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Applications of Deep Learning to Predict Epidemics in the Kingdom of Saudi Arabia Based on Time Series Data: A Comparative Study

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Abstract

The current study aimed at identifying the applications of deep learning to predict epidemics in the Kingdom of Saudi Arabia based on time series data. Time series analysis paid great attention to prediction as many studies indicated. Also, many applications were proposed for the purpose of predicting the future of life phenomena, diseases and epidemics. Due to the importance of comparison among the different prediction methods, the aim of this study was to make a comparison between the long-short-term memory network model and the Box-Jenkins Model in predicting infection or death resulting from epidemics in the Kingdom of Saudi Arabia. Each model was tested to predict three new days and a comparison was made between them based on relevant statistical criteria. The relationship such as (RMSE), (RUNS), (VAR), (MEAN) (AUTO) (RUNM). The study concluded that the proposed model that is appropriate for time series data is the model of neural networks with long short-term memory, and it has been applied to time series data. For the numbers infected with epidemics in the Kingdom of Saudi Arabia. Each model was tested to predict three new days and a comparison was made between them based on relevant statistical criteria such as (RMSE), (RUNS), (VAR), (MEAN), (AUTO) (RUNM). The study concluded that the proposed model that is appropriate for time series data is a model of neural networks with long-short-term memory. It was applied to time series data of numbers infected with epidemics in the Kingdom of Saudi Arabia.

Keywords: *Deep Learning, Time Series, Prediction.*

1. Introduction

Many epidemics and infectious diseases have spread around the world, including the Kingdom of Saudi Arabia, such as meningitis, the Spanish flu, and Corona. For this reason, the Kingdom of Saudi Arabia has sought to draw up plans and conduct many health researches try to eliminate these diseases and limit their spread.

Since there are devastating effects of epidemics and infectious diseases, wreaking havoc on social and economic development. Epidemics in the future may exceed outbreaks in previous years in terms of severity and danger. Therefore, it is important to exchange information, scientific knowledge, and best practices for predicting and managing

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epidemics and raising the level of preparedness in order to respond as soon as possible and optimally to any epidemic that may arise (United Nations, 2022).

Future forecasting is considered one of the most important decision-making tools and the most important element in the planning process for the future, and one of the most important basic issues used in several fields. Time series analysis is considered one of the common statistical methods used in forecasting on a large scale in many statistical, economic and health applications and in the field of computer science and neural networks and others; as the behavior of the dependent variable is predicted based on the behavior of this variable in the past. (Mosleh, 2018)

Time series analysis is based on a basic assumption, which is that time series is normal, meaning that it is normally distributed. This assumption has been overcome by some studies that have appeared related to abnormal time series. The method of time series analysis is based on the idea of finding a mathematical model suitable for the nature of the data, such that the residuals (statistics) between the true values of the series and the values estimated using that mathematical model is as small as possible. There is no kind of internal correlation between them (Okasha, 2002, P.517).

Based on the previous presentation, it is found out that the use of deep learning applications based on time series had an effective role in predicting the numbers of people infected with epidemics in the Kingdom of Saudi Arabia. The problem of the current study is determined in the following questions:

- What is deep learning?
- What are the applications of deep learning to predict epidemics in the Kingdom of Saudi Arabia based on time series data?
- What are the best models used to predict the number of infected people and deaths in epidemics in the Kingdom of Saudi Arabia?
- Are there differences between the LSTM model and the ARIM model?

This study may benefit officials in the Ministry of Health, various health centers, and all sectors of society in identifying the best models based on time series used to predict the number of infected people and deaths in epidemics in the Kingdom of Saudi Arabia.

2. Conceptual Framework of the Study

<u>Deep Learning Concept</u>

Deep learning is considered one of the branches of science that deals with artificial intelligence. It is currently considered a basic technology in the fourth industrial revolution. Due to its ability to learn from data, most deep learning research focuses on finding methods to derive a high degree of abstraction by analyzing a huge data set using linear and non-linear variables. It is widely applied in a variety of application fields such as health care, image recognition, analysis Texts, information security, and many other fields (Sarker, 2021, P. 420).

<u>Applications of Deep Learning to Predict Epidemics</u>

Many studies have shown the effectiveness and importance of using deep learning techniques in predicting the time series of some diseases. The following is a presentation of some applications of deep learning that are later used in predicting the time series of some epidemics as it follows:

- LSTM Model of Long-Term Memory Networks

Advanced memory modules are modules that are designed to overcome the vanishing gradient problem that negatively affects the efficiency of a simple temporal neural network. Gradient fading can be explained when the gradient becomes too small or too large, and this fading out reduces the effectiveness of the network. This problem appears during training processes, where examples are tracked and operations are executed while keeping the weight almost unchanged. (Zeroual, Harrou, Dairi & Sun, 2020, P. 3)

LSTM includes three basic gates that control the flow of information and are called input, coordination, and output gates. These gates simply consist of logistic functions of weighted groups, and the necessary weights for these operations can be obtained during training using backpropagation (Tian, Luthra & Zhang, 2020). It is worth noting that one of the features of the LSTM model is that it includes the ability to deal with long-term dependencies and large capacity on processing time series data. The input time data is given by X_t and the number of hidden units h, and the gates come with the following equations. (Zeroual, Harrou, Dairi, Sun, 2020, P. 3)

- Input Gate:

$I_t = \sigma(X_t W_{xi} + H_{t-1} W_{hi\,+}\; b_i),$

- Forget Gate:

$F_t = \sigma(X_t W_{xf} + H_{t-1} W_{hf\,+}\; b_f),$

- Output Gate:

$C_t = \tanh(X_t W_{xc} + H_{t-1} W_{hc\,+}\; b_c),$

- Intermediate Cell State:
- Cell State (Next Memory Input) $C_t = F_t \circ C_{t-1} \circ \hat{C}_{t,}|$
- New State: $H_t = O_t \circ \tanh\,(C_t)$
- $C_t = f_t \circ C_t H_{t-1}\;\tilde{C}_t$

▪ CNN Convolutional Neural Network Model

Recursive neural networks belong to the group of multi-layer artificial neural networks that have been successfully applied in image analysis and computer vision, especially in object recognition in images. Recurrent networks are inspired by biological processes in the brain, and the pattern of communication between neurons in them resembles the organization of the visual cortex (Y. Fu; C. Aldrich.,2019). Increasingly deep neural networks (ESAs) are a neural network model that has proven to be highly effective in areas such as image recognition and classification. An increasingly deep neural network usually consists of three types of layers: the convolutional layer, the pooling layer, and the full-connection layer (M. Ibbotson; Y. J. Jung. ,2020)

▪ Box and Jenkins ARIMA Model

It is an organized method for building and analyzing models until the optimal model was found out. It is considered the most optimal model if statistically significant information is available and if the errors in the model are independently distributed. In addition, it is one of the important statistical methods for analyzing time series. They are called autoregressive models and integrated moving averages. This model is used to represent a time series for a specific phenomenon to predict the values of the phenomenon in the future. (Sheikh, 2019, P. 47)

The ARIMA methodology was applied by Gwilyn Jenkinns and George Box. This term is based on three parts in its formulation:

1. Autoregressive Model (AR): This model takes the following formula:

$$X_t = \emptyset_1 X_{t-1} + \emptyset_1 X_{t-2} + \cdots + pX_{t-p} + et$$

<u>As</u>

X_{t-p}: Independent variables are values of the same variable ; hence the name endogenous, but for previous periods $(t-1, t-2, t-3, \ldots, t-p)$

e_t : The error term, or residual, that represents random occurrences that cannot be described by the model. The previous model is called autoregressive, but it resembles a multiple regression equation:

$$Y = a + b_1 X_1 + b_2 X_2 + \cdots + b_p X_p + e$$

The only difference is that

$$X_1 = X_{t-1}, \quad X_2 = X_{t-2}, \ldots, X_p = X_{t-p}, Y = X_t$$

Thus, the independent variables are values that differ for the dependent variable with lag times: (1 ,2 , . . . , p)

2. Moving Averages (MA): This model takes the following formula:

$$X_t = e_t - \theta_1 e_{t-1} - \theta_q e_{t-q}$$

As e_t : represents the error (or residual)

While

e_{t-1} , e_{t-2} , e_{t-3} , . . . , e_{t-q} are error values for previous periods.

3. Autoregressive and moving averages (ARMA). As for this model, the pattern of the data is often described well by a mixed process of the (AR & MA) element. The general formula of the mixed model is as follows:

$$X_t = \emptyset_1 X_{t-1} + \emptyset_2 X_{t-2} + \ldots + pX_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \cdots - \theta_q e_{t-q}$$

This formula ARIMA(p,d,q) can be expressed as follows

p: is the rank of the autoregressive model AR(p).

q: is the rank of the moving media model MA(q).

d: is the number of differences that make the series stable.

Stability

Determining the stability of the time series or not begins from the first stage of its analysis, as the first step in the diagnosis stage is knowing the stability of the time series. Unstable time series can be transformed into stable series, as the instability of the time series is either in the arithmetic mean or in the variance. The Partial Autocorrelation Function (PACF) is used to determine the appropriate model for the stable time series.

Unstable Models

These are models that do not have the characteristic of stability. Most time series models are of the unstable type due to the presence of a general trend, which makes them have several circles around which the data fluctuates. These series can be identified by observing the autocorrelation function, as its values do not go to zero. After the second or third displacement, their values remain large for a number of displacements. Unstable models are of two types:

1. Linear Models.
2. Non-Linear Models (Toa'me, 2012, PP.374-376).

Applications of Time Series-Based Deep Learning for Epidemic Prediction

The Concept of Time Series

They are values that appear according to time or a group of values that the phenomenon takes over a consecutive and equal period of time, which may be annual, seasonal (quarterly), monthly, daily, and so on. This is to know the nature of the changes that occur to the values of the phenomenon over time so that future estimates and predictions can be made. Time series analysis means analyzing its main components, which are the general trend of change in the value of the phenomenon on the long term. Furthermore, the seasonal trend, which are the changes that occur in the values of the phenomenon in short periods (less than years) such as seasonal, monthly and daily changes and periodic changes that occur in the value of the phenomenon periodically over periods exceeding a year and which are due to economic and political developments. Occasional changes that occur in the value of the phenomenon on an irregular basis as a result of the occurrence of natural disasters or wars. (Berry, 2002)

A time series is also defined as a group of observations of apparent values that are often taken at specific times of time (i.e., The intervals between one observation and the next may be equal or unequal, and in most cases, they are equal). If they are equal, they are expressed as $(Z_{t1}, Z_{t2} \dots., \dots., Z_{tn})$ at the time periods:$t_1, t_2, \dots, t_n$ as n refers to the number of observed values.The statistical series can be represented as follows:

$t = 0 \pm 1, \pm 2, \dots$ $\qquad Z_t = f(t) + a_t$

As

$f(t)$: It represents the regular part expressed by a mathematical function.

a_t : It represents the random part and may be called noise (noise).

The time series can be of a deterministic type, an example of this:

$$Z_t = \cos 2\pi a f_{(t)} t = 0 \pm 1, \pm 2, \dots$$

It means that it does not include the random part, and in this type of time series its future behavior can be determined, or the time series may be periodic. An example of this is data that appears in a sinusoidal form and can be represented in the following formula:

$Z_t = z_{t+s} \quad \forall t \; t = 0 \pm 1, \pm 2, \dots$

As s: is the period of the chain

Two types of time series can be distinguished:

Stable time series and unstable time series, as there are two states of stability:

1. Stability Average

It is the state of the series when it does not show a general trend and can be converted to stable using differences.

2. Stability Variance

It is the state of the series when no varying fluctuations appear in the form of the time series, and the variance can be fixed by obtaining the logarithm, the square root, or the reciprocals of the series data (Al Katea, 2007, PP. 11-12)

Implementation

The researcher depended on reports issued by the Ministry of World Health resulting from daily deaths due to epidemics during the period from 13/4/2020 to 14/7/2021. These reports include daily data on the number of infected cases, deaths, and recoveries from epidemics and viruses for the year 2019 for many countries. Deaths' data for the Kingdom of Saudi Arabia were used. The following table shows statistics for the study data

Table (1) Descriptive Statistics of the Study Data

Measures	Confirmed	Deaths	Recovered
Mean	106513.14	6002.52	79379.14

Median	103901.00	6000.00	97448.00
Std.Deviation	74511.285	4422.608	60923.384
Minimum	1	0	0
Maximum	260658	15001	191474

Study Aims and Hypotheses:

The study aims at:

1. Monitoring epidemics and deaths resulting from them, and the most important indicators that illustrate the extent of the tragedy.
2. Comparison between the Long Short-Term Memory Neural Networks (LSTM) Model and the Box and Jenkins ARIMA models to predict the number of daily deaths resulting from epidemics in the case of long time series, by verifying the following hypotheses:

▪ Deaths resulting from epidemics follow a normal distribution.

▪ There are no differences between the actual and estimated from the Box and Jenkins Model method and the LSTM neural networks.

▪ The Long Short-Term Memory Neural Networks (LSTM) model is better than the Box and Jenkins ARIM models.

Descriptive Statistics (Describing Data)

Data were collected, which consist of a time series of the daily numbers of deaths due to epidemics during the period from 13/4/2020 to 14/7/2021 to the historical curve of deaths resulting from epidemics in the following graph:

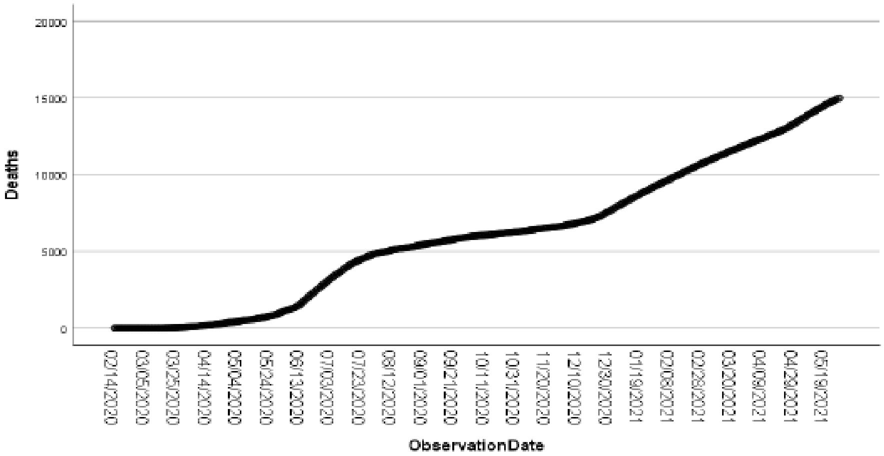

Figure (1) Daily Numbers of Deaths due to Epidemics according to the World Health Organization Report

Box and Jenkins Model for Predicting the Number of Daily Deaths Resulting from Epidemics in the Kingdom of Saudi Arabia

The use of Box-Jenkins models to predict daily deaths resulting from epidemics in the Kingdom of Saudi Arabia during the period 13/4/2020 until 14/7/2021 includes four phases: Identification, Estimation, Diagnostic Checking, and Forecasting. The following figure shows that model:

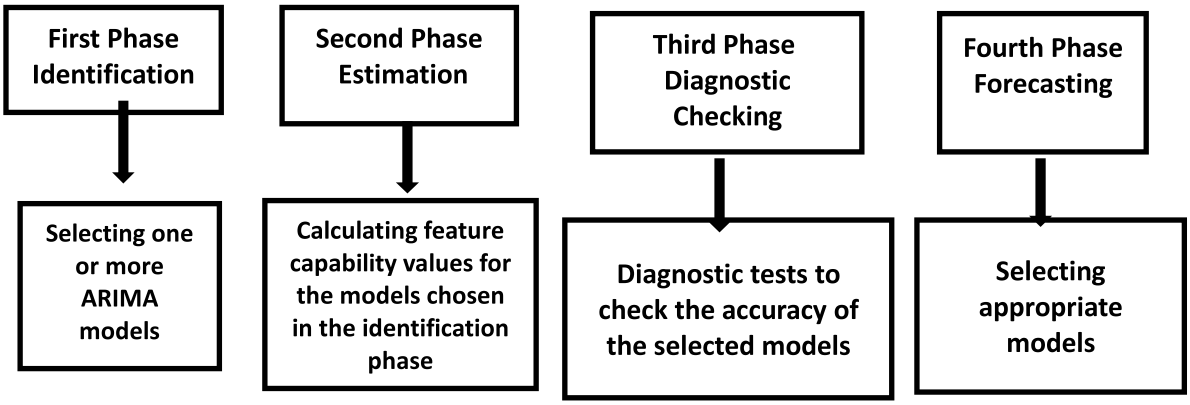

Figure (2) Box and Jenkins Model Path Map (ARIMA) (Designed by the Researcher)

1. Identification Phase:

The highest order autoregressive related variables were determined and a package model was used in addition to normal moving averages in Eviews 11 Software. Second order normal differences were then used after ensuring the stability of the time series. The parameters of this model were estimated and the necessary statistical standards were found to compare it with networks in the context of long time series during the model diagnosis checking phase.

Through that phase, the suitability of the models is studied to analyze the daily data series of the numbers of deaths resulting from epidemics that have been identified and estimated. Their efficiency and suitability is examined using the Akaike Information criteria (AIC) and its equation (AIC=2log maximum linkage) +2k, which has the lowest value. For these two standards (Matroushi, 2011), as shown in (Table 2).

Table (2) Statistical Standards Used to Compare the Selected Models

Model	RMSE	MAE	MAPE	ME	AIC	AQC	SBI
(K) ARIMA(1.2.0)	50.284	30.62294	11.501	0.142611	3.33361	3.33708	3.34243
(L) ARIMA(0.2.1)	50.28266	30.61821	1.828	0.294786	3.33735	3.34429	3.35499
(M) ARIMA(0.2.1)	50.29407	30.61865	1.494	0.16223	3033742	3.34089	3.34624
(N) ARIMA(2.2.0)	50.28952	30.62042	1.502	0.143777	3.33995	3.34689	3.35759
(O) ARIMA(2.2.2)	50.26758	30.60812	1.51	0.164006	3.34013	3.35401	3.37541

Based on the previous table, it is clear that using (1,2,0) ARIMA model is the best for data because it has a lower value for the AIC criterion.

Model Preference

Some criteria were used to evaluate the best models, the succession of residuals and their randomness, to express daily deaths resulting from epidemics in the Kingdom of Saudi Arabia. They are shown in the following table:

Model	RMSE	RUNS	RUNM	AUTO	MEAN	VAR
(K)	5.224	***	***	***	***	***
(L)	5.28266	*	OK	*	OK	***
(M)	5.29407	OK	OK	**	OK	***
(N)	5.28952	**	*	*	OK	***
(O)	5.26758	OK	OK	*	OK	***

Table (3) Comparison of the Residuals for the Box and Jenkins Models for Predicting Daily Deaths Resulting from Epidemics according to the Selected Criteria

Below is an explanation of the criteria used in comparing a set of models based on the smallest RMSE:

RMSE=Root Mean Squared Error

RUNS= Test for excessive runs above and down

RUNM= Test for excessive runs above and below median

AUTO=Box-pierce teast for excessive autocorrelation

MEAN=teast for difference in mean 1st half to 2nd half

VAR= teast for difference in variance 1st half to 2nd half

OK=not significant ($p >= 0.05$)

*=marginally significant ($0.01 < p <= 0.05$

**=significant $0.001 < p <= 0.01$

***=highly significant ($p <= 0.001$)

A method of long-term short-term memory neural networks (LMST) to predict the daily death numbers of epidemics:

Long-term memory neural networks (LMST) are a special type of recurrent neural network (RNN) architecture designed to model the problem of long-term, time-series dependency. They are considered more accurate than traditional RNNs; as the best results are obtained from their use. Long-term short-term memory consists of three gates. The input gate is tasked with adding useful information to the cell. The Forget Gate, which works to exclude useless information in the cell. The Output Gate, which extracts useful information from the current cell state to present it as an output. (Mohamed et al., 2022, P.30)

Neural Networks Design for Long-Term Memory (LMST)

The design of these networks goes through five stages: data collection, data processing, data partitioning, model improvement and training, and model evaluation (Khalifa, Wiem Ben, et al, 2020) (Omran et al., 2021) . Below is an overview of the stages in more detail:

1. The First Stage: Data were collected for the number of confirmed cases and deaths in epidemics from the period 13/4/2020 to 14/7/2021 and consists of time series data in the Kingdom of Saudi Arabia.
2. The Second Stage: This is data processing, and two steps are applied to the time series data in the Kingdom of Saudi Arabia through:

- Transforming data into supervised learning where the dataset is divided into input samples (x) and output (y) and the prediction is made with only one step (one day), the output (y) is the next time step (t+1) and for the input samples (x) 5 delay periods (5 days) were used.
- Data Scaling: It consists of rescaling data from the original range to a new range between 0 and 01 specifically, because LSTM models prefer to work on data within the range of their activation function [9] MinMaxScaler [0,1] (feature_range). The activation function ReLU was used in the evaluation phase.

1. Dividing the data set into two parts (80%) for the training set and (20%) for the test set. The training set is used to improve and train the models, while the test data set is used to evaluate the models. The data set was divided into input samples for the independent variable (X) and the dependent variable (y) as deep learning models are trained under supervised learning.
2. Improving the model and training by using long short-term memory (LSTM) as a candidate model for predicting epidemic disease deaths. A different number of hidden layers were applied, one layer and two layers (i.e., projection layer with hidden layer). The output layer includes one neuron and an activation function ReLU.(Adam &Tuner)
3. Evaluating the models to measure their performance. Three error criteria were used to estimate the forecast accuracy of the models. Two of these errors are scale-dependent errors, as these errors are on the same scale as the data itself and therefore cannot be used to make comparisons between time series data sets located at different levels. They are:

o The square root of the error of the mean RMSE (Root Mean squared Error)

It can be found in the following formula:

$$\text{RMSE}=\sqrt{\sum \frac{e_T^2}{n}} \quad e_T = Y_T - F_T$$

As

e_T : represents error or residuals, Y_T : represents the true values of the variable

F_T : represents the predicted values of the variable.

o Mean Absolute Error: It is calculated by the following equation:

$$\text{MAE} = \quad \text{MAE} = \sum \left(\frac{|e_T|}{n}\right)$$

The first and second tests are used to determine the predictive power of the model used, and the third error measure used in comparisons between several predictive models is the percentage error; i.e. mean absolute percentage error (MAPE), and is calculated as follows:

$$\text{MAPE} = \sum (|e_T|/Y_T)/n$$

This formula is used to compare several predictive models. This formula is used to determine the bias in errors towards the positive or negative direction. Whenever the individual value is close to zero, this indicates the accuracy of the prediction.

Comparison between LMST Model and the ARIMA Model for Daily Deaths Resulting from Epidemics:

After identifying the appropriate models for data and estimating their parameters, it was necessary to examine or select these models to verify the suitability of prediction and determine the best methods. Table (4) shows the comparisons between the models:

Table (4) Comparison of Daily Deaths as a Result of Epidemics

Model	Root Mean Square Error (RMSE)	Mean Absolute Error (MAE)	Mean Absolute Relative Error (MAPE)
ARIMA	50.291	30.62293	1.50
LSTM	29.8604	28.5943	0.4453

Based on the previous table, it was found out that the LSTM Network Model is the best and most suitable for data, as it has the fewest criteria used compared to (1,2,0) ARIMA Model. (Khalifa, Wiem Ben, et al, 2018)

Forecasting Using the Proposed Models

To predict the values for new cases for the purpose of comparison, (5) observations; deaths for the next five days, the days following 9/7/2021, were used as a test set. Table (5) shows the predicted values and the percentage of change, and from it we find that there is clear evidence of the efficiency of the LSTM Model. As it is considered the best and most appropriate of the ARIMA Model. Hence, the hypothesis was confirmed: "There is an advantage for the Long Short-Term Memory Neural Networks (LSTM) Model over the Box and Jenkins ARIMA Models."

Day	Actual	Expected		Change from Actual %	
		ARIMA	LSTM	ARIMA	LSTM
9 /7/2021	14806	14812.6	14809.2	0.04%-	0.04%
10/7/2021	14849	14850.61	14851.11	0.01%-	0.00%
11/7/2021	14903	14893.88	14903.85	0.07%	-0.07%
12/7/2021	14950	14953.86	14951	-0.03%	0.03%
13/7/2021	15001	14998.67	14999.7	0.02%	-0.02%
	74509	74509.63	74515.4	0.015%	0.0143%

It is clear from the previous table (5) that the LSTM Network Model is better and more suitable for the data.

3. Study Results

The study found out the following results:

LSTM artificial neural networks are more accurate and efficient in forecasting than the Box and Jenkins ARIMA Models, as LSTM neural networks have reached a high rate of accuracy while maintaining their advantage in forecasting for long time series.

It is preferable to use the LMST neural network model in forecasting and drawing plans, both long-term and short-term, because this model is distinguished by its speed and accuracy in data, more than in ARIMA models.

By applying Box and Jenkins ARIMA Models and LSTM Neural Networks, the following identified:

- LSTM Neural Networks excel in prediction as they have a methodology that does not depend on linearity in the data.
- LSTM Neural Networks are considered one of the best algorithms designed to model the long-run and time-series dependency problem

- LSTM Neural Networks perform more accurately than traditional RNNs.

4. Study Recommendations

The study recommends the following:

1. Taking the necessary measures to reduce the spread of diseases and epidemics through the competent authorities. Therefore, it is necessary to provide devices that measure early infections in epidemics, especially in the context of health crises such as the cholera epidemic and the Covid-19 pandemic.
2. Using smart technology methods such as neural networks and algorithms in dealing with the data series used in research and the possibility of obtaining the best results and comparing the results with the Box-Jenkins method and the LSTM method with other methods.
3. Publishing the results of this study and circulating them to conduct similar studies in other Arab countries that faced similar circumstances in order to compare and learn from different experiences and improve awareness and preparedness.
4. Inviting the media to present periodic programs and bulletins, and broadcasting awareness campaigns to limit the spread of epidemics for reducing infection and death rates, and enhancing health awareness in society.
5. Studying multivariate time series in future studies for forecasting in medical fields and studying diseases and epidemics that are affected by more than one variable, such as gender, age, and others.

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