Predicting COVID-19 Cases Using Some Statistical Models: An Application to the Cases Reported in China Italy and USA

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Abstract

Today, the new coronavirus disease (COVID-19) is a global epidemic that spreads rapidly among individuals in most countries around the world and, therefore, becomes the greatest worldwide threat. The aim of this study is to find the best predictive models for the confirmation of daily situations in countries with a large number of confirmed cases. The study was conducted on the countries that recorded the highest infection rate, namely China, Italy and the United States of America. The second goal is using predictive models to get more prepared in terms of health care systems. In this study, predictions were made through statistical prediction models using the ARIMA and exponential growth model. The results indicate that the exponential growth model is better than ARIMA models for forecasting the COVID-19 cases.
Keywords: ARIMA model; Box-Jenkins approach; Coronavirus; Forecasting; Holt's linear trend.

1. Introduction

The World Health Organization has declared COVID-19 as universal epidemic. All countries should take the necessary measures to limit the spread of the virus, on the basis of the analysis and modeling of data issued by the World Health Organization. This research recommends that all countries of the world should impose quarantine including restrictions on travel and public gatherings, leading to the closure of schools, universities and workplaces in order to achieve ("social divergence") in the short term. With limited intensive care units and increasingly growing deaths, the failure of intensive care system is highly probable. This will affect a much larger proportion of the world's population including youth in the workforce who may be asymptomatic but are forced to work from home and rationalize expenditures. The number of affected people in the world will increase dramatically in the next four weeks. This study aims at finding the best predictive models for confirmed daily cases in China, Italy and the United States of America. The second aim of the study is to reach clear expectation of cases with these models in order to obtain more preparedness in health care systems in each of these countries and in countries where the disease begins to spread. This virus is considered a modified Corona virus, or what is called Covid-19, one that infects the respiratory system of humans and animals, and causes infection. Pneumonia is idiopathic pneumonia associated with individuals working in the Huanan seafood market where live animals are sold. At the end of January 2020, nearly 75,755 people were confirmed in China and among the first 41 patients were found to be linked to the Huanan seafood market in the "Huan market" in Wuhan, China, confirmed the first death of the virus on January 9, 2020. It is estimated that there is a large number of people infected with this virus, but it has not been revealed until it is spread beyond the borders of China. The first case recorded in one family was in Vietnam through the transmission of the virus from father to son, but the first outbreak of the virus was on January 22 in Germany where infection was made by infected Chinese people in the state of Bavaria.

To control the spread of this virus, China banned the movement of 57 million people in Wuhan and 15 surrounding cities The tourist sites were closed, celebrations of the Chinese New Year were cancelled to avoid the transmission of the virus. Here, we must mention that infection can be transmitted through mucus and saliva droplets that come out of the mouth or nose scattered from the infected person and spread on the surfaces. Moreover, direct infection can occur by inhaling the breath that comes out of an infected person. There are some studies that work on discovering the causes that lead to the transmission of the infection among individuals including the incubation period for the disease which is five or more days as per the World Health Organization (WHO) reports so far. The WHO has decided that antibiotics do not eliminate viruses, but they eliminate graphical infections, and, therefore, antibiotics should not be used in the prevention or treatment of this virus. Antibiotics shall be used according to the doctor's direct instructions to treat bacterial infections. Until now there is no specific vaccine or drug. Therefore, people receive care to relieve symptoms, and although there are some medications and antibiotics that reduce the severity of the symptoms of this virus, there is no current treatment to prevent the virus. Trials are now underway to

test And some vaccines and possible drugs to treat this particular disease. In this regard, WHO is coordinating efforts to face this severe worldwide epidemic.

2. Methodology

This study was conducted on the basis of confirmed daily cases of COVID-19 that were collected from the official WHO website from January 22, 2020 to March 25, 2020. Analyzing time series can offer a very precise short-run forecasting on a relatively significant amount of data on the variables concerned, see Granger and Newbold [1]. The ARIMA models are common and popularly used in analyzing the univariate time series data. It is a mixture of three procedures; the first is autoregressive (AR) procedure; the second is the differencing; and the third is the moving-average (MA).

Such procedures are described as the default models in univariate time series analysis in the literature of statistical modeling and are widely utilized in many applications. The autoregressive form of order p, AR (p), may be described as:

$$x_t = c + a_1 x_{t-1} + a_2 x_{t-2} + \cdots + a_p x_{t-p} + \varepsilon_t \quad ; \quad t = 1,2,\dots T \tag{1}$$

where ε_t is the error term in the equation, indicating is a series of random variables with an independent and equal distribution (iid) also called a white noise, with $E(\varepsilon_t) = 0$ and $v(\varepsilon_t) = \sigma^2$ i.e $\varepsilon_t \sim iid\ N(0, \sigma^2)$. This model assumes that all past values will have cumulative impact on this point of x_t and so on. Therefore, it's called a long-term memory model.

2.1. Moving-Average (MA) Model

The MA procedure in time series analysis is said to have order q, MA (q), if:

$$x_t = \varepsilon_t - \theta_1 x_{t-1} - \theta_2 x_{t-2} - \dots - \theta_q x_{t-q} \tag{2}$$

This model is expressed in terms of past errors as explanatory variables. Therefore, only q errors will have effect, however, higher order errors don't affect x_t ; this means that it's a short memory model.

2.2. Autoregressive Moving-Average (ARMA) Model

The ARMA procedure in time series analysis is said to have order p and q, ARMA(p,q), if:

$$x_t = c + a_1 x_{t-1} + \dots + a_p x_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \dots - \theta_q \varepsilon_{t-q} \tag{3}$$

This model can be a mixture of both autoregressive and moving average models above.

2.3. ARIMA Models

In fact, ARMA models may be generalized to non-stationary time series by enabling the data series arising from ARIMA models to be differencing. The general non-seasonality model is known as ARIMA (p, d, q) where p, d, q are the order of autoregressive, the degree of differencing, and the order of moving average respectively. For instance, if x_t is non-stationary time series, the first-difference of x_t is taken so that Δx_t gets stationary, then the ARIMA (p, 1, q) model can be written as:

$$\Delta x_t = c + a_1 \Delta x_{t-1} + \dots + a_p \Delta x_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \dots - \theta_q \varepsilon_{t-q} \tag{4}$$

where $\Delta x_t = x_t - x_{t-1}$. A special case of equation 4, is the random walk model; where the orders p and q equal zero. i.e. ARIMA (0, 1, 0).

2.4. Box-Jenkins Approach

In the analysis of time series, the ARIMA model is used to determine the optimal fit of a time series model to previous values of a time series. The Box, et al. [2] method is introduced by the statisticians George Box and Gwilym Jenkins.

For more information about Box &Jenkins method for analyzing time series data; see Young [3], Frain [4], Kirchgässner, et al. [5], and Chatfield and Xing [6]. The subsequent stages of this methodology are summarized in figure 1.

Figure-1. Stages in the Box-Jenkins iterative approach
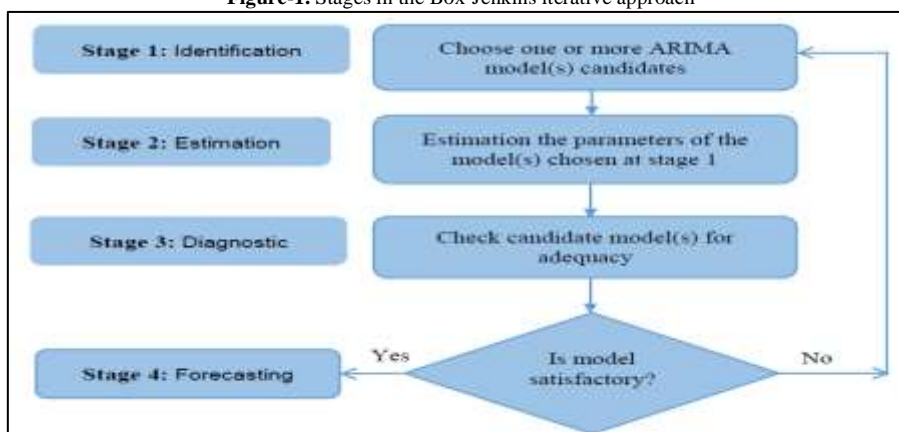
Source: Abonazel and Abd-Elftah [7]

These subsequent stages are shown in details below:
- ✓ *Model identification* : Ensure that the variables are stationary, define the seasonality of the series and use the Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) plots of the series to determine the autoregressive or moving-average portion to be included in the model.
- ✓ *Model estimation* : Using statistical techniques to derive at the coefficients that better fit the chosen ARIMA model. The most popular approach is the Maximum Likelihood (ML) method or alternatively, the non-linear least square approach.
- ✓ *Model checking*: Checking if the fitted model complies with the requirements of the stationary univariate procedure. In particular, the independence of residuals of each other and to be constant in mean and variation across time; the ACF and PACF plots are helpful in detecting misspecification. If model estimation is insufficient, we need to go back to phase one and seek to create a better one. In fact, the estimated model will be contrasted with other ARIMA model in order to select the best one. To choose between models; one may use model selection criteria   such as Akaike's Information Parameters (AIC) and Bayesian Information Criteria (BIC) which are described as:

$$\text{AIC} = 2m - 2\ln(\widehat{l}) \, , \text{BIC} = \ln(n)m - 2\ln(\widehat{l}) \tag{5}$$

where l indicates the maximum likelihood function for the model, n is the number of observations (sample size), and m is the number of estimated parameters within the model. In most situations, AIC and BIC are popular with the classical criterion i.e. the Mean Squared Error (MSE).
- ✓ *Forecasting*: If the chosen ARIMA model complies with the requirments of the stationary univariate procedure, this model may be used for forecasting purposes.

2.5. Holt's Linear Trend Method

The exponentially weighted moving average is the averages of smoothing random variability with the following attractive properties: (1) older data have a declining weight; (2) it is very simple to calculate; and (3) minimal data is needed. The current value of the average is obtained only by computing the weighted average of two variables, the present value of the variable, and the mean value from the last period.

This paper uses these attractive properties to stabilize existing random variations and to continually update seasonal and pattern changes. These can be extrapolated to predicting in the future. The simplicity of the process, coupled with its simplicity computational and data specifications, makes it particularly ideal for industrial contexts in which a large number of predictions are required for the selling of individual goods. A simple example of an exponentially moving average would be to the stochastic process given in the next context. Consider the question of having the expected value of a random variable, the mean of which varies between successive drawings. The following concept can be proposed: take a weighted mean of all previous data and use it as the prediction of the latest average of the distribution.

Holt [8], generalized basic exponential smoothing to enable pattern data forecasting. This approach includes a prediction equation and two smoothing equations (one equation for the level and the other for the trend):
The forecast Equation:

$$\hat{y}_{t+h|t} = l_t + hb_t \tag{6}$$

where the first equation equals (level equation):

$$l_t = \alpha\, y_t + (1 - \alpha)(l_{t-1} + b_{t-1})$$

and the other equation (trend equation) equals:

$$b_t = \beta^*(l_t - l_{t-1}) + (1 - \beta^*)b_{t-1}$$

Where l_t indicates the estimation of the series level at time t , b_t is the estimate of the seies trend (slope) at time t ,α is the smoothing parameter for level , $0 \leq \alpha \leq 1$ and β^* is the smoothing parameter for the trend , $0 \leq \beta^* \leq 1$

In the simple exponential smoothing method, the level equation shows that l_t is a weighted mean of observation y_t and the forecasted one-step-ahead training for time there is given by $(l_{t-1} + b_{t-1})$, the trend equation indicates that b_t is a weighted mean of the trend estimates at time t based on $(l_t - l_{t-1})$ and b_{t-1} , the previously estimated trend. The forecast function becomes no longer flat, and the h-step-ahead projection is equivalent to the previous estimation plus h times the last estimated value of the trend, so the projection is a linear function of h.

3. Data Analysis

The purpose of this paper is to predict the confirmed, recovered, and death cases of the pandemic coronavirus (COVID-19) for three selected countries:China, Italy, and USA. The analysis is conducted by comparing the performance of the selected models; i.e. the exponential growth and ARIMA models, using R language.

3.1. Descriptive Analysis

The data used in this paper is a daily time series for a time ranges from the 22nd of January 2020 to the 25th of March 2020[1]. The resulting sample size is 64 which satisfy the rule of having more than 50 observations in Box-Jenkins approach of time series forecasting [6].

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[1] Data is obtained from https://data.humdata.org/dataset/novel-coronavirus-2019-ncov-cases. Accessed 25th March 2020.

Table-1. Descriptive Statistics

	Country	Mean	Median	Max.	Min.	Std. Dev.	Skewness	Kurtosis
Confirmed	China	57726.84	77011.5	81661	548	30245.11	-0.880	2.084
	USA	4517.688	15	65778	1	12782.62	3.390	14.07
	Italy	10098.59	108.5	74386	0	19195.25	2.044	6.058
Recovered	China	30222.89	22943	73773	28	28065.15	0.307	1.449
	USA	1072.531	1	9362	0	2206.274	2.328	7.509
	Italy	29.10938	5	361	0	73.56567	3.243	13.348
Death	China	1968.547	2444	3285	17	1231.352	-0.428	1.539
	USA	849.3594	2.5	7503	0	1798.060	2.345	7.536
	Italy	63.5	0	942	0	171.5017	3.55	15.78

Based on this data, we will propose the appropriate ARIMA model and then compare it to the exponential growth model in forecasting the number of confirmed, recovered, and death cases for the next 30 days (26th of March to 24th of April). Table (1) represents the summary statistics for the numbers of confirmed, recovered, and death cases for the selected countries. It can be observed that as the coronavirus pandemic firstly begins in chine so, as a result the descriptive numbers of china are higher compared to other countries. It is also worth noting that the distributions of the data deviate away from normality and, as a result, the situation remains out of control.
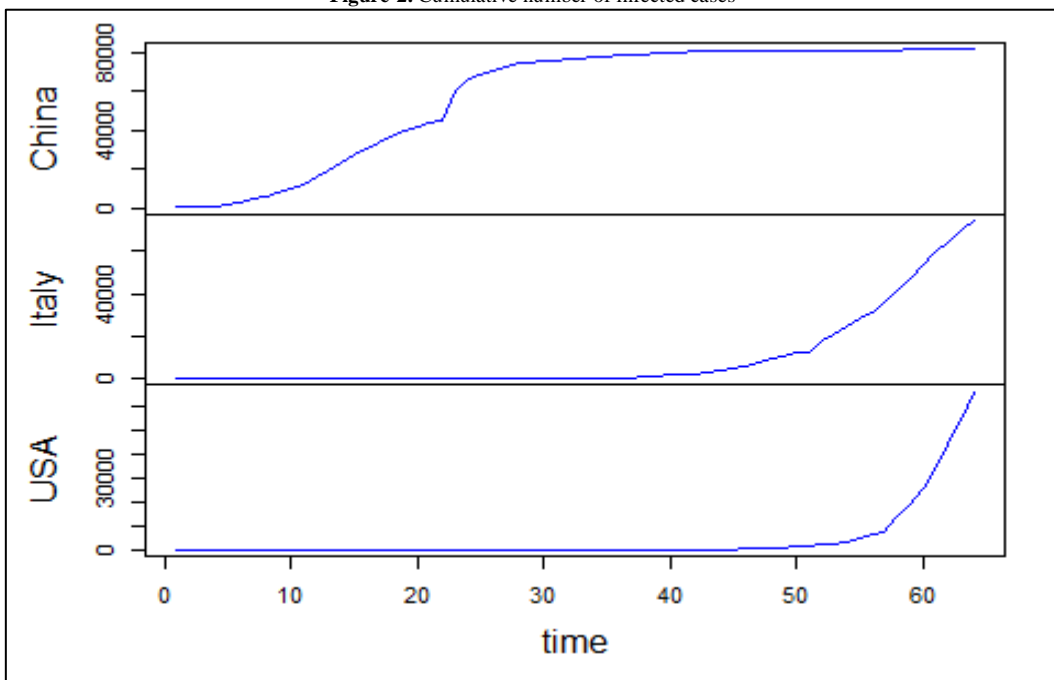
Figure-2. Cumulative number of infected cases

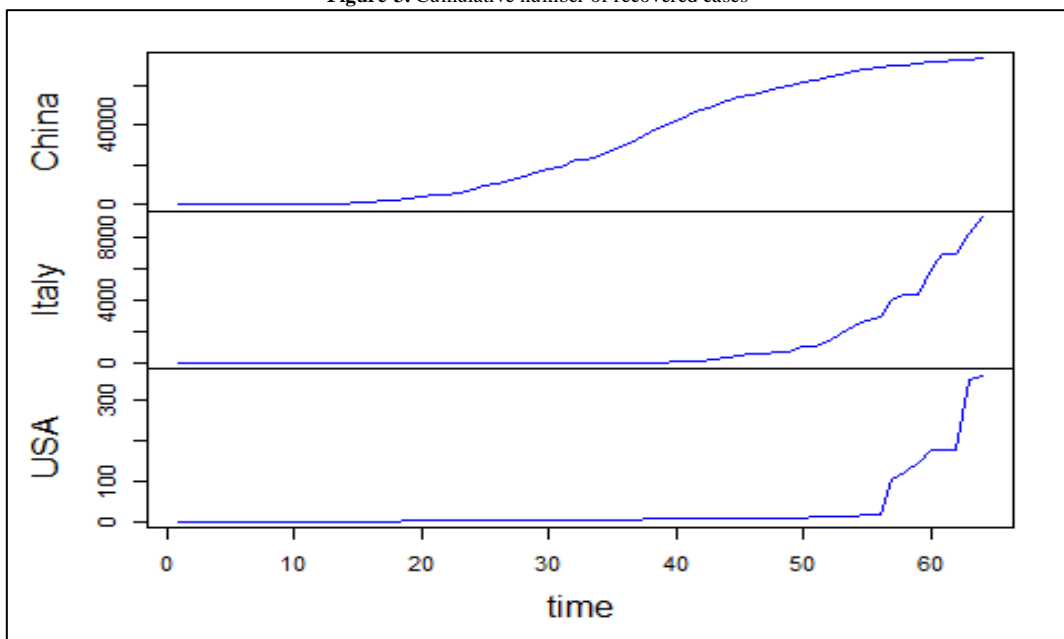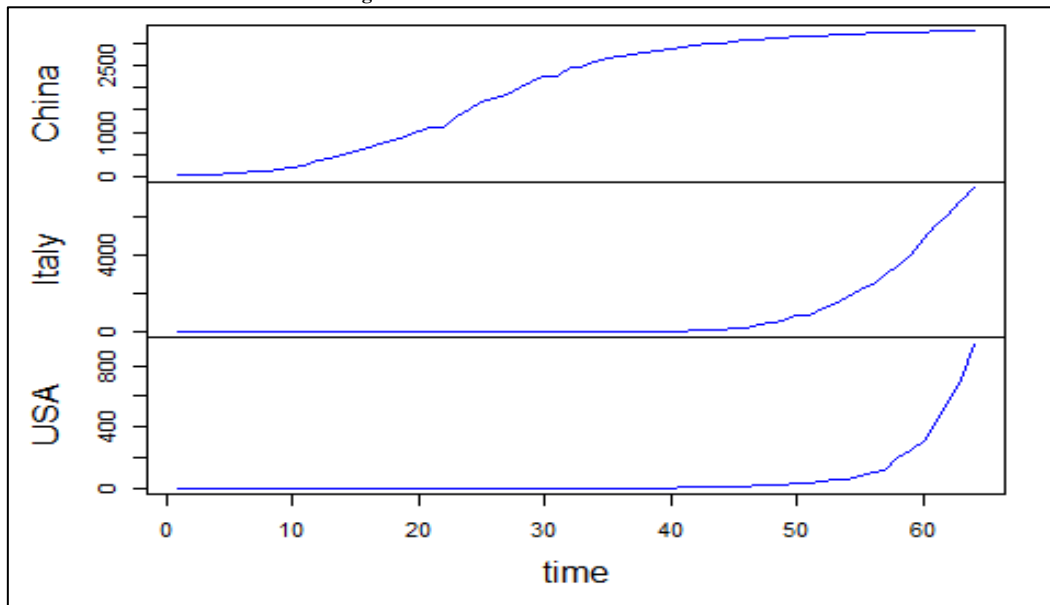
Figure-3. Cumulative number of recovered cases

Figure-4. Cumulative number of death cases

The preliminary analysis of the data was done by using time plots of the series as shown in figures 2-4. A visual inspection of the line chart indicates that numbers of confirmed, recovered, and death cases are not stationary. So, to reach stationary, we will take the differencing, as practiced, in developing ARIMA model, while analyzing the observed data for the exponential growth model. For each country, the best ARIMA model is selected. For more details, see Benvenuto, *et al.* [9], Bianconi, *et al.* [10], Dehesh, *et al.* [11], Elmousalami and Hassanien [12], Gupta and Pal [13], Utsunomiya, *et al.* [14], among others.

3.2. Exponential Growth VS ARIMA Models

Table (2) shows the parameter estimates for the ARIMA models for the selected countries associated with the standard error values in parenthesis. The ARIMA models are very important in time series analysis that are used in auto-correlated data analysis. These models include autoregressive (AR) model and moving average (MA) model.

As obvious from the table, the parameter d in all models equals 2 "i.e the 2nd difference". The suitable models for China are ARIMA(0,2,1), ARIMA(0,2,2), and ARIMA(0,2,2) for the confirmed, recovered, and death cases respectively, indicating that the parameters p, d, q are the same for the three types of data except for the parameter q for confirmed cases. For Italy, the parameters d, q are the same for the three types of data.

Table-2. Moving Average and Autoregressive Parameters

	Country	Model	AR(1)	AR(2)	AR(3)	MA(1)	MA(2)
Confirmed	China	ARIMA(0,2,1)	-	-	-	-0.718 (-0.098)	-
	Italy	ARIMA(1,2,0)	-0.541 (-0.105)	-	-	-	-
	USA	ARIMA(1,2,2)	0.8286 (-0.092)	-	-	-1.232 (-0.094)	0.7724 (-0.098)
Recovered	China	ARIMA(0,2,2)	-	-	-	-0.925 (-0.12)	0.5079 (-0.099)
	Italy	ARIMA(2,2,0)	-0.834 (-0.065)	-0.9095 (-0.059)	-	-	-
	USA	ARIMA(2,2,1)	-0.435 (-0.165)	-0.442 (-0.238)	-	-0.628 (-0.13)	-
Death	China	ARIMA(0,2,2)	-	-	-	-1.092 (-0.124)	0.4353 (-0.114)
	Italy	ARIMA(3,2,0)	-0.617 (-0.1199)	0.0358 (-0.145)	0.2886 (-0.121)	-	-
	USA	ARIMA(0,2,0)	-	-	-	-	-

Results of exponential growth model using Holt's method are reported in table (3). The optimal initial values are obtained and were optimized along with the smoothing parameters: see Hyndman, *et al.* [15] for details. After minimizing the sum of squared errors over the entire time series, the optimal values for α, β, l, b were calculated and reported in table (3), where alpha and beta are the values of smoothing parameter for the level i.e "the confidence level for prediction intervals". Lambda is the Box-Cox transformation parameter, and the transformation is automatically selected. The very small values of β indicates that the slope hardly changes over time, so the most susceptible numbers over time is the trend of death numbers in Italy.

Table-3. Parameter Estimates for Exponential Growth Model using Holt's method

| Country		Box-Cox transformation	Smoothing parameters		Initial states		sigma
		Lambda	Alpha	Beta	L	B	
Confirmed	China	0.538	0.9999	0.2259	22.5356	30.5464	14.8958
	Italy	0.2486	0.9999	0.2207	-4.1009	0.1049	0.9638
	USA	0.1129	0.8335	0.2118	-0.3279	0.2842	0.3399
Recovered	China	0.3761	0.6345	0.4315	6.1637	0.3364	1.1796
	Italy	0.2223	0.8894	0.1109	-4.5256	0.023	0.9573
	USA	0	0.2112	0.2112	-0.0997	-0.0555	21.9208
Death	China	0.6336	0.6158	0.2932	3.6708	2.5579	2.8649
	Italy	0.1754	0.9931	0.1054	-5.7469	0.0449	0.7656
	USA	0	0.8397	0.8397	-0.6239	-0.4795	16.9384

3.3. Forecasted Results

Figures 6 and 7 presents the trend of the actual and the forecasted numbers of confirmed, recovered, and death values with their 95% confidence intervals. The forecasted results indicate the following:

- For China, the numbers of confirmed and death cases will continue to be slightly increasing while the number of recovered cases is going to have noticed increase.
- Regarding the results of Italy, the exponential growth model insures a substantial increase in the predicted values compared to that of the ARIMA models.

Forecasted results concerning the USA predict *the highest values* compared to the other countries. The proposed two methods give a closer predicted values for both recovered and death values while the exponential growth predict a substantial increase in confirmed cases compared to that of the ARIMA model. Selection and accuracy measures for the forecasted models are reported in table (4) and presented in a form of a stacked bar chart in figure (5). The selection and accuracy measures are the Akaike information criterion (AIC), Bayesian information criterion (BIC), mean error (ME), root mean squared error (RMSE), mean absolute error (MAE), mean percentage error (MPE), mean absolute percentage error (MAPE), mean absolute scaled error (MASE) and autocorrelation of errors at lag 1 (ACF1). It is obvious from the table and the graph that the exponential growth method is better than ARIMA models for these data since it is associated with the lower values for the most criteria.

Figure-5. Stacked Bar Chart for Accuracy measure
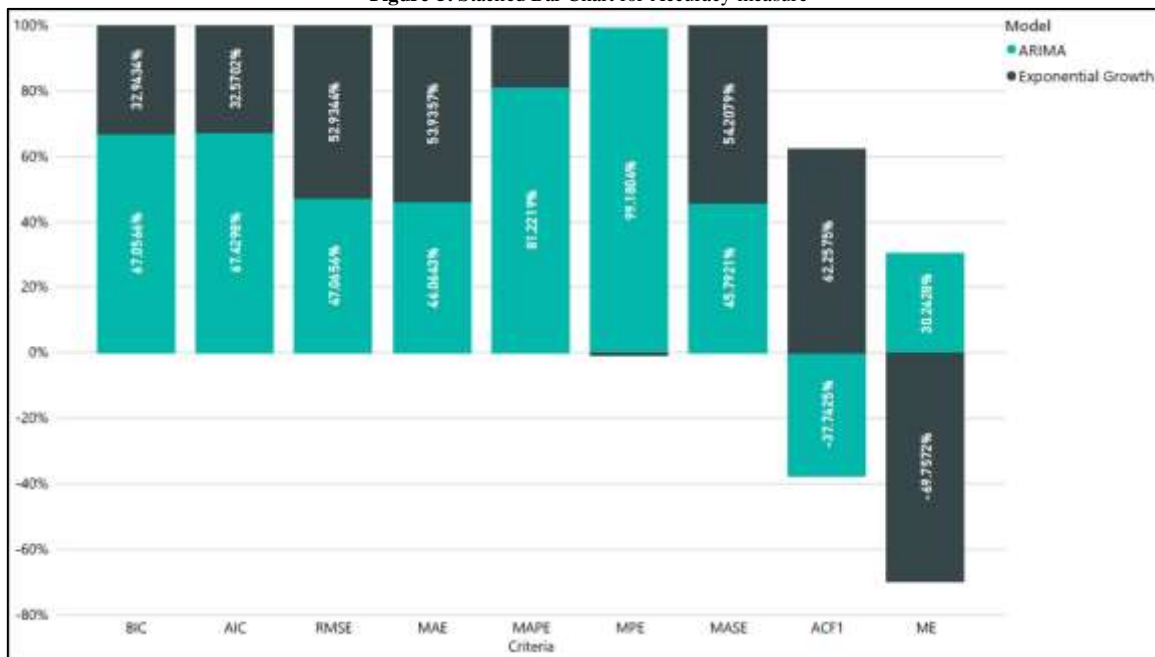
4. Summary and Conclusion

From the analysis of data issued by the World Health Organization, it is noted that there is an increase in the number of patients and deaths in the countries under this study: China, Italy and the United States of America. For China, the number of confirmed cases and deaths will continue to slightly increase while the number of recovered cases will increase noticeably. The situation in China has a relative improvement compared to other countries: an increased number of recovered cases and slightly increased number of deaths. The Chinese health system per 100,000 citizens is 3.6 beds in intensive care units, but with the slight increase of confirmed cases, China can control this crisis by expanding the construction of mobile intensive care units. However, China remains the most affected

country when compared to Italy and the United States of America in terms of the number of confirmed cases, deaths and recoveries.

Regarding Italy, the exponential growth model guarantees a significant increase in the expected values compared to the ARIMA models. Consequently, more injuries and fatalities will also have a significant impact in the coming period. As the health system of Italy for every hundred thousand citizens is 12.5 beds in the intensive care unit and with the increase in the number of confirmed cases, disruption in the health system will occur due to the inability to absorb the increased number of confirmed cases; therefore, Italy has to create more units of intensive care.
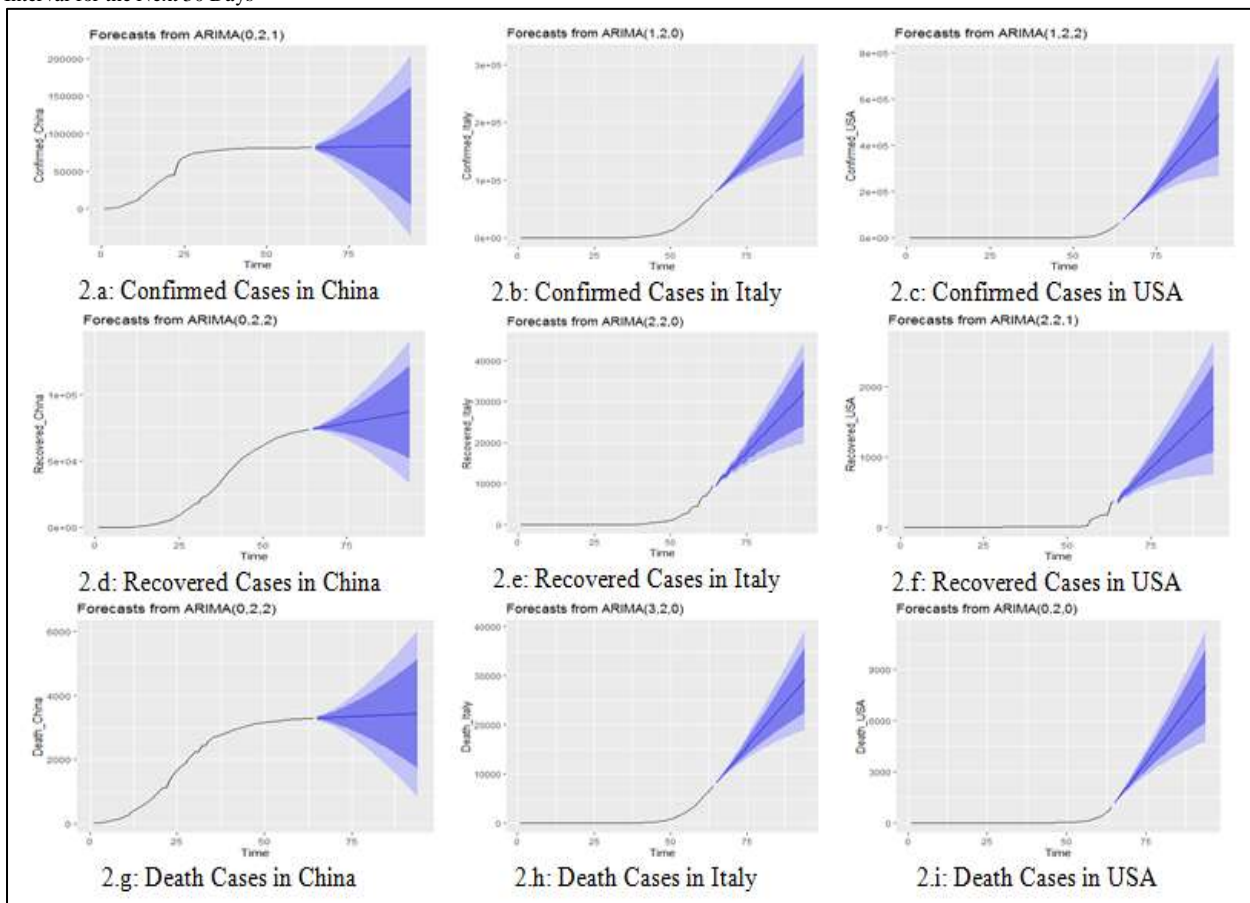
The results of the United States expect the highest values compared to other countries. Therefore, the numbers of confirmed cases, deaths, and recovered cases are expected to continue to increase. Therefore, a crisis is expected because the health system in the United States of America per 100,000 citizens is 34.7 beds in the intensive care unit. The United States of America is a country with a good health sector, but the increased number of confirmed cases will lead to imbalance. Therefore, it is necessary to expand the establishment of mobile intensive care units to reduce the aggravation of this crisis.

Therefore, this virus has effects on all sectors and activities, not only on health sector, but also on the economic, commercial, technological, educational, and other domains. Such harmful effects must be faced with the proper procedures in order to leave the other sectors unharmed.

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Fig-6. Observed and Forecasted Confirmed, Recovered, and Death Cases using *ARIMA Models* with the Forecasted Band at 95% Confidence Interval for the Next 30 Days

2.a: Confirmed Cases in China

2.b: Confirmed Cases in Italy

2.c: Confirmed Cases in USA

2.d: Recovered Cases in China

2.e: Recovered Cases in Italy

2.f: Recovered Cases in USA

2.g: Death Cases in China

2.h: Death Cases in Italy

2.i: Death Cases in USA

Fig-7. Observed and Forecasted Confirmed, Recovered, and Death Cases using *Exponential growth model* with the Forecasted Band at 95% Confidence Interval for the Next 30 Days
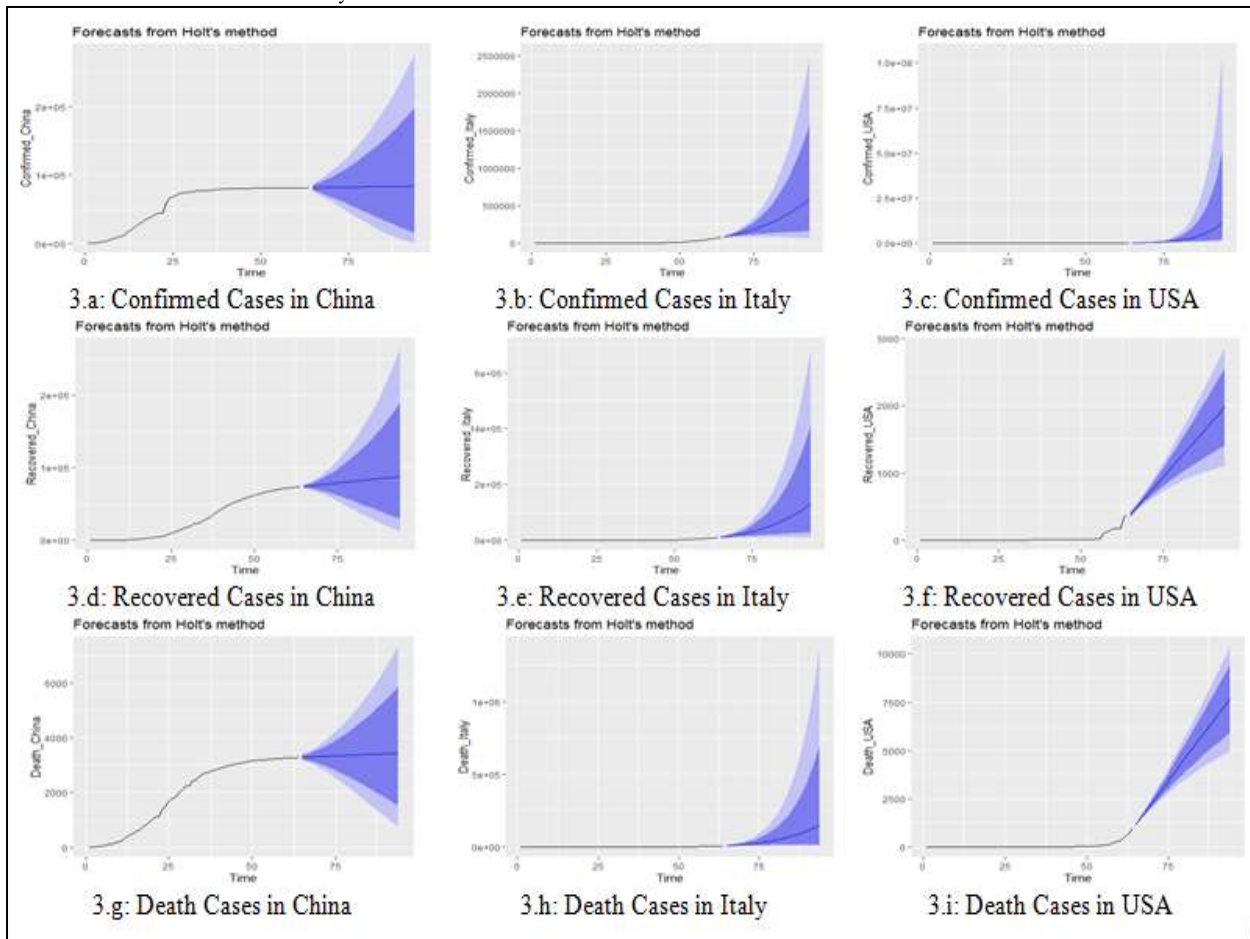

3.a: Confirmed Cases in China

3.b: Confirmed Cases in Italy

3.c: Confirmed Cases in USA

3.d: Recovered Cases in China

3.e: Recovered Cases in Italy

3.f: Recovered Cases in USA

3.g: Death Cases in China

3.h: Death Cases in Italy

3.i: Death Cases in USA

Table-4. Selection and Accuracy Measures for the Forecast Models

		AIC	BIC	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
ARIMA Models										
Confirmed	China	1121.970	1126.230	-9.998	1949.353	810.187	2.045	3.575	0.629	0.073
	Italy	991.580	995.840	125.808	683.188	295.442	5.336	11.246	0.250	-0.023
	USA	973.170	981.680	80.585	561.367	174.726	1.698	13.013	0.167	-0.062
Recovered	China	948.330	954.710	11.760	471.550	279.701	3.067	4.370	0.239	-0.013
	Italy	820.270	826.650	33.150	164.332	70.017	7.075	22.675	0.471	-0.176
	USA	568.870	577.380	3.551	21.630	5.672	4.059	13.294	0.990	-0.046
Death	China	634.410	640.790	0.029	37.436	22.354	2.216	3.605	0.431	-0.007
	Italy	708.250	716.750	14.563	67.130	28.130	8.942	11.808	0.236	-0.079
	USA	530.300	532.420	3.688	16.872	5.750	4.407	22.281	0.385	-0.095
Holt's method										
Confirmed	China	617.776	628.571	-361.705	2010.778	943.403	-2.133	4.664	0.733	0.104
	Italy	267.315	278.109	-84.793	729.263	307.613	-	-	0.261	0.072
	USA	133.912	144.707	-23.505	841.059	247.403	-0.346	11.981	0.237	0.435
Recovered	China	293.178	303.973	-126.277	508.441	323.228	1.433	3.834	0.276	0.010
	Italy	266.446	277.240	-0.337	224.370	90.137	-	-	0.606	-0.339
	USA	667.230	668.265	4.083	21.225	7.434	-	-	1.297	0.261
Death	China	406.763	417.558	-5.593	38.000	22.790	0.725	3.997	0.439	-0.029
	Italy	237.856	248.651	-13.008	78.707	33.654	-	-	0.283	0.080
	USA	634.225	645.020	4.194	16.401	5.443	-	-	0.364	0.112