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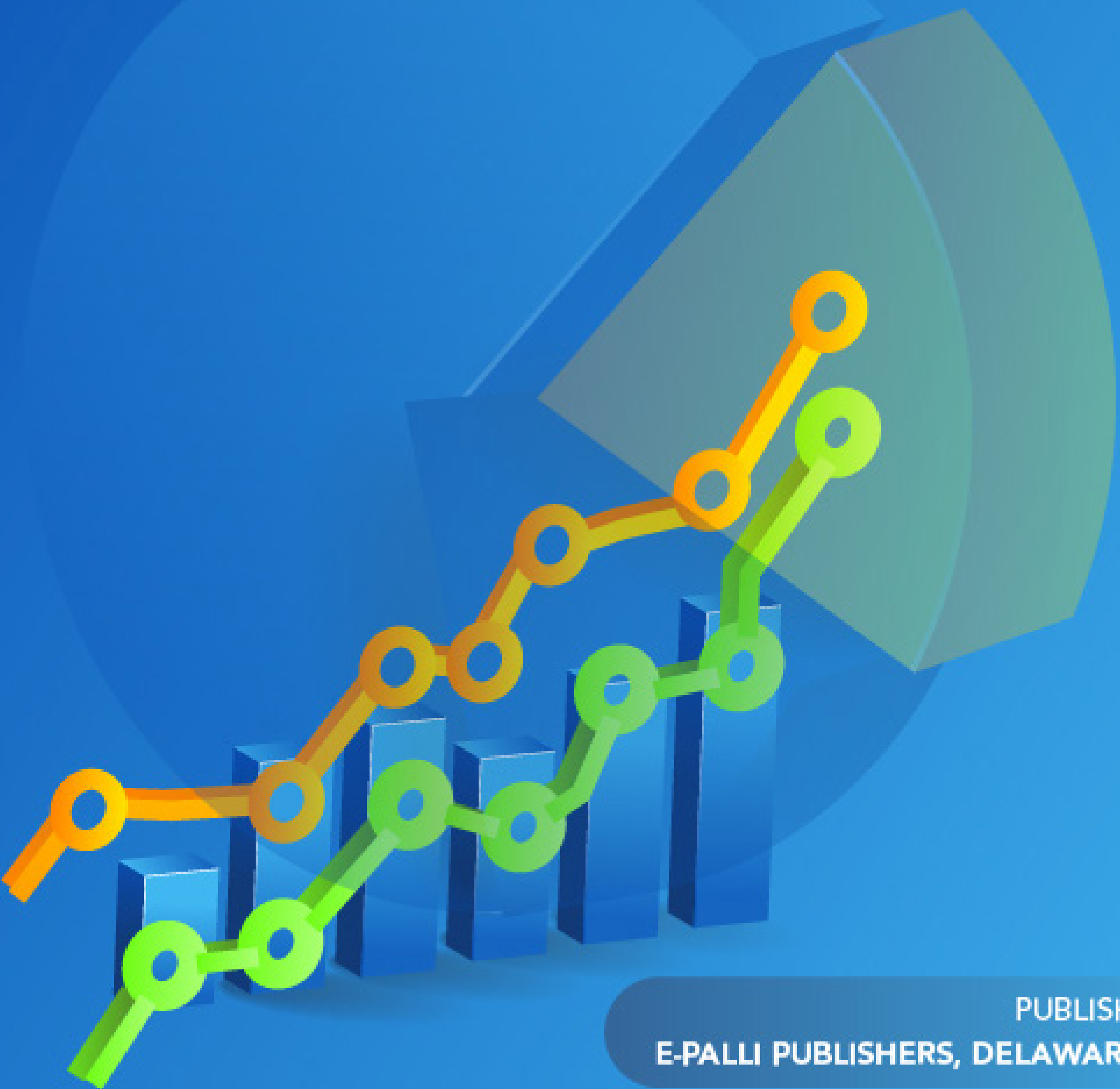

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Comparative Analysis Of Predictive Performance Of Holt-Winters And Facebook Prophet On Kenyan Covid-19 Data

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ABSTRACT

Comparative time-series forecasting is essential for identifying and predicting the trajectories of infections such as COVID-19. This study offers a thorough comparison of two time series forecasting methodologies: The Holt-Winters (HW) exponential smoothing technique and Meta's (Facebook's) Prophet model, as applied to COVID-19 case data. We assessed each model's capacity to capture trend dynamics, seasonal variations, and sudden structural shifts linked to pandemic waves and policy measures, using publicly accessible epidemiological time-series data. The Holt-Winters model, which focuses on level, trend, and seasonality components, offers a clear foundation for short-term forecasting but has shortcomings when faced with irregular shocks and non-linear patterns. Conversely, Prophet's decomposable additive structure, which includes automatic changepoint detection and variable seasonality, exhibits superior flexibility to sudden changes in the transmission patterns. Forecast accuracy was evaluated using conventional error metrics (Root Mean Square Error; RMSE, Mean Absolute Error; MAE, R-Squared; R2), indicating that Holt-Winters (HW) typically surpassed Facebook Prophet in both daily and cumulative confirmed cases of COVID-19. The comparative analysis emphasizes the significance of model selection according to the epidemic environment and illustrates the advantages of conventional time-series techniques for reliable public health forecasting. This study provides methodological insights for academics and decision-makers in pursuit of efficient methods for monitoring and forecasting the dynamics of infectious diseases.

INTRODUCTION

Time-series forecasting is emerging as a significant component in the study of epidemiological data, particularly in anticipating the COVID-19 pandemic, which aids in understanding the past and present while projecting future patterns based on historical data (Tomov *et al.*, 2023). Epidemiological data are complex and volatile, necessitating the use of multiple forecasting models to mitigate individual shortcomings and generate more accurate forecasts based on the data characteristics (Yin *et al.*, 2024). Holt-Winters (HW) Exponential Smoothing (ETS) and Facebook Prophet (Prophet) are straightforward and easy to understand, making them accessible to policymakers. They have been frequently utilized owing to their simplicity (Rizvi, 2024; Fatima & Rahimi, 2024). Similarly, the models require data to be stable, which is not always the case in real-world datasets (Yadav & Goswami, 2024). However, they frequently struggle with nonlinear patterns and complicated data trends, thereby reducing their predictive performance in dynamic settings (Tulli, 2020). With the introduction of machine learning, particularly the Facebook Prophet model, the approach to epidemiological forecasting has undergone a significant revolution. The model utilizes sophisticated algorithms to boost prediction accuracy, and its ability to account for seasonality enables it to anticipate distinct waves of outbreaks with greater precision (Babu *et al.* 2022). This underscores the necessity of ongoing studies and improvements in the epidemiological field, as well as the need for continuous model updates to respond to emerging disease trends and data characteristics. This study evaluated the predictive performance of various models and their effectiveness in capturing subtle temporal correlations in the COVID-19 time-series data.

This study compares time series modeling methods, Holt-Winters (HW) and Facebook Prophet, using Kenyan COVID-19 data, especially for daily confirmed and cumulative cases. To address the daily incident and cumulative case counts with distinct dynamics, a comparison was conducted using standard preprocessing and validation procedures. With the current minimal research comparing the said methods and using Kenya's data with its unique dynamics, determining the most suitable and resilient method for real-time forecasting remains uncertain.

By methodically assessing the effectiveness of Holt-Winters exponential smoothing (ETS) and Facebook Prophet models using Kenyan COVID-19 data, this study applied each technique to the daily and cumulative confirmed cases between March 2020 and December 2023. In the following section, we review the related literature.

Literature Review

The literature on time-series forecasting in epidemiology is extensive, with numerous studies exploring various methodologies and their applications. Traditional approaches, such as Holt-Winters (HW), have been the

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cornerstone of statistical forecasting because of their ability to model linear relationships and seasonality in data. It was designed by Chatfield and Yar (Chatfield & Yar, 1988). The Holt-Winters (HW) technique is a conventional exponential smoothing approach to forecasting that was proposed by Winters in 1960. This model is valued for its ability to handle seasonality and trends in time-series data, making it suitable for predicting epidemic dynamics. Recent studies have demonstrated its application in various regions, showcasing its accuracy and utility in public health domain. For instance, Elmunim (2024) and Andayani (2023) demonstrated the effectiveness of Holt-Winters (HW) in predicting COVID-19 infection trends, providing valuable insights for healthcare policy and proper resource allocation (Swapnarekha *et al.*, 2021). While the Holt-Winters (HW) model has proven effective in various contexts, it is important to consider its limitations, such as the assumption of constant seasonality and trends, which may not always hold in rapidly changing epidemic scenarios. Additionally, comparing this model with other statistical and machine learning approaches could enhance the predictive power and adaptability to real-time data fluctuations (Hussien *et al.*, 2025). Holt-Winters Exponential Smoothing can be significantly affected by outliers caused by epidemic outbreaks, leading to inaccurate forecasts (Ersöz *et al.*, 2022). The Holt-Winters (HW) model is static, which may not adapt well to sudden changes in epidemic trends (Xian *et al.*, 2023). Inflexibility with Complex Patterns, the model struggles with diseases that have irregular incidence patterns because it assumes a consistent seasonal effect (Ramanathan *et al.*, 2020). The model's reliance on historical data can lead to inaccuracies in parameter estimation, particularly in the early stages of an outbreak (Melikechi, 2022). Its limitations in epidemiological contexts highlight the need comparative analysis with more sophisticated models that can accommodate the complexities of disease transmission and seasonal variation.

Recent advancements in time-series machine learning techniques have prompted researchers to compare multiple models to enhance forecasting accuracy. The Facebook Prophet model offers several advantages over traditional models in epidemiological forecasting. This technique was developed by Meta (Facebook) (Taylor & Letham, 2018). The Facebook Prophet model has been increasingly utilized to forecast epidemic trends, particularly in the context of the COVID-19 pandemic (Babu *et al.*, 2022; Mphale *et al.*, 2022). Its application is driven by its ability to handle time-series data with seasonality and its robustness in making predictions over different time frames. The model's utility in epidemiology is underscored by its performance in predicting infection rates, mortality, and other critical metrics essential for public health planning and response. The models are accessible to users without extensive programming knowledge, facilitating their broader adoption in epidemiology (Triebe *et al.*, 2021). These factors highlight the importance of using the Facebook Prophet in conjunction with other models and data sources to ensure comprehensive and reliable epidemic forecasting. This trend highlights the importance of not only evaluating individual models but also exploring recent approaches that leverage the strengths of multiple methodologies.

In summary, the literature on time-series forecasting in epidemiology underscores the evolution of modeling techniques from traditional statistical methods to advanced time-series machine learning algorithms. This study builds on the existing body of knowledge by providing a comparative analysis of Holt-Winters (HW) Exponential Smoothing and Facebook Prophet, contributing valuable insights into their effectiveness in predicting epidemiology data.

MATERIALS AND METHODS

Data Collection

We employed two time-series models to compare their predictive performance on Kenyan COVID-19 data. The secondary time-series data sourced from the Our World in Data repository covered the period from March 15, 2020, to December 31, 2023. Of the 1387 data points collected, 80% were designated for training purposes, and the remaining 20% were set aside for testing. The models assessed for their performance included Holt-Winters (HW) Exponential Smoothing, and Facebook Prophet, which were both evaluated using R software. The figure below summarizes the methodology.

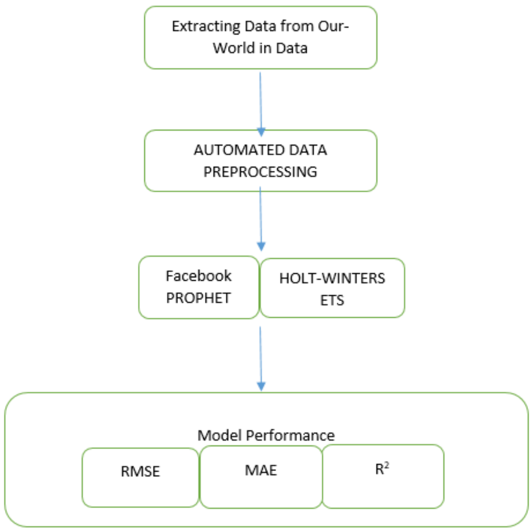

Figure 1: Flowchart of the Proposed Methodology

Date preprocessing

No missing entries were present in the datasets. For time series models, it is important to have data that are constant over time to ensure effective time series forecasting (ArunKumar *et al.*, 2022). To solve this, we deployed automated approaches in R version 4.5.1, leveraging packages such as the modeltime, prophet, tidyverse, and timetk. We also applied automated functions, such as prophet_reg(), auto.arima(), and exp_smoothing(). These functions automatically calculate the required amount of differencing, thus reducing the need for manual trial and error. This arrangement ensured that the data preprocessing and analysis were both rapid and reproducible.

Model selection

The reliability of the time-series regression models was assessed using three standard evaluation indicators: mean absolute error (MAE), root mean squared error (RMSE), and coefficient of determination (R2). Accurate forecasting is essential for determining the feasibility of alternate model combinations. The following assessment criteria have been used to evaluate these models' prediction performance.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \hat{x}_i)^2} \quad (1)$$

$$MAE = \frac{1}{n}\sum\frac{|x_i - \hat{x}_i|}{x_i} \quad (2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (3)$$

From the equations (1, 2, and 3), n represents the data points (i.e. quantity of observations). In this case, the response variable's actual and anticipated values are denoted by x_i and $\hat{x}_i$, respectively. A better model fit is shown by lower RMSE and MAE values and higher R^2.

Holt-Winters Exponential Smoothing (ETS)

Holt-Winters (HW) is a univariate time-series modeling method that closely examines the previous values of a time-series and assigns weights to them based on the lag. The combination of the initial values and the corresponding weights is then applied to predict future values. Exponential smoothing comes in three primary forms, each of which focuses on certain combinations of Level, Trend, and Seasonality. Holt-Winters Exponential Smoothing uses all three components in its computational process. The basic structure of HW model is shown by equation (4):

$$\hat{X}_{t+h|t(k)} = (L_{t-1} + hb_t)s_{t+m-m(k+1)} \quad (4)$$

where, m represents the total quantity of cycles; for instance, m = 4 for every quarter of data and m = 12 for the data collected every month.

Facebook prophet model

Meta (Facebook) created the Facebook Prophet model, a forecasting technique (Taylor & Letham, 2018). This technique incorporates parameters for holidays, trends, and seasonality, which will help to shape the prediction results and to provide a better performance with time-series data with seasonal effects. Equation (5) combines these elements:

$$x_t = T_t + s_t + H_t + \varepsilon_t \quad (5)$$

The resultant value, represents, non-periodic growth variations or trend, seasonal shifts, holiday impacts, and an error term are represented by x_t, T_t, s_t, H_t and ε_t respectively.

RESULTS AND DISCUSSION

The goal of the present study is to assess the predictive ability of the Holt-Winters (HW) and Facebook Prophet techniques using the COVID-19 dataset. The dataset from Our World in Data was used for this purpose. In the dataset, there is one entry for each day starting from March 15, 2020. Data were split into training and test sets to determine the effectiveness of Holt-Winters (HW) and Facebook Prophet. Eighty percent of the data were utilized for model training, and the remaining twenty percent were set aside as the test set. This method mimics real-world situations in which future predictions are made using historical data.

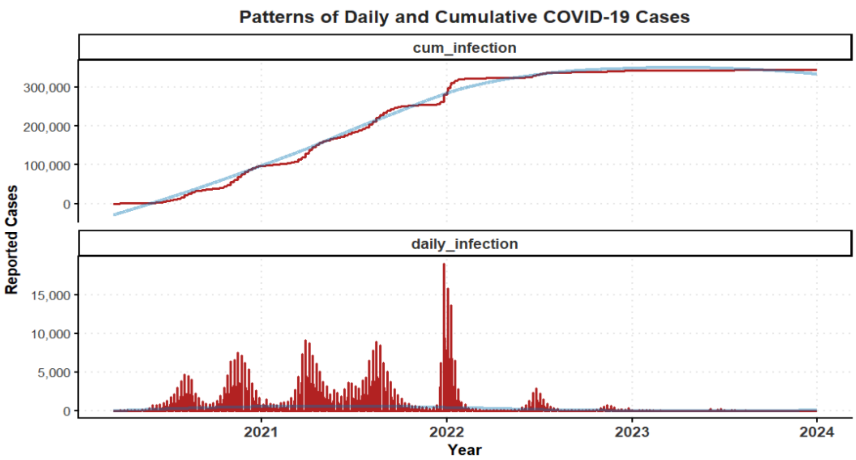

Figure 2: Trend of Daily and Cumulative Cases

Three standard error metrics, namely RMSE, MAE, and R-squared (R^2), were used to determine the effectiveness of the forecasting models. Without considering the direction of the error, the Mean Absolute Error (MAE) calculates the average size of the errors in a group of predictions. Significant errors are given more weight by the

Root Mean Squared Error (RMSE), which also penalizes models that generate significant variances. R-squared is a measure that indicates the extent to which the variation of a dependent variable is explained by an independent variable in a regression model. The R-squared values ranged from 0 to 1. These metrics provide a thorough understanding of the model performance in terms of relative accuracy and scale sensitivity.

Since our prime motive was to compare the efficacy of popular time series machine learning forecasting models in their prediction ability during the waves of COVID-19 cases, predictions of daily and cumulative cases, were analyzed and tabulated in Table 1,2 and plotted in Figure 2.

Kenya's total number of confirmed cases increased between 2020 and 2022 before stabilizing between 2022 and 2023 (Figure. 2). Seven waves of daily new cases were most visible in the study of daily confirmed cases. The latter two peaks exhibited a declining tendency, whereas the first five peaks increased (Figure. 2). Furthermore, the cumulative cases with a positive growth rate, which include erratic shifts that rise or decrease and may occur periodically, vary from the daily confirmed incidents. To determine which model can suit this data with the present pattern and features, we will particularly analyze the prediction ability of Holt-Winters Exponential Smoothing (ETS) and Facebook prophet. The models' performance for both cumulative and daily confirmed COVID-19 cases in Kenya is clearly shown in the tables below.

The assessment findings of the two forecasting techniques on the test dataset are summarized below. The Holt-Winters model produced the lowest RMSE and MAE and the highest R-squared, indicating better accuracy and robustness in identifying the true structure of the current data. Tables 1 and 2 below show the values of the error metrics taken into consideration for this forecasting models Notably, in the predictive performance of both daily and cumulative case data, the Holt-Winters Exponential Smoothing, ETS(A, AD, A) model showed a better fit with a larger R-squared (0.16, 0.83) and lower MAE (4, 587) and RMSE (23.48, 680) (see Table 1). The Facebook Prophet model, on the other hand, underperforms by a wide margin, as seen by its substantially lower R-squared (0.03, 0.74) and greater MAE (38, 7658) and RMSE (82, 9599). This notable difference highlights the better fit and ability of the Holt-Winters (HW) model to capture the true patterns of daily and cumulative COVID-19 cases in Kenya, as well as its remarkable capacity to explain the variation within the training dataset.

Table 1: Comparative Predictive Performance of Holt-Winters and Facebook Prophet on Daily Cases Data

ID	Description	MAE	RMSE	R^2
1	ETS(A,AD,A)	4.00	23.48	0.16
2	PROPHET	38.10	82.80	0.03

Table 2: Comparative Predictive Performance of Holt-Winters and Facebook Prophet on Cumulative Data

ID	Description	MAE	RMSE	R^2
1	ETS(A,A,A)	587.67	680.38	0.83
2	PROPHET	7658.34	9599.89	0.74

In the present COVID-19 data, it is evident that the traditional time series model (Holt-Winters) is the most effective. The greater error metrics of the Facebook Prophet show that it is inappropriate for this forecasting situation. The lack of sufficient historical data may be the reason for the increased error metric values for the Facebook Prophet. Therefore, given the scarcity of historical datasets, it has been determined that the standard time series model has the ability to properly estimate COVID-19, hence its application may be useful in containing this pandemic spread in similar settings.

Discussion

The World Health Organization (WHO) declared COVID-19 a global crisis because it had spread to most nations and posed an existential threat to humanity. The scientific community is becoming more interested in determining the optimal predictive model for this pandemic, and more significantly, for each individual nation, so that governments can create efficient policies to stop the global transmission of this pandemic. Therefore, it is essential to establish one or more context-specific models that will provide accurate forecasting results to assist governments in allocating resources efficiently. This study examined the COVID-19 pandemic in Kenya from March 2020 to December 2023 and compared the prediction capabilities of the Holt-Winters Exponential Smoothing and Facebook Prophet models. Holt-Winters Exponential Smoothing was found to be the best model for predicting daily and cumulative infections, with the least RMSE (23.48, 680.38) and MAE (4.00, 587.67), when compared with Facebook Prophet RMSE (82.80,9599.89) and MAE (38.10, 7658.34) (Tables 1 and 2).

By analyzing Kenya's COVID-19 data, the findings validate the valuable contributions and introduce new viewpoints on the application of diverse time series forecasting methods. Interestingly, despite the increasing reliance on machine learning in current research, traditional techniques such as Holt-Winters (HW) have shown superior performance over advanced algorithms such as the Facebook Prophet in forecasting COVID-19 data in Kenya. These observations are in line with those of Pfeifer *et al.* (2024), who emphasized that the dataset characteristic can significantly impact the effectiveness of a model. A closer inspection revealed that conventional models outperformed the others in the current study, indicating that the mathematical simplicity of the statistical models can be beneficial. The straightforwardness of the Holt-Winters methods helps avoid overfitting, a challenge sometimes faced by advanced machine-learning models in resource-constrained environments such as Kenya, where data may be inconsistent. This perspective is supported by Abbasimehr *et al.* (2020), who expressed concerns about employing more advanced models without a thorough contextual analysis. This study highlights that the most effective model is not necessarily the most intricate, contributing to the ongoing discourse on the importance of model selection in empirical studies. By integrating these insights into the COVID-19 datasets examined in this study, we emphasize the need for data-driven, sophisticated approaches to infectious disease forecasting. This recommendation specifically addresses the calls for diverse methodologies made by Majhi *et al.* (2023) and others who advocate hybrid modeling techniques.

Facebook Prophet's dependence on changepoint detection to predict shifts in patterns may be one of the reasons for its inadequate results. Rigorous pattern identification using Facebook Prophet was less successful because the patterns in the Kenyan COVID-19 dataset employed here were somewhat stable with moderate shifts. Additionally, Facebook Prophet lacks the autoregressive processes seen in traditional techniques and instead relies on additive decompositions, and this probably limits its capacity to accurately predict short-term temporal relationships.

CONCLUSION

This study offers a thorough comparison of the predictive ability of time-series forecasting algorithms utilizing COVID-19 data, with a particular emphasis on Facebook Prophet and Holt-Winters Exponential Smoothing. The results show that although Facebook Prophet has its advantages, it is not good at identifying patterns in the current COVID-19 data. Conversely, conventional time series models, particularly Holt-Winters Exponential Smoothing, show better prediction ability, which makes the technique ideal for the complexities of COVID-19 prediction. The government and associated departments can use the Holt-Winters (HW) model to forecast COVID-19 daily and cumulative confirmed cases rather than the Facebook Prophet model in this context. A comprehensive study on cumulative COVID-19 cases can help determine the severity of the situation. This will help policymakers take preventive measures and actions, such as fulfilling the oxygen and vaccination demand and arranging beds and medical personnel to control the COVID-19 situation. This research will also help policymakers to keep track of how different decisions, such as vaccination, lockdown, and, quarantine is helpful in reducing the death count. This can be done by monitoring the difference between predicted and actual deaths after the implementation of policies.

Nonetheless, it is important to acknowledge the limitations of this study. Additional studies are required to confirm these results in different contexts, as the efficacy of the models may vary across datasets and epidemiological circumstances. Furthermore, environments with scarce resources may face difficulties owing to the computing requirements of advanced machine learning models. Future studies should investigate hybrid strategies that combine the advantages of machine learning with conventional techniques, perhaps producing even more reliable predictive solutions. Scholars are encouraged to develop novel methodologies and algorithms that may increase prediction accuracy and efficacy. Forecasting models must be regularly updated to handle the complexities of healthcare and epidemiological environments as the pandemic evolves. This study adds to the existing body of knowledge by offering insightful comparisons of the prediction performance of the Holt-Winters Exponential Smoothing and Facebook Prophet models in COVID-19 time-series forecasting. By highlighting the strengths and weaknesses of each technique, this study aims to inform future research and assist practitioners in selecting the most appropriate and context-specific forecasting models for their needs.

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