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Data-Driven Innovative Approaches in Mass Vaccination: A Success Journey

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Abstract

Background:

During the COVID-19 pandemic, an effective delivery of vaccines from healthcare facilities to individuals was presented a multifaceted logistical hurdle. To tackle this issue, the paper explores a data-driven digital solution for vaccination planning. The Emirates Health Services (EHS) has spearheaded the utilization of Artificial Intelligence (AI) in crafting public COVID-19 vaccination strategies with a focus on the targeted population.

Objective:

The primary objective of this project was to develop a data driven solution capable of identifying individuals deemed 'At Risk', thus necessitating prioritization for booster doses to minimize breakthrough infections. EHS aims to leverage advanced AI technologies in a follow-up study to accurately identify high-risk populations in need of vaccination in the Northern Emirates region.

Materials and Methods:

It is a methodological paper focusing on the development of a data driven tool for continuous monitoring, where the EHS Intelligence (PaCE) platform's AI capabilities to construct a robust risk prediction model are discussed for its Vaccine Breakthrough Analysis. A highly interpretable dashboard was developed including the details pertaining to vaccination history, demographic information, and infection rates were integrated into the model to enhance its accuracy.

Results:

This project introduced a data-driven analytical framework that is employed in EHS with the support of sophisticated AI-augmented analytical platform to stratify the population and determine optimal vaccination coverage strategies. The framework supports for our future studies including the development of AI-driven risk prediction model that successfully identified high-risk individuals requiring booster doses after a certain duration post their second vaccine dose. It outlined the timeframe following the second dose wherein breakthrough infection prevalence surged, enabling timely intervention and targeted vaccination campaigns.

Conclusion:

EHS's pioneering initiative in leveraging Analytics-powered solutions for informed decision-making, specifically in vaccination strategy formulation, highlights the need of employing innovative technologies in public health initiatives. By harnessing evidence-based analytical approaches, EHS not only identified vulnerable populations but also optimized resource allocation for enhanced vaccination coverage.

Keywords: COVID-19 vaccination, booster Dose, technology-driven solution, data driven dashboard, United Arab Emirates.

Introduction

The COVID-19 pandemic has posed significant challenges to global healthcare systems for over a year. While efforts to minimize its transmission, widespread vaccination was recognized as crucial for pandemic control. However, efficient and responsible vaccine distribution, especially the last-mile delivery, remains a complex logistical challenge, emphasizing the importance of effective supply management. The debate on COVID-19 vaccine prioritization revolves around balancing direct protection for high-risk individuals and indirect protection through limiting transmission.

The studies show that adults aged 65+ face higher risks of severe outcomes, essential health workers with greater exposure may be at higher risk of infection. Limited data on contact rates across demographics led to a retrospective analysis of vaccination strategies in many countries. One of the investigations used a mathematical model and detailed contact data, and five prioritization strategies were evaluated. A tiered approach prioritizing adults 65+ initially showed the greatest reduction in deaths, while prioritizing high- contact workers initially led to fewer clinical infections. For booster doses,

prioritizing adults 65+ consistently averted the most deaths and potentially clinical cases, contingent on variant epidemiology and vaccine efficacy **[1]**. Some of the healthcare providers embraced the adoption of digital techniques, with one research study involves developing a decision support system (DSS) for COVID-19 vaccination capacity planning in the Netherlands, utilizing the national priority list and allowing users to experiment with strategies. Additionally, a mathematical model is presented to assign inhabitants to medical hubs, implemented in collaboration with the Dutch Municipal and Regional Health Service (GGD GHOR Nederland) **[2]**. Another project conducted by centers on the strategic planning and placement of COVID-19 vaccination sites, introduced a mathematical programming model that was designed to identify the most suitable vaccination sites from a predefined pool **[3]**.

There are multiple studies that introduced a machine-learning model designed to predict the likelihood of survival or fatality for patients either confirmed or suspected to have COVID-19. it demonstrated the effectiveness of algorithms in accurately identifying high-risk patients across four clinical stages, and provide support to healthcare professionals in making informed decisions and prioritizing patient care during the ongoing pandemic **[4]**. Another study addresses the urgent need for equitable access to COVID-19 vaccines worldwide by proposing a sustainable supply chain model. Additionally, a robust data-driven model, based on a polyhedral uncertainty set, is introduced to tackle uncertainties in global vaccine distribution **[5]**. Over the past few months, researchers and medical experts have been actively engaged in efforts to generate fresh insights and develop models/tools to tackle this contagious illness and lessen its impacts. These initiatives encompass a range of endeavors, including the formulation of new drugs and vaccines, the design of epidemiological models to anticipate disease spread, the creation of mobile applications for tracking infected individuals and detecting emerging cases, as well as the implementation of innovative strategies and technologies to effectively manage hospital resources and capacities **[6-13]**.

From a capacity planning standpoint, adopting this comprehensive approach is crucial to prevent inefficient resource allocation and promote fair vaccine distribution. Transparency in the processes and progress of the COVID-19 vaccination program is essential due to its significant social impact **[14]**. In the context of EHS with its 136 facilities, the proposed framework was established for providing sustainable, efficient, innovative, and high-quality healthcare services, treatments, preventive measures implementing strategic policies in-line with national/international standards. EHS initiated the application of AI techniques for COVID-19 management, estimation of epidemic trends, and exploration of safe vaccination drives with continuous stakeholder engagement. Effective and validated Machine Learning Models were developed for sustainable and systemic responses to public health concerns. AI-augmented dashboards were designed in the EHS healthcare system for prediction of COVID related ICU mortality risk factors, which lead to AI application in identification of high-risk populations who need vaccination and prioritization in boosters as a prevention method. The model was beneficial for the public, and healthcare providers such as physicians, administrators and entire staff of EHS facilities for high productivity and their wellbeing.

Objectives

EHS is a public health care system consisting of 17 hospitals and 100+ primary healthcare and public health centers. It primarily focuses on patient engagement and care, providing global leadership in healthcare aligned with the highest standards of excellence and professionalism. It acts responsibly at all levels, demonstrates high respect and regard for the rights and privacy of all stakeholders, takes the necessary measures to ensure optimal performance, and effectively/proactively approaches to achieve the best possible results using innovative ideas. The main focus of the organization is to deliver AI integrated healthcare service delivery that exceeds patient expectations and community happiness **[15]**.

One of the biggest challenges in Public health sector was the prediction of high-risk group for COVID-19 infection and setting vaccination priorities among the diverse population of UAE. It is crucial for any public health system to identify which patients will need immediate care and to balance the workload of the hospital workforce for vaccination administration. A highly interpretable dashboard was developed, incorporating data, statistics, and forecasts, with potential applications of machine learning models that utilize symptoms and various patient characteristics to predict the COVID-19 infection risk in the UAE population. As part of providing high-quality vaccination services to the patients, an extended project was conducted to find the factors leading to COVID-19 infections and predicted the COVID related ICU mortality in EHS **[16-19]**.

As part of it, the main objective of this paper is to outline the strategy adopted by EHS during the COVID-19 pandemic, which involved developing a data-driven dashboard with sustainable AI models to predict health-related indicators, providing clinical solutions to benefit the entire UAE. To demonstrate our commitment to social responsibility, we set the following short-term plans to achieve the main goal of the entire project.

In order to adopt the vaccination strategies and predict high risk population group for COVID-19 infection, an evidence based scientific approach was required, and the diverse nature of the previous studies emphasized that there is no golden standard for prioritizing the groups for vaccination at different stage doses and boosters. Hence the development of a framework using advanced technologies was essential for finding the patient characteristics associated with high-risk group for COVID-19 infection, as a preliminary step. Accordingly, the main project objectives were

formulated as follows.

- To identify an effective strategy for vaccination coverage across the northern emirates
- To establish data-guided analytical strategies by finding the people who would need to be prioritized for boosters to reduce breakthrough infection

Methods

The focus of this methodology paper is on discussing the development of a framework to pinpoint the high-risk population susceptible to COVID-19 infection to ensure efficient vaccination coverage and booster doses during the pandemic. It is important to note that this paper does not aim to produce statistical data on COVID-19 vaccination and the coefficient of factor association with its prioritization for vaccination/boosters. Instead, it seeks to reveal the methodology or framework employed by the Data and Statistics Department (DSD) of a healthcare entity of UAE, developing an insight-driven analytical approaches and how its implementation facilitated timely decision-making within the organization. The research ethics committee (REC) approval (MOHAP/DXB-REC/ MJJ/No. 58/ 2022) and the organization's administrative approval was obtained for its source study.

The framework was developed based on the previous months' retrospective details from the EHS facilities and in collaboration with physicians' experiences. A pilot study was conducted in a single facility as part of a preliminary investigation. As part of implementing sustainable programs to achieve excellence in health service quality and patient outcomes, the organization planned to develop advanced AI-driven machine learning programs that compared deep-learning-based algorithms (decision tree-based, Random Forest, Neural Network, and Gradient Boosting models). These models will assist in the effective prognosis, prevention, and control of COVID-19 in the UAE population. As result, innovative high technology models were developed to achieve excellence in health service quality, patient experience, and effective utility & well-being of the healthcare workforce. The expected outcome includes improved user experience, clinical excellence, and financial outcomes in the EHS facilities.

As a preliminary study, the project used data driven techniques for identifying high risk group and their patterns to prioritize the administration of COVID 19 vaccination. The model consists of multiple variables such as emirates, facilities, sectors, number of doses administered, booster administration, and patient characteristics such as Age, gender, nationality, etc. Using EHS intelligence (PaCE) platform which has AI capabilities, a data-centric and metric based dashboard was designed to provide a District level view of COVID-19 Vaccination data, ultimately helped to provide data transparency and visibility to the health sector, clinical staffs for further mitigation strategies, developments and innovations on technology platform. This led to the development of highly interpretable machine learning models comprising of multiple patient characteristics and national factors for vaccination and it was to predict the high risk population groups for immediate vaccine administration. For generating predictive and prescriptive results, various AI-based multiple machine learning algorithms such as decision tree-based model, Random Forest, and neural network were used. In subsequent research, champion models were identified and the discriminatory power of the models were calculated using the receiver operating characteristic curve and Area under the curve (AUC). The platform is featured with collection of real-time feedback mechanism to capture staff/physician/people experience. In addition, it facilitates feedback collection from local leaders and piloted using the Model for Improvement. As part of this early study, trends on high-risk groups and other related key performance indicators (KPIs) were monitored using the EHS intelligence platform, which is an advanced data analytics SAS-based platform with purpose-built visualizations and dashboards. The project results were shared with all relevant stakeholders by providing access to the platform, ensuring evidence-based practices in EHS facilities.

Follow-up studies are planned to focus on cost efficiency, where EHS excellence will be demonstrated by developing a suitable prediction model to manage healthcare expenses and ensure effective resource utilization across all EHS facilities. As part of the framework, an innovative AI approach was formed to foresee the risk group for vaccination priorities which significantly enhance patient outcome and reduced losses in healthcare facilities. These plans and projects helped the EHS entity to set targets and develop strategies for policy recommendations on vaccination administration and to improve timely access for the general public to healthcare settings. These data guided, analytics-powered solutions empowered the EHS providers to plan the necessary resource planning, and care strategy for improved patient outcomes **[20-21]**.

Stages of Stakeholder Engagement

As a methodology paper aimed at showcasing our achievements in technology implementation for vaccination prioritization, the project was undertaken by DSD team as a population-based retrospective study for identifying and analyzing trends over time, such as changes in disease incidence or treatment outcomes, and determining potential risk groups. The study cohort included the encounters reported in all the EHS facilities and it was classified according to their demographic characteristics and followed up for the incidence and vaccination status. The analysis further expanded to the development of an optimal AI model in subsequent studies and estimation of health indicators such as infection risk rate, mortality risk rate and vaccination rate among different population groups. The data scientists and statisticians of DSD performed estimation and exploratory data analysis on the listed health indicators in terms of diversity in patient

characteristics and healthcare parameters. Missing information was the major problem encountered during the investigation and follow-up, it was effectively addressed using better tracking systems.

The DSD staff, public health staff, clinical doctors and hospital administrators were worked together on the project development and they found "at risk" group for vaccination and boosters according to various health indicators. Multiple meetings were conducted by the statisticians and data scientists of DSD with the stakeholders and shared the updates/outcomes for ensuring evidence-based practices in EHS facilities. Healthcare providers were the major contributors to this project by updating/uploading/verifying patient records through Wareed online platforms. DSD staff voluntarily took the responsibility of setting regular training sections and acted as a monitoring body for the availability of accurate vaccination data for effective decision making.

EHS deals with huge amount of valuable data and therefore this technology-driven solution helped to derive précised results, distribution of vaccination statistics via innovative visualized tool of highly interpretable dashboard and bring timely delivery of health care services to the general public. The trend, patterns, current statistics and predicted rates with visualized facts were made accessible through SAS based EHS intelligence platform which helped end-users for quick actionable decisions. Its impact on EHS facilities was reflected through revised instructional manuals and policies. As an extension of this population based study, there were different AI models processed and implemented for effective health related decisions in the organization.

Results and Outcome

The Emirates Health Services (EHS) was one of the first organizations in the region to apply advanced analytical tools and AI techniques for COVID-19 management, especially for estimation of epidemic trends, and exploration of safe vaccination drives. The project resulted vaccination details by seven emirates of UAE and statistics by first dose, second dose, booster dose, sectors, patient characteristics and other relevant factors. The further studies included development and implementation of effective and validated Machine Learning Models with all relevant features, which significantly contributed to better patient care in the EHS healthcare system with the following best patient outcomes.

Provided summary of demographic characteristics, infection prevalence, vaccination status and other key variables within the studied population

- identified high-risk populations who need vaccination.
- stratified the population for effective vaccination coverage across the northern emirates.
- designed COVID-19 vaccination strategies focusing on the vulnerable population.
- identified people at risk who would need to be prioritized for boosters to reduce breakthrough infection.
- identified the high-risk group who need booster doses after a certain period.
- highlighted that after how many months of the second dose there is an increase in breakthrough infection prevalence.

During the pandemic, dashboard results were distributed to the leaders and healthcare professionals of the organization in regular intervals, which includes vaccination details by patient demographics, first dose/2nd dose and booster dose details by age and elderly. Dashboard presented vaccination facts and booster dose statistics by different emirates of UAE and each facility of EHS, for effective decision making on vaccination delivery. The results were shared with healthcare providers including physicians and administrative staff of EHS facilities via AI driven dashboard available in the EHS intelligence (PaCE) platform.

The platform facilitates knowledge sharing among EHS stakeholders and easy decision- making for the leadership team. EHS intelligence platform was developed as one of the solutions to work as a central location for end-users to access/interact/analyze/share up-to-date healthcare information for better patient outcomes. The estimation of high risk in identified groups enlightened the healthcare providers to follow the best precautionary practices for supplementing COVID-19 care and provision of vaccination with booster doses. Ultimately, the results disseminated have great potential for high-quality patient care. The applied framework assisted in effective prognosis, prevention, and control of COVID-19 in the UAE population.

Discussion

Evidence based approaches have been widely utilized in the context of COVID-19 to estimate and predict various outcomes, including the identification of high-risk patients who are more likely to require hospitalization or experience severe complications leading to mortality. But there has been comparatively less emphasis on using advanced analytical solutions, dashboard features and machine learning techniques for prioritizing vaccination efforts. Prioritization of vaccination involves determining which population groups should receive COVID-19 vaccines first, based on factors such as age, occupation, underlying health conditions, and vulnerability to infection.

A systematic review reported in 2023 based on 39 studies reveals AI-based prediction of COVID-19 hospitalization and death between 2019 and 2022. These studies predominantly utilized Random Forest as the best-performing model. The AI models were trained on cohorts from different countries, data collection encompassed demographic information, clinical records, laboratory results, and pharmacological treatments, forming high-dimensional datasets. Internal validation via cross-validation was common, but external validation and calibration were often lacking. however models still demonstrated moderately

good performance, with AUC values exceeding 0.7. Despite this, all models exhibited a high risk of bias and concern regarding applicability **[22]**.

The University of Cincinnati has unveiled a potent new AI tool capable of forecasting an individual's likelihood to receive the COVID-19 vaccine. The system combines human judgment with math and machine learning to guess if someone might be hesitant about getting the vaccine. This predictive system utilizes a limited dataset encompassing demographics and personal beliefs, including risk aversion and loss aversion. These findings introduce a promising technology with potential applications beyond vaccine acceptance, extending to mental health prediction and facilitating more targeted public health initiatives **[23]**.

Another review of AI-based approaches in COVID-19 vaccination explores how AI is transforming the development of COVID-19 vaccines. It is used to analyze small compounds and peptides, guiding the creation of new therapeutics and vaccine candidates. Machine learning techniques leverage existing data to detect COVID-19 drugs and improve vaccine development. These models identify the most promising vaccine targets and address safety, efficacy, manufacturing, and logistics challenges. AI assists in selecting effective vaccine candidates that trigger immune responses. It highlights recent advancements and prospects for AI-driven COVID-19 treatment discovery, focusing on barriers, solutions, and intelligent training methods **[24]**.

Given the limited global vaccine supply and the need to efficiently distribute vaccines to those who need them most urgently, the application of High-level analytical frameworks, Progressive data analysis strategies and development of AI models for vaccination prioritization is of paramount importance. In line with this, our paper aims to advocate for technological advancement in this domain. These models could help public health authorities and policymakers allocate limited vaccine doses effectively, ensuring that those at highest risk of severe disease or transmission receive priority access to vaccination.

Project Impact

The major difficulty for the healthcare providers was to identify the population groups who are more prone to COVID-19 infection for immediate vaccine administration and the group that required boosters. The pandemic response required a strategy that would not only include clinical support but encapsulate an inter-system mechanism for effective management of COVID-related data. To achieve the project objective, both traditional techniques as well as advanced analytical solutions, were used for clinical decision making in relation to vaccination and boosters. Accordingly, vaccination strategies were designed and stratification was done of the vulnerable population. The project also highlighted how many months after the second dose breakthrough infections increased. In its further studies, a highly accurate optimal AI model resulted in the best patient outcomes in the country during the pandemic. Over the time, the suitable revision of the model lead to identification of the patients at high infection risk of COVID-19 and determine the incidence of COVID related ICU mortality.

The Project led to policy recommendations and improved individualized departmental strategies in EHS facilities. The findings supported in quantifying the demand for resources, vaccination services and for risk stratification to identify population cohort at higher risks. This technology-driven solution helped to update the statistics and brought timely delivery of health care services with revision of COVID instructional manuals and health related policies. As a result, precautionary measures and preventive steps were introduced in all the EHS facilities in the UAE. EHS established as a successful healthcare leader in the region through the designed data driven and AI supported programs/projects by devising smart and advanced AI analytical tools that resulted in effective decision making in clinical settings and best clinical solutions.

Conclusion

The findings from this project emphasize the pivotal role of innovative analytics methodologies and data driven frameworks in refining public health interventions and fortifying defenses against infectious diseases like COVID-19. This paper highlights the success story of a healthcare organization in development and implementation of an advanced cutting-edge analytics framework for efficiently identifying and prioritizing high-risk populations for COVID-19 vaccination in the UAE. By leveraging deep-learning algorithms in subsequent studies, the framework enhanced decision-making processes within EHS facilities, leading to improved patient outcomes, resource utilization, and cost efficiency. The successful integration of technology into vaccination prioritization strategies demonstrates its potential to revolutionize public health initiatives and contribute to the effective management of pandemics.

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