IMM

Journal of New Frontiers in Healthcare and Biological Sciences

ISSN 2719-2385 (Online)

Volume 2, Issue 2, 2021, 1-15

Home page: www.imathm.edu.lk/publications

Modeling Wave-Like Patterns of Daily Infected Cases of COVID -19 in the UK

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ABSTRACT

The World Health Organization (WHO) declared COVID-19 to be a pandemic when it became clear that the illness was severe and that it was spreading very fast over a wide area. As a result, there were more than 252 million infected cases and 5million death total reported globally after one year. The United Kingdom (UK) is the highly affected European country during the end of the year 2021. Hence, the study is designed to model daily infected cases in the UK. The daily infected cases of the UK for the period of 22nd January 2020 to 17th October 2021 were obtained from the Humanitarian Data Exchange (HDX).The behavior of the daily infected cases is recognized by time series plots and Auto Correlation Function (ACF). The Sama Circular Model (SCM) and Seasonal Auto-Regressive Integrated Moving Average (SARIMA) were tested to forecast the daily infected cases. ACF, Anderson Darling test, and Ljung-Box Q (LBQ)-test were used to validate the model. The performance of the model was assessed by the relative and absolute measurements of errors. The results of the study revealed that the SCM is outperformed SARIMA. The SCM has captured 4 repeating behaviors whereas SARIMA has captured only 1 behavior. Measurements of errors were very low in SCM compared with SARIMA in forecasting. Four repeating behaviors of daily cases in the UK are identified. It is recommended to find the underlying factors for such behaviors. Also, it is worth conducting similar studies for other countries as well.

Keywords: COVID -19, SCM, SARIMA, Daily Cases

1. INTRODUCTION

1.1 Background of the Study

The COVID-19 is the worst pandemic in 21st Century. World Health Organization (WHO) reports there were more than 252 million cases and 5million death total reported globally after one year. COVID-19 means Corona (CO), Virus (VI), Disease (D), and year 2019 (19) (Sugiyanto & Muchammad, 2020). United Kingdom (UK) is the highly affected European country at the end of the year 2021 from COVID-19. The first infected case was reported from the UK on 31st January 2020. At the present UK had exceeded more than 9.4 million infected cases and more than 7.7 million of them recovered. The death total exceeds 142,533 within two years. The rate of daily infected cases in the UK was 13% approximately. The rate of recovery was 81% approximately. The behavior of daily infected cases shows an increasing trend and it is not a favorable situation for the economic and social stability of the country.

1.2 Research Problem

The rate of daily infected cases in the UK is high and it shows an increasing trend. The daily infected cases in the UK show a wave-like pattern and increasing trend. Konarasinghe, (2021-a): (2021-b): (2021-c): (2021-d): found that there were many seasonal or repeating behaviors within the daily infected cases in the Philippines, Italy, Iran, and Argentina. There could be similar behaviors within the daily infected cases in the UK. If so, it could be a symptom to find out the reasons for the increasing trend of the daily infected cases. Identifying such behaviors of the daily cases would be a guide to minimize or control the outbreak. Hence, modeling daily infected cases and finding out the behavior of the outbreak would be more important to the future of the UK.

1.3 Objective of the Study

The objective of the study is to forecast daily infected cases of COVID-19 in the UK.

1.4 Significance of the Study

The results of this study can be applied to develop effective strategies to control the outbreak in the UK. It is another guide to work out the logistic requirements of health services with minimum waste (Konarasinghe, (2021-a). The results of the study can be applied to schedule lockdowns, lockups, delivery systems, virtual activities, etc (Konarasinghe, (2021-a). It would be another guide for new business portfolios mainly, E-Commerce, virtual business, domestic business, etc, (Konarasinghe, (2021-d). The authorities should guide and assist business communities with such business developments (Konarasinghe, (2021-d). The present business processes should be re-engineered by observing the future behavior of the pandemic to minimize both systematic and unsystematic risk in business (Konarasinghe, (2021-d).

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2. LITERATURE REVIEW

The review of the study was focused on modeling the outbreak of COVID-19 in the UK, yet there were not much studies found in the review.

2.1 Studies Based on Modeling COVID-19 Outbreak in UK

Mishra, et al (2020) have applied Bayesian models to predict daily infected cases of COVID -19. Congdon, (2021) has applied Richards bivariate model to forecast infected cases. Campillo, et al (2021) have applied the Susceptible–Exposed –Infectious–Recovered-Dead (SEIR–D) model to forecast the outbreak. Keeling, et al (2021) have applied SEIR model to predict the epidemic spread in ten regions of the UK. The same SEIR model has been applied by Keeling, et al (2020) to predict the spread in the first wave. Danon, et al (2020) have applied SEIR to predict the spread. The different approaches based on confidence intervals have been applied by Jamshidi, et al (2020) to predict infected cases and death of the pandemic. Konarasinghe,(2020-a) has applied Double Exponential Smoothing (DES) to forecast the daily infected cases during the early stage of the pandemic. A Bayesian SEIR model has been applied to forecast the spread of the outbreak by Liu (2020).

The SEIR was the most commonly applied model to predict the outbreak of the pandemic in the UK. Besides, Richards's bivariate model, DES, Bayesian models, and confidence intervals were other approaches applied for the aim. The applications of stochastic models were very limited. Therefore, the ability to capture uncertainty is very limited. COVID -19 pandemic almost completing the second year. The repeating behavior of the daily infected cases should be monitored at this stage, but, the least attention has been paid on it. Besides, the verification process has not been explained in many published articles. Some studies have paid the least attention to measuring the forecasting ability of the models.

3. METHODOLOGY

The daily cases of COVID-19 in the UK for the period of 22nd January 2020 to 17th October 2021 were obtained from the Humanitarian Data Exchange (HDX). The pattern of the daily infected cases paves the path for the model selection to predict daily cases in the UK (Konarasinghe, 2016-a; 2016-b; 2021-a; 2021-b; 2021-c; 2021-d) and (Konarasinghe, W.G.S., & Abeynayake, 2014). There could be trends, seasonal, cyclical, heavy, and minor volatility within the period of the data set (Konarasinghe, W.G.S. & Abeynayake, 2014). The time series plot and Auto Correlation Function (ACF) were used to recognize the patterns, as done by Konarasinghe, W.G.S., & Abeynayake (2014). As per the pattern of the data series, Sama Circular Model (SCM), and Seasonal Auto-Regressive Integrated Moving Average (SARIMA) models were selected to model the daily infected cases in the UK. The model assumptions were tested by the Anderson Darling test, ACF, and Ljung-Box Q (LBQ) test (Konarasinghe, W.G.S., et al, 2015). The forecasting ability of the model asses by three measurements of errors, as per

ISSN 2719-2385 (Online)

Konarasinghe, (2018; 2016-c; 2015-a; 2015-b).They are; Mean Absolute Percentage Error (MAPE), Mean Square Error (MSE), and Mean Absolute Deviation (MAD) Konarasinghe, (2018; 2016-c; 2015-a; 2015-b). Log transformed data were used for the data analysis of the study.

3.1 Circular Model and Sama Circular Model

The development of the CM was based on; Fourier Transformation, the theory of Uniform Circular motion and Multiple Regression Analysis (Konarasinghe, W.G.S., 2016). The SCM is the improved version of the CM (Konarasinghe, W.G.S., 2020-a; 2018-b)

3.1.1 Circular Model (CM)

As explained in Konarasinghe, W.G.S.(2016), if a time series follows a wave with *f* peaks in *N* observations, then the series could be modelled by the Circular Model (1);

$$Y_t = \sum_{k=1}^{n}(a_k \sin k\omega t + b_k \cos k\omega t) + \varepsilon_t \tag{1}$$

$$\omega = 2\pi \frac{f}{N};\ a_k \text{ and } b_k \text{ are constants}$$

Model assumptions of the CM are;

Y_t is trend-free, k is a positive real number, $\sin k\omega t$ and $\cos k\omega t$ are independent; residuals are normally distributed and independent.

3.1.2 Sama Circular Model (SCM)

A limitation of the CM is that it is not applicable for a series with a trend. Konarasinghe, W.G.S. (2020-a; 2018-a; 2018-b) suggests the method of differencing to mitigate the limitation of the CM. In usual notation, differencing series of Y_t are as follows;

First differenced series: $Y_t^{'} = Y_t - Y_{t-1} = (1-B)Y_t$ (2)

Second differenced series:

$$Y_t^{''} = Y_t^{'} - Y_{t-1}^{'} = (Y_t - Y_{t-1}) - (Y_{t-1} - Y_{t-2}) = Y_t - 2Y_{t-1} + Y_{t-2} = (1-B)^2 Y_t \tag{3}$$

Similarly, d th order difference is, $Y_t^d = (1-B)^d Y_t$ (4)

Where, B is the Back Shift operator; $BY_t = Y_{t-1}$.

Assume Y_t^d is trend-free. Let, $Y_t^d = X_t$ then X_t could be modeled as;

$$X_t = \sum_{k=1}^{n}(a_k \sin k\omega t + b_k \cos k\omega t) + \varepsilon_t \tag{5}$$

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Hence; $(1-B)^d Y_t = \sum_{k=1}^{n} (a_k \sin k\omega t + b_k \cos k\omega t) + \varepsilon_t$ (6)

The model (6), the improved Circular Model was named as "Sama Circular Model Konarasinghe, W.G.S. (2018-a).

3.2 Seasonal Auto Regressive Integrated Moving Average (SARIMA)
ARIMA modeling can be used to model many different time series, with or without trend or seasonal components, and to provide forecasts (Box & Jenkins, 1970); (Box, & Jenkins, 1976). The model as follows;

An ARIMA model is given by:

$$\phi(B)(1-B)^d y_t = \theta(B)\varepsilon_t$$

Where; $\phi(B) = 1-\phi_1 B - \phi_2 B^2 \ldots\phi_p B^p$

$\theta(B) - 1 - \theta_1 B - \theta_2 B^2 \ldots\ldots\theta_P B^q$ (7)

ε_t = Error term

D = Differencing term

B = Backshift operator ($B^a Y_t = Y_{t-a}$)

Analogous to the simple SARIMA parameters, these are:

Seasonal autoregressive - (Ps)

Seasonal differencing - (Ds)

Seasonal moving average parameters - (Qs)

Seasonal models are summarized as ARIMA (p, d, q) $(P, D, Q)_s$

Number of periods per season - S

$$(1-\phi_1 B)(1-\varphi_1 B^s)(1-B)(1-B^s)Y_t = (1-\theta_1 B)(1-\theta_1 B^s)\varepsilon_t \quad (8)$$

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4. RESULTS

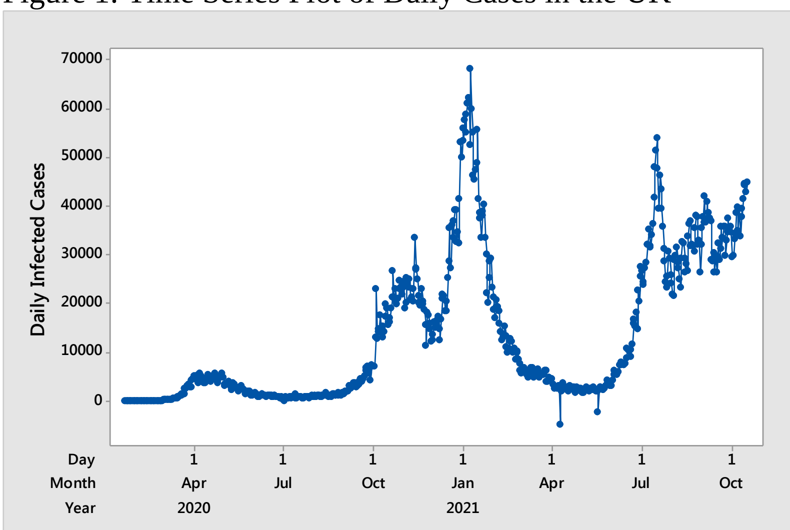
The analysis contains two main parts:

4.1 Pattern recognition of daily infected cases in the UK.
4.2 Forecasting daily infected cases in the UK.

4.1 Pattern Recognition of Daily Infected Cases in the UK

Figure 1 is the time series plot of daily infected cases of the UK for the period of 22nd January 2020 to 17th October 2021. The first confirmed case was reported on 31st January 2020. After 3rd October 2020 daily infected cases have been growing exponentially. It increased till 8th January 2021.There were 2,490,326 infected cases reported within 98 days. Exponential decay has been observed afterward till 22nd February 2021. The second exponential growth began on 17th June to 17th July 2021. There were 7, 96,526 infected cases reported within 31 days. The behavior of infected cases shows a minor trend with fluctuations afterward.

Figure 1: Time Series Plot of Daily Cases in the UK



The pattern of the data series shows that the recent behavior of infected cases after 27th July 2021 is a suitable part of the data series to forecast daily infected cases in the UK. Therefore, the pattern of the period of 27th July to 17th October 2021 was examined furthermore. Figure 2 is the time series plot of daily infected cases for the selected period. According to Figure 2, there is volatility with an increasing trend of daily infected cases in the UK.

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Figure 2: Daily Cases of 27th June to 17th October 2021

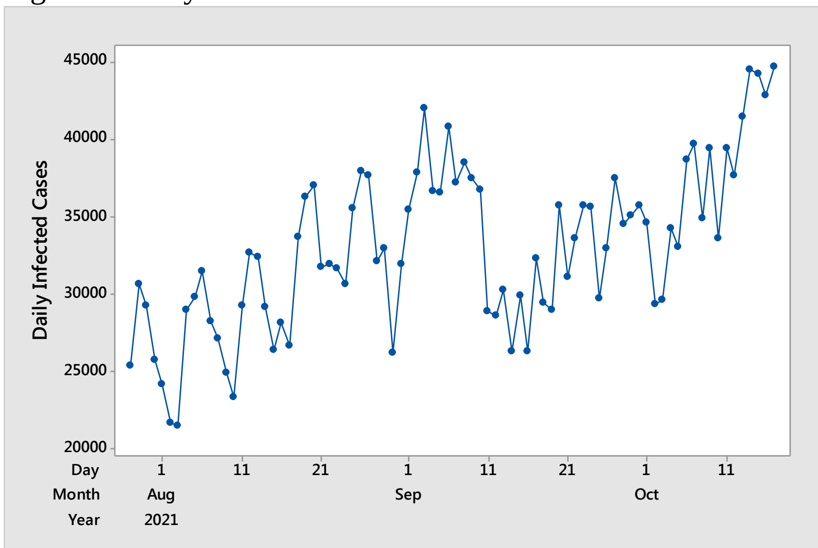


Figure 3 is the ACF of the daily infected cases. It shows a seasonal or repeating behavior of 7 days. The behavior of daily cases in ACF, it had been assumed that there could be one repeating behavior is clearly visible. There have been few significant lags. Therefore, the series has confirmed the weak stationary.

Figure 3: ACF of Daily Cases (DC)

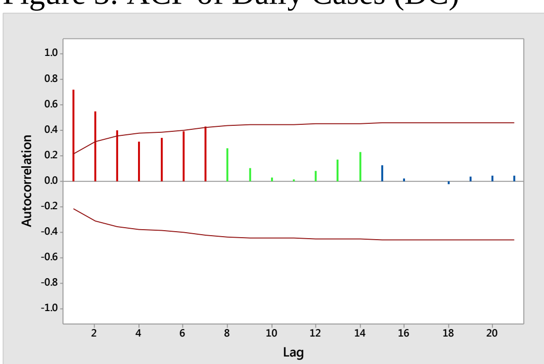
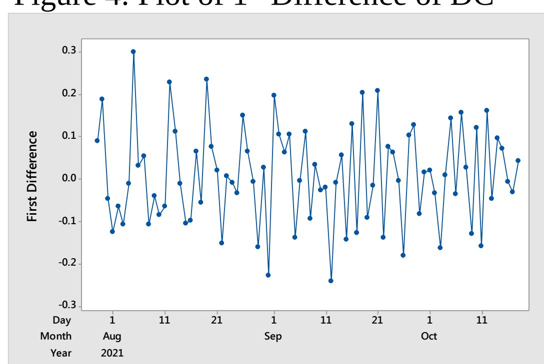


Figure 4: Plot of 1st Difference of DC



The first difference series of daily infected cases of the UK has shown in Figure 4. The first difference series should obtain to examine the wave pattern of the series to apply SCM (Konarasinghe, W.G.S., 2019; 2020-b). The wave-like pattern with high volatility has been observed throughout the series. The existing wave-like pattern is a piece of solid evidence to select and apply SCM to model daily infected cases in the UK. Besides, stationary is another evidence to select and apply SARIMA to model the infected cases.

4.2 Forecasting Daily Infected Cases in the UK

The selected wave breaks into 56 trigonometric series from sin $0.25\,\omega t$ to sin $7\,\omega t$ and cos $0.25\,\omega t$ to cos $7\,\omega t$. The results of the Table 1 revealed that there were 2 significant trigonometric series out of 56.

ISSN 2719-2385 (Online)

Table 1: Model Summary of SCM

Model	Model Fitting		Model Verification	
$Y_t = Y_{t-1} + 0.0559\cos 0.5\omega t + 0.0509\cos 1.5\omega t$	MAPE	0.7956	MAPE	0.6733
	MSE	0.0106	MSE	0.0080
	MAD	0.0822	MAD	0.0713
	Normality	P = 0.528		
	Independence of Residuals	Yes		

They are; $\cos 0.5\omega t$ and $\cos 1.5\omega t$ .The model satisfied the validation criterion of normality and independence of the residuals in the fitting. The measurements of errors were very low under the fitting and verification. Figure 5 is the actual vs. fits of SCM. The behavior of actual daily infected cases and fits are similar, deviations among them had been very low. Figure 6 is the actual vs. forecast of SCM. The deviation among actual daily infected cases and forecast became low. The forecast behavior of the daily infected cases follows quite similar to actual behavior.

Figure 5: Actual vs. Fits of SCM

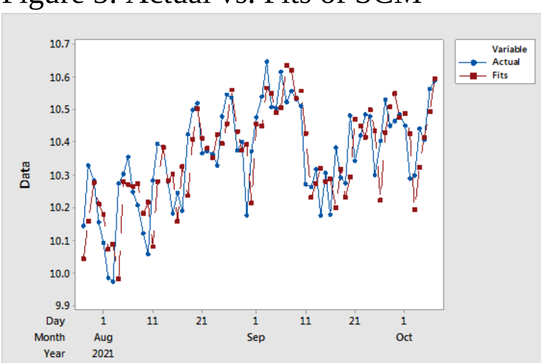
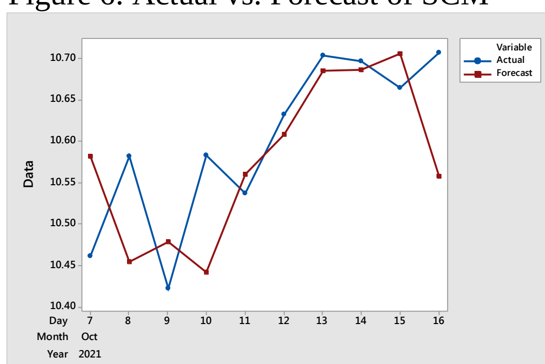


Figure 6: Actual vs. Forecast of SCM



The satisfaction of model assumptions, measurements of errors, and capturing the behavior of fits and forecast with actual behavior were highly satisfactory. Figure 6 is another evidence to prove that the SCM is capable to follow wave-like patterns (Konarasinghe, W.G.S. 2020-b). Hence, SCM is suitable to forecast daily infected cases of COVID -19 in the UK. The fitted SCM is;

$$Y_t = Y_{t-1} + 0.0559\cos 0.5\omega t + 0.0509\cos 1.5\omega t \tag{9}$$

Figure 7 indicates that the wave lengths are 7 and 8 days. That means daily infected cases in the UK repeated in 7 and 8 days intervals.

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Figure 7: Plot of $\cos 0.5\omega t$

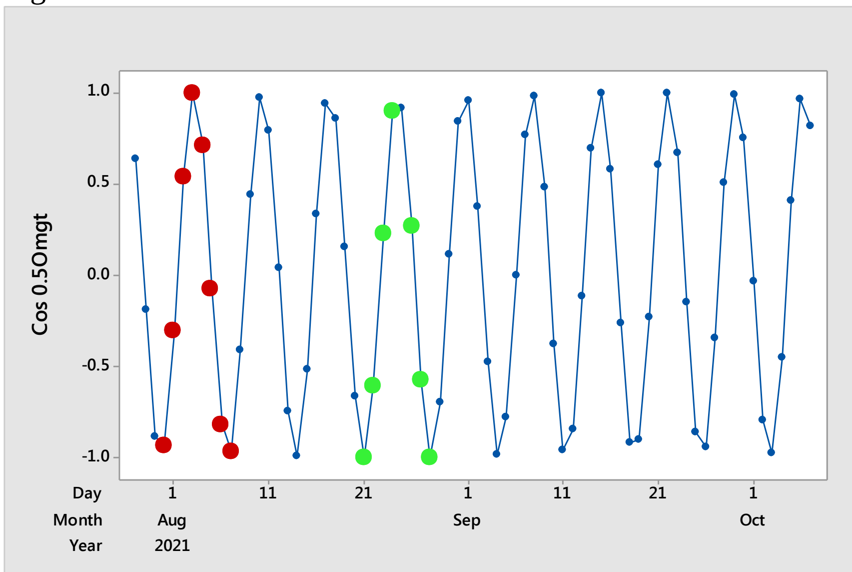
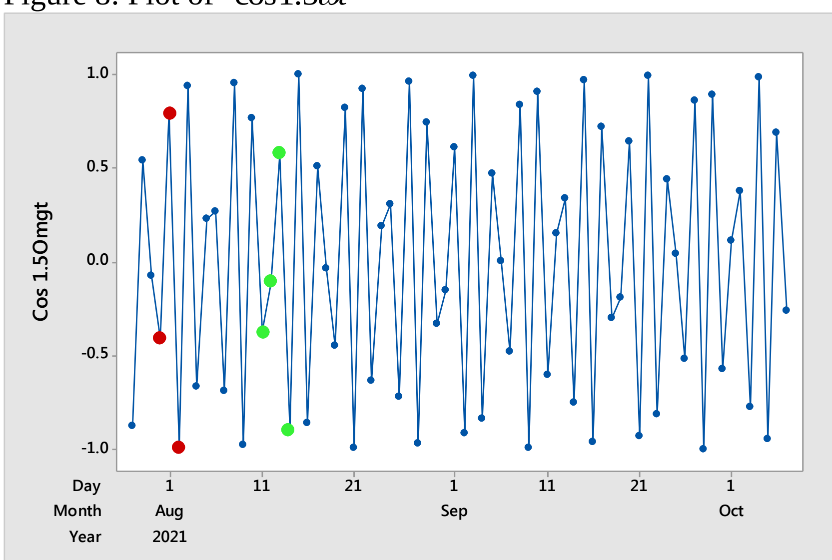


Figure 8 indicates wave lengths of 3 and 4 days. That means daily infected cases in the UK are repeated in 3 and 4 days periods.

Figure 8: Plot of $\cos 1.5\omega t$



The significant trigonometric series, and of Figures 7 and 8 indicated the repeating behaviors of 7, 8, 3, and 4 days periods. The SARIMA model runs with several seasonal lengths. One repeating behavior of 7 days has been observed from ACF in Figure 3. The SARIMA model runs with 7 days of repeating behavior at the beginning. But the tested behavior is not significant. Hence, the model runs with 5, 6, and 8 days repeating behaviors. The best fitting model and the performances are show in Table 2.

ISSN 2719-2385 (Online)

Table 2: Model Summary of SARIMA

Model	Model Fitting		Model Verification	
ARIMA(1,1,0)$(1,0,1)_6$	MAPE	0.6087	MAPE	1.8744
	MSE	0.0065	MSE	0.0545
	MAD	0.0631	MAD	0.1997
	Normality	P= 0.239		
	Independence of Residuals	Yes		

The model assumptions were confirmed by the Anderson Darling test, LBQ test, and the ACF. Both relative and absolute measurements of errors are low under the fitting and verification of ARIMA (1, 1, 0) $(1, 0, 1)_6$. The model has lowest measurements of errors under the fitting. But increased under the verification. Figures 9 and 10 are the actual, fits, and forecast of ARIMA (1, 1, 0) $(1, 0, 1)_6$. Actual and fits of daily infected cases in Figure 9 have the least deviation and fits follow similar behavior of the actual cases. But the deviation between actual daily cases and forecast in Figure 10 is more. It shows an underestimation of daily cases and it does not follow the similar behavior of the actual daily cases in the UK.

Figure 9: Actual vs. Fits

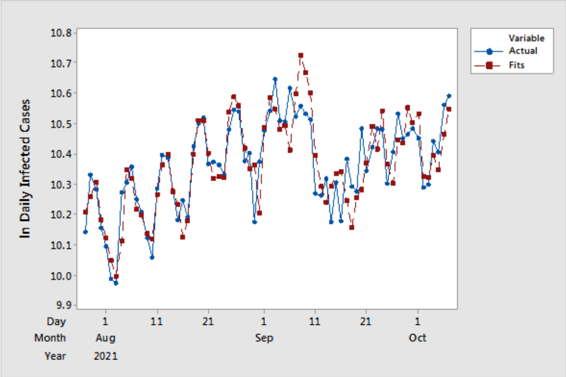
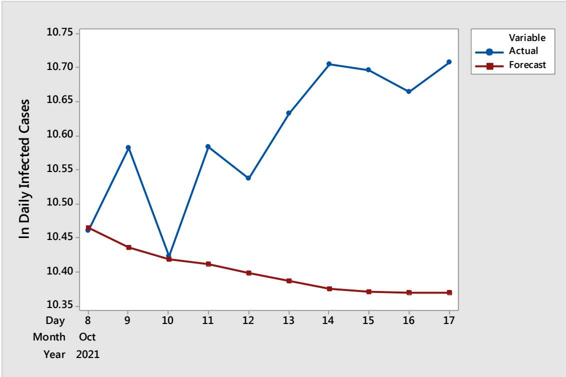


Figure 10: Actual vs. Forecast



The model comparison between SCM and ARIMA (1,1,0)$(1,0,1)_6$ in Figure 11.

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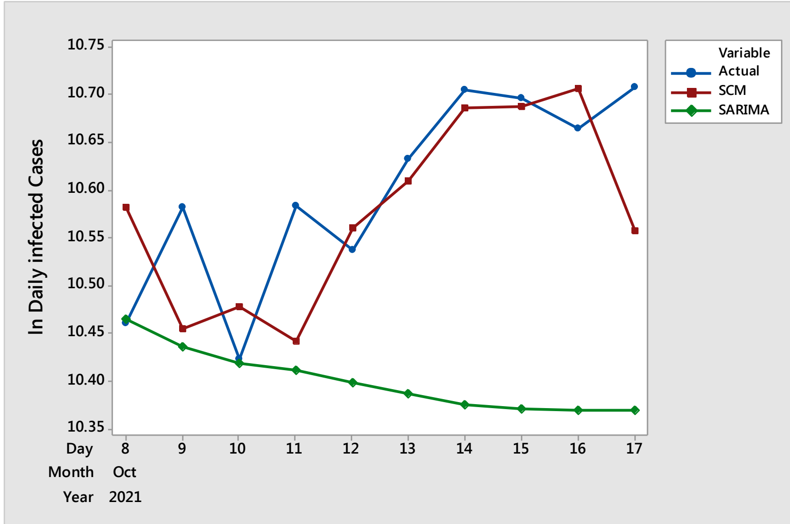
Figure 11: Model Comparison SCM and SARIMA



The SCM follows quite similar behaviors with the least deviation of daily infected cases in the UK. Whereas the performances of the SARIMA model are contrasted with SCM in forecasting daily infected cases. Figure 11 is a good evidence to say that the SCM outperformed ARIMA $(1,1,0)(1,0,1)_6$ in forecasting daily infected cases. Considering the results indicated by two significant trigonometric series of SCM, the repeating behaviors of daily infected cases accommodated of 3, 4, 7 and 8 days. Whereas ARIMA $(1,1,0)(1,0,1)_6$ is capable to accommodate the repeating behavior of 6 days.

5. CONCLUSION AND RECOMMANDATIONS

The SCM is the best-suited model for forecasting daily infected cases of COVID-19 in the UK due to the performances under the fitting and verification. The SCM has the ability to capture many repeating behaviors at once with minimum effort.

This study has captured four repeating behaviors of 3, 4, 7 and 8 days. This repeating behavior would be one of the perfect guidelines to control the outbreak of the pandemic in the UK. The predicted behavior of this study would be a guide to control movements of the general public, lockdown schedules and transportation schedules for the essential services, preparing an effective working schedule for the employees in both the public and private sector etc.(Konarasinghe, 2021-d).A vaccine is a part of medical care. Medical care constitutes only 10% to 20% of health outcomes, approximately (AIM, 2019). The remaining 80% to 90% incorporates several social factors, including other healthcare practices (AIM, 2019).Food habits, healthy lifestyles, working styles and other non-pharmaceutical activities are a few factors associated with healthcare practices (AIM, 2019). Medical care is not sufficient to prevent the outbreak of the pandemic. The general public should practice healthcare to prevent the disease.

ISSN 2719-2385 (Online)

Non-pharmaceutical interventions are the primary mitigation strategy to control and minimize the outbreak of the COVID-19 pandemic (Kantor & Kantor, 2020). Sneeze on tissues/elbows, avoid touching the face and avoid handshakes, wear masks, wear protective glasses, wash hands, hand sanitizer, (Kantor & Kantor, 2020). Logistic support is another supportive factor to controlling the outbreak of the pandemic. The results of this study would be a guide to work out the logistic requirements effectively and efficiently. They can work out the requirements by observing the repeating behavior of the daily cases. This would facilitate minimizing the waste and the cost of the productions. The rate of daily infected cases in the UK is soaring and it is not favorable to the sleek function. The results of the study can be applied to control the outbreak by imposing effective quarantine procedures monitoring strictly. The government should provide facilities to the producers to produce healthy food and beverages to improve the immunity of the human body and restrict unhealthy food and beverages (Konarasinghe, 2021-d). Further, the results of the study would be a guide to take initiative to develop and implement proactive measures to control the outbreak in the UK. The COVID -19 pandemic almost completed the second year. The repeating behaviors of daily infected cases could be exist in other countries as well. Hence, it is strongly recommended to explore the repeating behaviors of the outbreak in other countries without any delay.

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