilization for advising deployment of a booster dose

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Abstract

With the present highly infectious dominant SARS-CoV-2 strain of B.1.1.529 or Omicron spreading around the globe, there is concern that the COVID-19 pandemic will not end soon and that it will be a race against time until a more contagious and virulent variant emerges. One of the most promising approaches for preventing virus propagation is to maintain continuous high vaccination efficacy among the population, thereby strengthening the population protective effect and preventing the majority of infection in the vaccinated population, as is known to occur with the Omicron variant frequently. Countries must structure vaccination programs in accordance with their populations’ susceptibility to infection, optimizing vaccination efforts by delivering vaccines progressively enough to protect the majority of the population. We present a feasibility study proposal for maintaining optimal continuous vaccination by assessing the susceptible population, the decline of vaccine efficacy in the population, and advising booster dosage deployment to maintain the population’s protective efficacy through the use of a predictive model. Numerous studies have been conducted in the direction of analyzing vaccine utilization; however, very little study has been conducted to substantiate the optimal deployment of booster dosage vaccination with the help of a predictive model based on machine learning algorithms.

Keywords: predictive model, COVID-19, vaccination

Introduction

Since the outbreak of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causal agent of Coronavirus Disease (COVID-19), the pandemic has wreaked havoc on humans and posed a grave danger to the world’s economic growth. The virus spreads through close contact with an infected person, usually through respiratory droplets produced when an infected person coughs or sneezes. It has spread to more than 200 countries and territories, infecting more than 500 million people and killing more than 6 million people all over the world (Mathieu et al. 2021). However, the COVID-19 pandemic also demonstrated the superior capability of modern medicine, which was able to develop the first experimental vaccine 42 days after the disease emerged (Moderna, Inc. 2020). Tozinamaren (BNT162b2), also known as the Pfizer–BioNTech COVID-19 vaccine sold under the brand name Comirnarty, was the first vaccine to be added to the World Health Organization’s (WHO) Emergency Use List (EUL) on 31 December 2020, just a year after the first outbreak (Polack et al. 2020; World Health Organization 2022).

Numerous vaccinations are now being used worldwide, with some countries currently administering the fourth dose to their populations (Group 2022; Mathieu et al. 2021). Currently, the SARS-CoV-2 variant of B.1.1.529 (Omicron) is responsible for the majority of infections occurring at present. Although less fatal, it is more infectious than the last dominant strain of B.1.617.2 (Delta). Moreover, it can also evade double vaccination and the immune system (Rössler et al. 2021). Omicron, therefore, caused numerous reinfection and outbreak among the fully vaccinated individual. Those who have received a vaccine with less efficacy are more vulnerable to Omicron infection (Andrews et al. 2022).

This raises concern that the COVID-19 pandemic may not be over anytime soon and that it is a race against time until a more resistant variant emerges. In the meanwhile, the most effective strategy to prevent the virus from spreading is to maintain continuous immunization, which increases the protective effect on the individual. This is because the vaccine’s efficacy against the Omicron variant declines fairly quickly (Andrews et al. 2022).

However, keeping up with the number of populations who received the first dose, second dose, third dose, fourth dose, and so on are time extensive considering the nature of the deployment of the vaccine, which focuses mainly on how quickly the vaccine can be deployed as much as possible not how can we track it afterward. In this paper, we propose a predictive model for predicting the susceptible vaccinated population using generalized vaccination distribution data, daily vaccination rate, and vaccine type, in conjunction with a recurrent neural network for predicting the spread of infection in a specific geographic area.

This enables countries to plan their vaccination programs in accordance with their populations’ susceptibility to infection, optimizing vaccination program by not deploying vaccines too rapidly but enough to protect the majority of the population from infection, thereby containing the spread of infection.
Proposal

To ascertain the population’s susceptibility to COVID-19, we must first ascertain vaccination utilization in the region. The vaccination utilization data may comprise the vaccination rate, the proportion of types of vaccines deployed, the ordinal number of vaccine doses administered, and the vaccination population’s age distribution. Additionally, the inclusion of statistics on the unvaccinated and partially vaccinated population will result in an increase in the prediction’s accuracy.

As far as we are aware, the application of ANNs to predict vaccine/pharmaceutical utilization is extremely limited. However, the potential for machine learning to assist us in predicting population susceptibility to COVID-19 and optimizing vaccination programs is indeed intriguing and may benefit us for eradication of COVID-19 pandemic.

The prediction model will let us see how effectively a country’s population is protected against COVID-19 and when a booster dosage is required to maintain adequate protection. Due to the fact that each person got their vaccination doses at a different interval, determining when the population will need the booster dosage is challenging, if not impossible. As illustrated in Figure 1, booster doses above the recommended double doses of immunizations are not distributed equally around the globe, as booster doses are not yet generally recommended in the majority of the world.

The predictive model may be built on machine learning (ML) algorithms such as support vector machines, random forests, and k-nearest neighbors. In addition, the predictive model may also be built on statistical models such as logistic regression, generalized linear models, and generalized additive models.

Hariharan et al. (2020) observed that random forest (Figure 2) was the most effective ML algorithm for predicting vaccine utilization. Additionally, the authors noted that the model outperformed the conventional technique of vaccination utilization tracking. Another study used the artificial neural network (ANN) to forecast pharmaceutical utilization based on geographical location (Fruggiero et al. 2012).

Jamshidi et al. (2020) have proposed numerous strategies for combating the COVID-19 pandemic through employing various machine learning algorithms, including the Recurrent Neural Network (RNN), the Long Short Term Memory (LSTM), the Generative Adversarial Network (GAN), and the Extreme Learning Machine (ELM). These algorithms may be used for a variety of purposes, including infection transmission prediction, medication dosage estimation, visualization of spread, and treatment recommendation.

Davahli et al. (2021) has developed a deterministic and stochastic RNN of LSTM and Mixture Density Network (MDN) for real-time prediction of the virus across United States.

By calculating the mixing coefficient, mean, and standard deviation (SD), the MDNs enables the estimation of the mixed distribution. This way, MDNs estimate probability distributions for potential outcomes rather than producing completely defined outputs like what LSTMs do.
By combining LSTM and MDN, the COVID-19 spread of infection predictive model is developed. We can reliably predict the next outbreak and spread of infection using two sequence-learning models: a deterministic LSTM model that delivers deterministic output and a stochastic LSTM/MDN model. Both the deterministic LSTM model and the stochastic LSTM/MDN model performed well in predicting the infection trend.

This demonstrated that machine learning may be repurposed from predicting infection transmission to predicting optimal vaccine distribution, since both of these characteristics are critical to the success of disease control, where viral transmission is continuously monitored and susceptible populations are protected.

Infact, one possible strategy has been proposed, but it focuses only on vaccination distribution without booster doses and excludes the decline in vaccine efficacy and virus reproduction number. Although not yet implemented, Awasthi et al. (2020) has built a pipeline called VacSIM for optimizing COVID-19 vaccine distribution using Deep Reinforcement Learning models and contextual bandit machine learning framework.
Although the application is primarily for the United States and the PVI does not take into account vaccinated population, it demonstrates that a predictive model based on machine learning and statistical models is capable of tracking vaccine booster doses and recommending an ideal vaccination scheme.

Despite the fact that numerous studies have been conducted in a similar direction of developing a predictive model for predicting vaccine efficacy decline over time and population susceptibility, it would require state-of-the-art data analysis as well as robust machine learning algorithms to carefully analyze vaccination data from the time the first vaccine was administered to the present and in real-time. This would be a difficult task, but one that would be very beneficial to the public health community and the fight against COVID-19.

Implications

The development of a predictive model capable of predicting vaccine efficacy decline in the population and advising on when to initiate a booster dose vaccination program to maintain an adequate level of protection in the community would be required to contain the pandemic for an extended period of time until it subsides. This would need the development of a model capable of predicting vaccine efficacy in the population over time. Additionally, the model must be capable of predicting the effect of vaccination on disease transmission within the population.

If successful, we will have control over the pandemic’s direction and will have an upper hand containing the virus by keeping the population adequately protected against COVID-19.

Data availability

Data sharing not applicable to this report as no datasets were generated or analysed during the current study.

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Conflicts of interest

The author reports no conflict of interest.

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