

Application of Simple Exponential Smoothing Techniques for Forecasting Birth Rates in Maiduguri, Borno State

Aliyu, Bayero Abdullahi, and Nuhu Ibrahim

Department of Mathematics and Statistics, Federal Polytechnic Mubi, Adamawa State, Nigeria.

Corresponding author: Aliyuabdullahiabayero@gmail.com

Abstract

The Specialist Hospital of Maiduguri Metropolitan Council, one of the most popular hospitals in the state where births occur variously delivers women and their newborn babies, the choice of the hospital to conduct this research. The research covers a period of ten years, from 2013 to 2022. The aim is to determine a functional model suitable for forecasting future baby births. This will assist the government in planning for infants, nursing mothers, and projections for infrastructure and human resource development. Different smoothing constants using alpha (α) to find the best model for forecasting baby births. Specifically, smoothing constants of $\alpha = 0.1, 0.2$, and 0.5 were used in the analysis. The results indicate that a higher smoothing constant provided the best model for the forecasted births. A smoothing constant of $\alpha = 0.5$ appears to provide the most accurate forecast, as its figures are closer to the observed values than the other smoothing constants. Efforts were also made to determine the smoothing constant that minimizes the error. Towards this end, MAE, MAPE, and MSE were calculated to find the smoothing constant that minimizes the error. In the process, it was noticed that $\alpha = 0.9$ gives the lowest values of Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE), and therefore was selected as the best smoothing constant that minimizes the error.

Keywords: Exponential Smoothing, Error Measure, Forecasting, Smoothing Constant, MAE, MAPE, Baby Birth, Hospital.

Introduction

The high rate of infant mortality in both pediatric and nursery wards is of great concern, and researchers are trying to identify the factors that hinder infants' survival in the hospital (Umar et al., 2023). Mortality refers to the incidence of death during a specific period and is influenced by factors such as sex, occupation, technological advancements, standard of living, and healthcare (Jones et al., 2017). Measuring the health of living conditions in a country is an essential aspect of any preventive or improvement program.

Time series can be used for planning and forecasting by employing appropriate methodology to improve established and existing beliefs. Models are commonly used to predict future values of a time series (Cordeiro, 2008). A time series is a sequence of observations indexed by time, usually ordered in equally spaced intervals and correlated with each other. The importance of time series studies is well-known today. These studies provide indicators of a country's economy, including the unemployment rate, export and import rates of products, and more. The most interesting and ambitious task in time series analysis is forecasting future values. Models are commonly used to predict future values of a time series. Exponential smoothing methods are the most widely used forecasting methods (Ostertagova, 2011).

Exponential smoothing is an intuitive forecasting method that weights the observed time series unequally (Smartson and Thabani, 2023). Recent observations are given more weight than distant observations. The unequal weighting is achieved by using one or more smoothing parameters that determine the weight given to each observation. The simplest technique of this type is simple exponential smoothing, which is suitable for a series that moves randomly above and below a constant mean and has no trend or seasonal patterns (Patel et al., 2021). Thus, the essence of statistical analysis is to discover new ways of improving the present from the past and projecting into the future for the benefit of humanity.

Aim and Objectives

The objective of the study is to determine a functional model for forecasting annual baby births at the Specialist Hospital in Maiduguri Metropolitan.

To assist the government in planning for infants and nursing mothers, as well as making projections for future needs to enhance state development.

Materials and Methods

The data used for the study were birth records obtained from General Hospital, Maiduguri, Borno state. The data consist of annual counts of births recorded over eleven years, from 2013 to 2022, inclusive. The data collected from the hospital exhibited a high rate of fluctuation from year to year. Extreme cases occurred when data were not properly recorded for some months. The researcher had to use their initiative to account for the missing values. By doing so, the researcher made estimates from the available data to enable continuous research.

Three alpha values (0.1, 0.2, and 0.5) were used as smoothing constants for the study. The choice of these alphas was made after a series of trials with several values between 0 and 1. To find the best smoothing constant for forecasting baby births at the hospital. The forecasting results will be verified to determine the error value using MAE, MSE, MSD, and MAPE. The lowest value among the lowest error measures will be selected as the best for forecasting.

Simple Exponential Smoothing Model

Exponential smoothing is a forecasting method that calculates an average and is suitable for both short-term and long-term forecasting. Exponential smoothing calculates the smoothed series using a damping coefficient and the previous value of the smoothed series (Jadidi et al., 2015). Data on the underlying series is available. The extrapolated smoothed series remains constant, equal to the last value of the smoothed series (Sanjoy, K. P. 2011). Simply put, simple exponential smoothing is a special case of exponential smoothing that uses less data. The simple moving average assumes that the level of the time series should fluctuate around a constant level or change slowly over time.

The simple exponential smoothing model

The simple exponential smoothing model is given by the equation

$$Y(t) = \beta(t) + \epsilon(t), \quad (1)$$

Where $\beta(t)$ takes a constant at time t and may change slowly over time,

$\epsilon(t)$, is a random variable used to describe the effect of stochastic fluctuation.

Let an observed time series be $y_1, y_2, y_3, \dots, y_n$. In any case, in this simple model, predicting y_t is equivalent to predicting β . To estimate β , it makes sense to use all past observations. However, due to declining correlation as you go back into the past, older observations may be less reliable.

Formally, the simple exponential smoothing technique equation takes the form of:

$$F_{t+1} = \alpha y_t + (1 - \alpha)F_t, \quad (2)$$

where y_t is the actual known series value at time t ;

F_t is the forecasted value of the variable Y at time t ;

F_{t+1} is the forecasted value at time $t+1$;

α is the smoothing constant (Brown, 1961).

The forecast F_{t+1} is based on weighting the most recent observation y_t with a weight of α and weighting the most recent forecast F_t with a weight of $1-\alpha$.

To start the algorithm, we require an initial forecast, an actual value, and a smoothing constant.

Since F_t is not known, we can:

- Set the first estimate equal to the first observation. Furthermore, we will use $F_1 = y_1$.
- Use the average of the first few observations of the data series for the initial smoothed value.

The smoothing constant, α , is a selected number between zero and 1, i.e., $0 < \alpha < 1$.

Rewriting the model (2), we can see one thing about the SES model

$$F_{t+1} - F_t = \alpha (y_t - F_t). \quad (3)$$

Change in the forecasting value is proportional to the forecast error. That is

$$F_{t+1} = F_t + \alpha e_t, \quad (4)$$

Where residual

$$e_t = y_t - F_t \quad (5)$$

is the forecast error at time t .

The exponential smoothing forecast is the previous forecast plus an adjustment for the error that occurred in the last forecast (Eva and Oskar, 2012).

By iterating formula (2), we get:

$$F_t = y_1; F_2 = \alpha y_1 + (1 - \alpha) F_1 = \alpha y_1 + (1 - \alpha) y_1; F_3 = \alpha y_2 + (1 - \alpha) y_1; F_4 = \alpha y_2 + (1 - \alpha) y_1 + \alpha y_1 + (1 - \alpha) y_1 =$$

$$\alpha y_2 + \alpha (1 - \alpha) y_1 + (1 - \alpha)^2 y_1;$$

$$F_4 = \alpha y_3 + (1 - \alpha) F_3 = \alpha y_3 + (1 - \alpha) (\alpha y_2 + \alpha (1 - \alpha) y_1 + (1 - \alpha)^2 y_1) =$$

$$\alpha (y_3 + (1 - \alpha) y_2 + (1 - \alpha)^2 y_1) + (1 - \alpha)^3 y_1;$$

The forecast equation in general form is

$$F_{t+1} = \alpha \sum_{i=0}^{\infty} (1 - \alpha)^i y_{t-i} \quad (6)$$

F_{t+1} is the forecast value of variable Y at time $t + 1$, based on knowledge of the actual series values: y_t, y_{t-1}, y_{t-2} , and so on, going back in time to the first known value of the time series, y_1 (Ostertagova, 2011).

Therefore, F_{t+1} is the weighted moving average of all past observations.

The series of weights used in producing the forecast F_{t+1} is:

$$\alpha, \alpha (1 - \alpha), \alpha (1 - \alpha)^2, \dots \quad (7)$$

it is evident from (7) that the weights are exponential, hence the name exponentially weighted moving average (Aczel, 1989). The exponential decline of the weights toward zero is evident.

The decay is slower for small values of α , so we can control the rate of decay by choosing α appropriately. In other words, the term "smoothing factor" applied to α is a misnomer, as larger values of α actually reduce the level of smoothing, and in the limiting case with $\alpha = 1$, the output series is just the current observation.

Simple exponential smoothing is easily applied and produces a smoothed statistic as soon as two observations are available.

Measuring Forecast Error

After specifying the model has been specified, its performance characteristics were verified and validated by comparing its forecasts with historical data for the process reported in the literature.

Researchers have not reached a consensus on the best measure for determining the most appropriate forecasting method (Sungil and Kim, 2016). The most important concern in evaluating the quality of a forecast is accuracy, which is the goal of minimizing error (Cordeiro, 2008). Common

indicators used to evaluate accuracy are mean absolute error, mean squared error, root mean squared error, and mean absolute percentage error.

Mean Squared Error,

$$MSE = \frac{1}{n} \sum_{t=1}^n (f_t - y_t)^2 \quad (8)$$

Root mean squared error,

$$RMSE = \sqrt{MSE} \quad (9)$$

Mean absolute percentage error,

$$MAPE = \frac{1}{n} \sum_{t=1}^n \frac{|f_t - y_t|}{y_t} \quad (10)$$

Mean absolute error

$$MAE = \frac{1}{n} \sum_{t=1}^n |f_t - y_t| \quad (11)$$

Where y_t is the actual value at time t ; f_t is the forecast value at time t ; n is the total number of periods.

Mean absolute error is a measure of overall accuracy that indicates the degree of spread, where all errors are assigned equal weight. If a method fits the past time series data very well, the mean absolute error is near zero, whereas if a method fits the past time series data poorly, the mean absolute error is large. Thus, when two or more forecasting methods are compared, the one with the minimum MAE can be selected as the most accurate (Ryu et al., 2003). Mean MSE is a measure of overall accuracy that indicates the degree of spread. However, large errors are given additional weight. This is a generally accepted technique for evaluating exponential smoothing and other methods (Jarrett, 1991). Often, the square root of MSE, RMSE, is considered since it denotes the seriousness of the forecast error in the same dimensions as the actual and forecast values. MAPE is a relative measure that corresponds to MAE. This is the most useful measure for comparing forecast accuracy between different items or products, as it measures relative performance. It is one measure of accuracy commonly used in quantitative methods of forecasting (Makridakis, 1998). If the **mean absolute percentage error** is less than 10%, it is interpreted as excellent and accurate forecasting. Between 10% and 20% is considered good forecasting, between 20% and 50% is acceptable forecasting, and over 50% is inaccurate forecasting (Lewis, 1982). The choice of an error measure significantly impacts the conclusions drawn about the most accurate forecasting method from a set (Jones et al., 2017).

Selecting the best value for the smoothing constant

The ability to select an appropriate value for the exponential smoothing constant is the first step towards minimizing errors in forecasting. Researchers disagree on determining the optimal value of this fixed parameter, which is constrained between zero and one. There are no established rules for selecting the best smoothing constant in simple exponential smoothing (Al-Tai, F. 2004). Most of the time, the researcher uses the trial-and-error method to find the appropriate smoothing constant from a series of alpha values between zero and one (Al-Tai, F. 2004). The objective is to select a smoothing constant that balances the benefits of smoothing random variations with the benefits of responding to real changes when they occur. In practice, the smoothing constant is often chosen through a grid search of the parameter space, where different values for alpha are tried, starting with $\alpha=0.1$ to $\alpha=0.9$, with $\alpha=0.9$ being the final value tested. The value of α with the smallest error is chosen for producing future forecasts (Eva and Oskar, 2012).

Results and Discussions

The number of baby births obtained from Specialist Hospital, Maiduguri, from 2013 to 2022 is presented in Table 1 below.

Table 1: Observed Values of Baby Births from 2013 to 2022.

Time (t)	Observed Value (vl)
2013	1182
2014	1165

2015	1175
2016	1158
2017	1145
2018	1134
2019	1160
2020	1138
2021	1158
2022	1175

Table 2 below represents the time series observed for periods 1 to 10 and corresponding forecast values for the year 2023, using $\alpha = 0.1, 0.2,$ and 0.5 .

Time (year)	t y_t	Observed Values	Forecast $\alpha = 0.1$	Forecast $\alpha = 0.2$	Forecast $\alpha = 0.5$
2013	1182	1182	1182	1182	1182
2014	1165	1180	1179	1174	1174
2015	1175	1180	1178	1174	1174
2016	1158	1178	1174	1166	1166
2017	1145	1174	1168	1156	1156
2018	1134	1170	1161	1145	1145
2019	1160	1169	1161	1152	1152
2020	1138	1166	1156	1145	1145
2021	1158	1165	1157	1151	1151
2022	1175	1166	1160	1173	1173
2023	Forecast	1167	1170	1176	1176

The error measures were calculated for different values of exponential smoothing constants. Table 3 shows the values of MAE, MAPE, and RMSE for different α values.

α	MAE	MAPE	RMSE
0.1	1204.02	16.89	2250.54
0.2	1202.05	16.87	2248.68
0.3	1201.14	16.86	2245.74
0.4	1198.37	16.84	2244.68
0.5	1196.16	16.83	2242.65
0.6	1194.53	16.81	2240.77
0.7	1192.42	16.79	2237.77

0.8	1190.55	16.78	2235.78
0.9	1181.33	16.72	2232.38

Discussion

The purpose of this research is to evaluate forecast accuracy using time-series data obtained from a specialist hospital in Maiduguri. To actualize this objective, simple exponential smoothing (SES) techniques were used. Smoothing constants of $\alpha = 0.1, 0.2$, and 0.5 were used to calculate the optimal value for the best suitable forecast. Table 2 above represents the analysis of the time-series data using three smoothing constants $\alpha = 0.1, 0.2$, and 0.5 . The forecast figures indicate that a smaller alpha $\alpha = 0.1$ produced a higher forecast compared to the observed values. Likewise, $\alpha = 0.2$ produces values lower than those produced by alpha 0.1 . Using alpha 0.5 gives the forecast figures closer to the observed values, which indicates that a higher smoothing constant gave the best forecast and should be used to forecast baby births in the Specialist Hospital, Maiduguri. Hence, ten years from 2013 to 2022 data on baby births were collected for this research. The forecast for the eleventh year was made using the smoothing constants of $\alpha = 0.1, 0.2$, and 0.5 . (LI, et al; 2008) These produce the forecasts of 1167, 1170, and 1176, respectively, for the eleventh year. Table 3 above also represents the values of MAE, MAPE, and RMSE. The values of the Error Measures depended on the choice of the smoothing constant, α . In this research, the values of the smoothing constant used range from 0.1 to 0.9 . From Table 3, it is easy to notice that the values of MAE, MAPE, and RMSE decreased with increasing α up to 0.9 . As mentioned earlier, given a series of error measures, the lowest value of MAE, MAPE, and RMSE gives the best forecast that minimizes the error. From Table 3, we should select 0.9 as the best smoothing constant since its MAE, MAPE, and RMSE give the lowest figures.

Conclusion

The research on the application of Simple Exponential Smoothing Techniques for forecasting birth rates in Maiduguri, Borno State was successfully conducted. The exponential smoothing (SES) technique is typically based on the assumption that the time series level should fluctuate around a constant level or change gradually over time. The exponential smoothing technique provides the idea that the most recent observations usually provide the best guide to the future, so we require a weighting scheme with decreasing weights for older observations. The choice of the smoothing constant is important in determining the operating characteristics of exponential smoothing. The choice of α is one of the major steps towards achieving the best model in exponential smoothing (Umar et al., 2023). Smaller values of α result in a slower response, which may lead to little or no change in the trend's fluctuation, and the smoothed value will react slowly (Brown, 1961). On the other hand, larger values of α provide a quick response, causing the smoothed value to react quickly. Ideally, the larger the value of α , the quicker the real change is noticed in both the smoothed value and its random fluctuation. The simple exponential smoothing (SES) model is only suitable for non-seasonal patterns with approximately zero trend and short-term forecasting. The double exponential smoothing model is appropriate for time series that contain trends and seasonal patterns. However, this is beyond the scope of this research.

Recommendations

- The Borno state government should use the analysis made here to improve the welfare of newly born babies and their nursing mothers.
- The government should make it a policy for every hospital in the state to have a functional forecasting model of annual births to enable the management of the hospital to plan ahead.

- The government should embark on an open campaign to educate married couples on the importance of reporting any new birth to the appropriate authority for documentation.

Conflict of interest by the authors:

There are no conflicts of interest declared by the authors.

References

- Al-Tai, F. (2004) A. *Estimate the Multiplier Smooth Parameter with Simulation*. Journal of Tamiat Raidam, Computer Science and Mathematics, No.1, Baghdad, Iraq, 2004.
- Brown, R. Meyer, R. F.(1961): "*The Fundamental Theory of Exponential Smoothing*. *Operational Research*, 9, 673-685.
- Cordeiro, C., Neves, M. M. (2008). *Bootstrap and Exponential Smoothing working together*. Forecasting time series, Proceedings in Computational Statistics, Physica-Verlag. 891-899.
- Sungil Kima and Heeyoung Kim (2016). A new metric for absolute percentage error for intermittent demand forecasts. [International Journal of Forecasting Vol.32, Issue 3](#), Pages 669-679
- Smartson. P. Nyoni, Thabani Nyoni.(2023).Applying Holt's Double Exponential Smoothing Method in Forecasting Adolescent Fertility for Sierra. *International Research Journal of Innovations in Engineering and Technology (IRJIET)*, Vol.7, Issue 2, pp. 344-348.
- Gelper, S.; Fried, R.; Croux, CH.: *Robust Forecasting with Exponential and Holt Winters Smoothing*, Journal of Forecasting, Vol. 29, 285- 300, 2010.
- Holt, C. (1957) *Forecasting trends and seasonals by exponentially weighted average*. N. R. Memorandum 52/1957, Carnegie Institute of Technology.
- Jadidi, M. & Taufiq, R. R. (2015). *Implementation of Smoothing Methods for Forecasting Store Retribution Income Progress*, Vol. 1, pp. 1133-1142.
- Jarret, J.:(1991). *Business Forecasting Methods*. Cambridge, MA: Basil Blackwell.
4. Diebold, F.
- Lewis, C. D.: *Industrial and Business Forecasting Methods*, London, Butterworths, 1982.
- LI, Z. P., YU, H., Liu, Y. C., Liu. FO. (2008). *An Improved Adaptive Exponential Smoothing Model for Short-Term Travel Time Forecasting of Urban Arterial Street*. *Acta Automatica Sinica*. Vol. 34, No. 11, 1404-1409, .
- Ostertagova, E., Ostertag, O. (2011). *The Simple Exponential Smoothing Model*, Proceedings of the 4th International Conference on Modelling of Mechanical and Mechatronic Systems Technical University of Kosice, Vol. 27, 380-384, 2011.
- Yorucu, V.: 2003. *The analysis of forecasting performance by Using Time Series Data for two Mediterranean islands*, Review of Social, Economic & Business Studies, *Dining Facility*. The Journal of Hospital Financial Management, Vol. 11, No. 1, Vol. 2, 175- 196.
- Eva Ostertagova and Oskar Ostertag (2012). Forecasting: Methods the Simple Exponential Smoothing Method. *Acta Electrotechnica et Informatica*, Vol.. 12, No. 3, 2012, 62–66, DOI: 10.2478/v10198-012-0034-2
- Patel, K. K., Prasad, J. B., and Biradar, R. A. (2021). Trends in and determinants of neonatal and infant mortality in Nigeria based on Demographic and Health Survey data. *Journal of Biosocial Science*, 53(6), 924-934.
- Sanjoy, K. P.(2011). Determination of Exponential Smoothing Constant to Minimize Mean Square Error and Mean Absolute Deviation," *Global Journal of Research in Engineering*, Vol. 11, 786.901.
- Umar Yusuf Madaki, Umar Chiroma Adamu, Adamu Adamu Muhammad, and Ishaq Abdullahi Baba (2023). Forecasting Infant Mortality Rate using Exponential Smoothing and Moving Average Techniques. *Gadua Journal of Pure and Allied Sciences*. Vol. 2(1): 40-49.