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Predicting Student Enrollment at the Education College of Benghazi via Mathematical Modeling Approaches

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ABSTRACT

This study aims to demonstrate the process of three different models for predicting the number of undergraduate students enrolled at the Education College of Benghazi in a certain period. These models are Exponential change method, logistic method and the least squares method. Data was collected from registration and admissions office of the education college of Benghazi for the years 2015-2023. This data will be used to forecast for all methods that will be discussed in this research. For evaluating and comparing the efficiency and accuracy of these methods, Mean Absolute Deviation (MAD), Mean Absolute Percent Error (MAPE), and Root Mean Square Error (RMSE) were used. Enrollment data analysis allowed for the comparison of the models to the actual enrollment in regards to which method gave the best prediction of future student enrollment. The least squares method provided the most accurate estimations, with the precision rate of 92%. The three models were further used to predict enrollment levels for the Education College of Benghazi in the future semesters.

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1.Introduction

Several higher education institutions require the integration of forecasting into their development processes. A major aspect of this forecasting involves predicting the number of assigned to specific programs. This approach helps to meet college needs and address the distribution of resources effectively to their distinct college contexts [29]. In addition, it is to support the government in its provision of funds for higher education [17].

Colleges of Education in Libya are important institutions designed to train future teachers. The predicted increase in student enrollment is a result of the increasing demand for education. Therefore, numerous factors that education colleges face in the process of forecasting student enrollment include population growth, economic fluctuations, limited budgets, changing students' preferences, and evolving education polices. As a result, student enrollment

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predicting is important to Educational Colleges due to its influence of teacher training, curriculum development and Educational Qualification meeting student's demands. Most colleges today use conventional methods of forecasting and these are often insufficient. Consequently, the search for an accurate, evidence-based approach to forecast future student population is rather urgent.

Among these, there is the use of mathematics approaches as one of the popular methods of assessing historical data to forecast the future student enrollment [29] [1]. A mathematical model represents the behavior of real system, and

can predict future outcomes [9] [24]. This study examines three models: exponential change, logistic methods, and least squares methods to predict undergraduate enrollments at the Education College of Benghazi from Fall 2015 to Fall 2023. The term of prediction refers to the scientific method used to estimate future procedures by investigating historical data [12]. The researchers characterize a procedural prediction in this study as a forecasted numerical value for a future event, which can be determined through a mathematical approach. Although several mathematical techniques exist for predicting, further research is required to improve the accuracy of predictions concerning student populations.

The study objective to fill the research gap by comparing student enrollment prediction methods for the Education College of Benghazi from year 2015 to year 2023. The performance of the model will be verified by mean absolute deviation (MAD), the relative error of the mean average absolute error (MAPE), and root mean square error (RMSE). This research is among the first to the beast of the researcher's knowledge to develop a prediction model for the Education College of Benghazi. It provides a valuable insight that assist educational policymakers in making informed decisions on regarding resource allocation and preparing colleges for future demands.

2. Related works

Predicting student enrollment is crucial for educational institutions, using various methods for accurate forecasts. Research indicates a variety of mathematical modeling techniques are used for this purpose. Some methods include: 1) Machine learning methods [39] [4] [15] [16] [33]; 2) The Random Forest method [37]; 3) ARIMA and LSTM models [3] [32]; 4) Generalized weighted proportion estimation models [41]; 5) Natural language processing methods [22] [34]; 6) Time series analysis [35] [38] [40] [7]; 7) Educational data mining techniques [25] [21]; 8) Newton-Gregory Polynomial Method [27]; 9) Markov Chain Models [43].

This research paper describes several approaches employed in mathematical modeling to forecast student enrollment. The methods discussed include exponential growth, logistic regression, and least squares. The exponential growth model is often used to make assumptions about short-term growth in population. Nonetheless, may overestimate long-term growth by failing to consider the limiting factors [4] [26] [1].

Logistic regression is a nonlinear method developed from the exponential model, which takes carrying capacity into account and is suitable for formulating of long-term predictions [20] [42] [21] [8] [23] [1]. This model reflects natural factors and can be used to forecast network traffic, which might also be adapted for student enrollment predictions [19].

The least squares regression model minimizes the sum of the squares of the residuals and can be used to predict various factors; such as students' academic performance and enrollment trends [31] [36] [1] [30] [10]. This method is effective for evaluating students' progress, and for planning future educational-activities. It is recommended that institutions should utilize a variety of techniques and subsequently compare the results to improve enrollment predictions [2] [11]. Furthermore, when using exponential and logistic models, the least squares method enhances prediction accuracy. The Curve Fitting Least Square method is particularly effective for large discrete datasets, as it minimizes data distortion [14].

3. Methodology

The methodology of this study involves utilizing three mathematical models to predict students' enrollment in the College of Education. This process includes actual enrollment data and the potential to develop numerical models for future enrollment predictions. The models used in this study require a comprehensive set of historical data across one or more census frames. When presented in graphical form, these data reveal certain characteristics or trends [18] [6].

3.1. ***Dataset***

Each of the three types of models used in this study has its own characteristics that make it suitable for performing certain data operations. Student census models will be approximated and estimated using statistical data collected from the registration and admissions office at the Education College of Benghazi, covering the semesters from Fall 2015-2016 to Fall 2023-2024 (Table 1). This data is used to forecast student census and determine which of these methods most accurately reflects the reality of the Education College of Benghazi. It is also important to note that all information was collected except for the Fall 2020-2021 semester due to the COVID-19 closure.

Table 1. Students' numbers enrolled at Education College of Benghazi

Year	Students enrolled			
	Fall	**S. No.**	**Spring**	**S. No.**
2015-2016	1	639	2	638
2016- 2017	3	841	4	812
2017- 2018	5	929	6	985
2018- 2019	7	1157	8	1324
2019- 2020	9	1238	10	1380
2020-2021	-	-	11	1436
2021- 2022	12	1330	13	1378
2022- 2023	14	1456	15	1549
2023-2024	16	1888	-	-

For the purpose of this study, the researchers employed data on the total number of students enrolled in the Education college of Benghazi, as presented in the Table 1. The analysis of the data reveal consistent trend of growth as shown in (Figure 1).

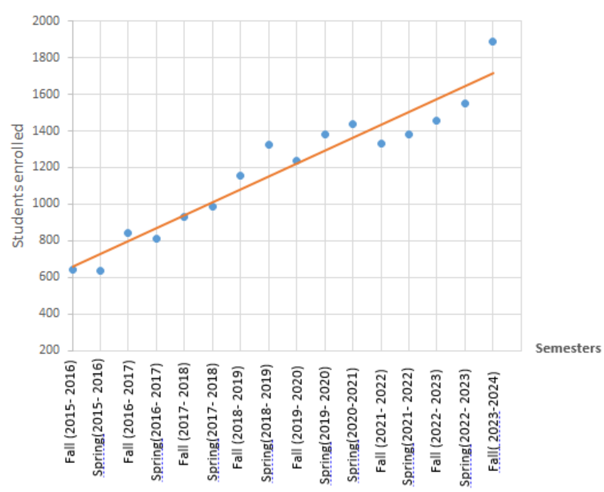

Figure 1. The student population

3.2. Mathematical forecasting models

In the following section, three different modeling approaches will be introduced: The Exponential change method, the Logistic method, and the Least square method.

3.3. Exponential Change method

The exponential change method is an accurate and widely used approach for estimating population size when vital statistics are unavailable [1]. The exponential change model known as (accelerated change), it sees that change occurs continuously rather than at intermittent intervals. The exponential rate of population change during the base period can be calculated as follows:

$$r = \frac{ln \frac{y_b}{y_\circ}}{z}$$

Based on this value, the calculation of the number of students utilizing the exponential method is derived from the established relationship [1] [28].

$$y(t) = y_\circ e^{rx}$$

Where

r = the rate of change for semi- annual (per semester) exponential growth.

$y_\circ$ = the number of enrolled students for the base semester.

y_b = the number of enrolled students for the launch semester.

z = the number of semesters between the base semester and launch semester.

x = the number of semesters between launch semester and future semester.

To estimate the number of enrolled students in the Education College of Benghazi for the semesters spanning the academic years 2015-2019, it is necessary to compute the semi-annual exponential growth rate $\boldsymbol{r}$ for the period from the base semester of fall 2015-2016 to the launch semester of spring 2019-2020. This analysis covers z which is a total of eight semesters. We get $r = 0.096242$. Therefore

$$y(t) = y_\circ e^{0.096242\,x} \qquad (1)$$

This model can now be used to make future forecasting regarding the expected number of students. Therefore, by employing the exponential change method with Equation (1), the estimated number of students for the semesters that following the spring semester of 2020-2021 through the fall semester of 2023-2024 is in (Table 2) as follows.

Table 2. Predicted students number using Exponential Change method

Semester	**Semester number**	**Real numbers**	**Students predicted number**
Spring(2020-2021)	11	1436	1519
Fall (2021- 2022)	12	1330	1672.91
Spring(2021- 2022)	13	1378	1841.92
Fall(2022- 2023)	14	1456	2028
Spring(2022- 2023)	15	1549	2232.88
Fall(2023-2024)	16	1888	2458.46

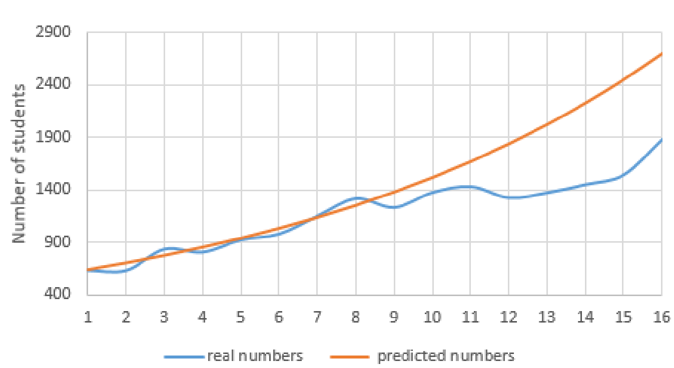

Figure 2. Predicted students number using exponential change method

The analysis of (Figure 2) reveals that the graph representing the exponential change method indicates a close approximation to actual data trends during the early semesters. However, as time progresses, the graphical representations begin to significantly diverge from the observed real data trends.

3.4. Logistic method

This strategy is classified as a logistic strategy. It posits that the population in a specific area will continuously increase until it reaches a limit, beyond which it will stabilize [13]. The logistics approach can be expressed using the following formula:

$$y_t = \frac{y_s}{1+ e^{a+bx}} \quad (2)$$

Where

y_t= the number of enrolled students at time t.

y_s= the saturated number of students, is given by

$$y_s = \left| \frac{2\, y_0\, y_1\, y_2 - y_1^2 (y_0 + y_2)}{y_0\, y_2 - y_1^2} \right|$$

y_0 = the Initial number of enrolled students at the begging of the historical time period

y_1 = the number of students at the middle of the historical time period

y_2 = the number of students at the end of the historical time period

x = the difference in time between semester of prediction and base semester

a, b = the constants are given by

$$a = \ln \frac{y_s - y_2}{y_2} \quad , \quad b = \frac{1}{n} \ln \frac{y_0\,(y_s - y_1)}{y_1\,(y_s - y_0)}$$

We have in this case, $a = 4.19223$, $b = -0.04717$, $y_0 = 639$, $y_1 = 929$, $y_2 = 1380$, $y_s = 92694.83$,

and $x = 10$ semesters.

Utilizing the Logistic method, the estimated number of students transitioning from the spring semester of 2020-2021 to the fall semester of 2023-2024 is calculated based on the equation (2) as shown in (Table 3) and (Figure 3).

Table 3. The predicted students number using logistic method

Semester	Semester number	Real numbers	Students predicted number
Spring(2020-2021)	11	1436	2192.08
Fall (2021- 2022)	12	1330	2295.33
Spring(2021- 2022)	13	1378	2403.33
Fall(2022- 2023)	14	1456	2386.68
Spring(2022- 2023)	15	1549	2634.34
Fall(2023-2024)	16	1888	2757.79

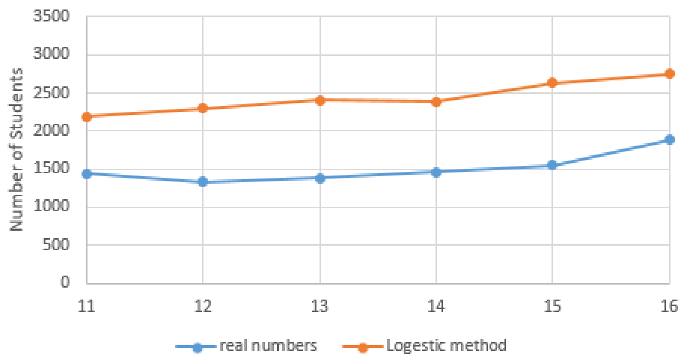

Figure 3. Predicted number of students by logistic method

Figure (3) demonstrates that the graph of the logistical approach significantly deviates from the actual graph from the beginning.

3.5. Least squares method

Simple regression analysis is used to identify the relationship between two variables. The least squares method is used to conduct the regression analysis based on the data presented in (Table 1) above. In this analysis, the dependent variable is the number of students y, while the independent variable is the semester x [33]. Figure (4), provide a graphical representation of the data which exhibits a linear relationship. Therefore, we can model this relationship as a linear equation in the following form.

$$f(x_i) = b\, x_i + a \qquad (3)$$

In this context, $f(x_i)$ signifies the fitted value, while the model parameters, designated as a and b, need to be estimated based on the available data. Here, i represents the index of the data points. The dataset commences in the fall of 2015-2016, with this period identified as $(x_1 = 1)$, and it progresses sequentially until the fall of 2023-2024, corresponding to the i point index.

We will determine the values of parameters a and b using the least squares method. The sum of squared errors is defined as follows.

$$S_e(a,b) = \sum_{i=1}^{16} (y_i - (b\, x_i + a)\,)^2 \qquad (4)$$

Since we need the least of the square of this error, we differentiate equation (4) with respect to the parameters a and b as follows.

$$\frac{\partial S_e(a,b)}{\partial b} = 0 \quad \rightarrow \quad b \sum_{i=1}^{16} (\,x_i)^2 + a \sum_{i=1}^{16} x_i = \sum_{i=1}^{16} x_i y_i \qquad (5)$$

$$\frac{\partial S_e(a,b)}{\partial a} = 0 \quad \rightarrow \quad b \sum_{i=1}^{16} x_i + 16a = \sum_{i=1}^{16} y_i \qquad (6)$$

As per the information provided in table 1, following calculations are to be made.

$$\sum_{i=1}^{16} x_i = 136\ ,\ \sum_{i=1}^{16} y_i = \ 18980\,,\ \sum_{i=1}^{16} x_i y_i = 185371\ ,\ \sum_{i=1}^{16} (\,x_i)^2 = 1496$$

Substituting into equations (5) and (6), we get $a = 585.23$, $b = 70.709$. Therefore, the linear model is

$$f(x_i) = 70.709\, x_i + 585.23 \qquad (7)$$

The slope of the line is positive which simply means that there is a direct proportion with the number of student.

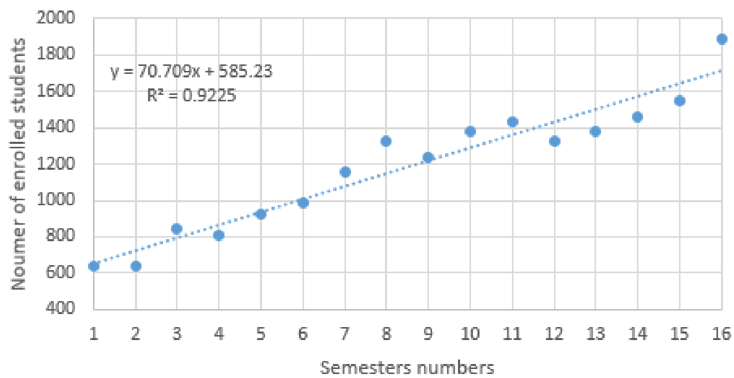

Figure 4. The student population based on Table 1

The coefficient of determination is known as the R^2 which describes the level of variability of student enrollment explained by the variability of semesters'. The value of R^2can be between 0 to 1. In the case of regression, the R^2 coefficient is to ascertain proportionate percentage of total variability that could have been explained by the model developed in this analysis.

$$R^2 = \frac{\sum_{i=1}^{16}(y_i - \bar{y})^2 - \sum_{i=1}^{16}(y_i - f(x_i))^2}{\sum_{i=1}^{16}(y_i - \bar{y})^2}$$

where $\bar{y} = 1186.25$ (the mean of the variable y_i), and $R^2 = 0.92253$

$\sum_{i=1}^{16}(y_i - f(x_i))^2 = 142750.1735$, $\sum_{i=1}^{16}(y_i - \bar{y})^2 = 1842661$

Therefore, we can claim that the model (7) can explain the data for 0.92% of the variance in the data. The standard error will be calculated as the square root of the sum of squares divided by $n-2$, where n denotes the number of observations.

$$SE = \sqrt{\frac{S_e(a,b)}{n-2}}$$

Then we can write the error $y_i - f(x_i)$ and the percentage error

$$PE = \frac{|y_i - f(x_i)|}{y_i} * 100$$

The critical value of t-distribution with $n - 2 = 14$ degrees of freedom for 95% confidence interval is $t_{\frac{\alpha}{2}} = 2.145$, the limits of the 95% confidence interval for the expected number of students can be calculated by

$$CI = f(x_i) \mp t_{\frac{\alpha}{2}} SE \sqrt{1 + \frac{1}{n} + \frac{(x - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}}$$

As shown in the above equations, we also estimated the expected number of students for further semesters (see Figure 5). The last two columns refer to the 95% confidence interval for the expected number of students for each semester as shown in (Table 4).

Table 4: Predicted student population and 95% confidence interval limits

Semester number	Real numbers	Predicted values	Percentage error	Lower limit	Upper limit
1	639	655.9338	3%	415.9232	895.9444
2	638	726.6426	14%	490.6824	962.6028
3	841	797.3515	5%	547.5326	1047.1704
4	812	868.0603	7%	638.6196	1097.501
5	929	938.7691	1%	711.7543	1165.7839
6	985	1009.478	2%	784.2826	1234.6734
7	1157	1080.187	7%	856.2302	1304.1438
8	1324	1150.896	13%	927.5562	1374.2358
9	1238	1221.604	1%	998.2713	1444.9367
10	1380	1292.313	6%	1068.3562	1516.2698
11	1436	1363.022	5%	1137.8266	1588.2174
12	1330	1433.731	8%	1206.7162	1660.7458
13	1378	1504.44	9%	1274.9993	1733.8807
14	1456	1575.149	8%	1325.3301	1824.9679
15	1549	1645.857	6%	1409.8968	1878.8172
16	1888	1716.566	9%	1476.5554	1956.5766

To construct the confidence intervals for the parameters of the model a and b, we first find the standard errors of a and b by using the following formulas:

$$SE(a) = a \pm t_{\frac{\alpha}{2}} S_a \quad , \qquad \mathrm{SE(b)} = b \pm t_{\frac{\alpha}{2}} S_b$$

Where

$$S_a = S_\epsilon \sqrt{\frac{\sum x_i^2}{n\sum(x_i - \bar{x})^2}} \quad , \quad S_b = \frac{S_\epsilon}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

The results of confidence interval for the parameters (a) and (b) shown in (Table 5).

Table 5. Confidence interval

Variables	Education College	Variables	Education College
a	585.225	b	70.70882
S_ε	100.9774	S_b	5.47627
S_a	52.95301	Lower limit	58.96339
Lower limit	471.6521	Upper limit	82.45425
Upper limit	698.7979	b	70.70882

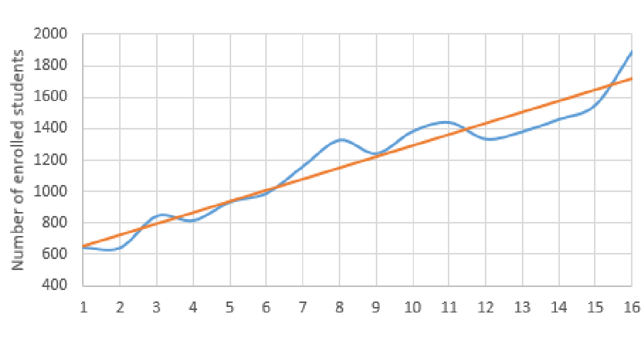

Figure 5. Predicted students number using Least squares method

Three mathematical techniques have been employed to determine the number of students in the Education college of Benghazi from the academic year 2015/2016 to 2023/2024. Tables 2, 3 and 4 present the results of the study conducted among students. Moreover, the forecasted numbers were graphically shown in (Figure 6).

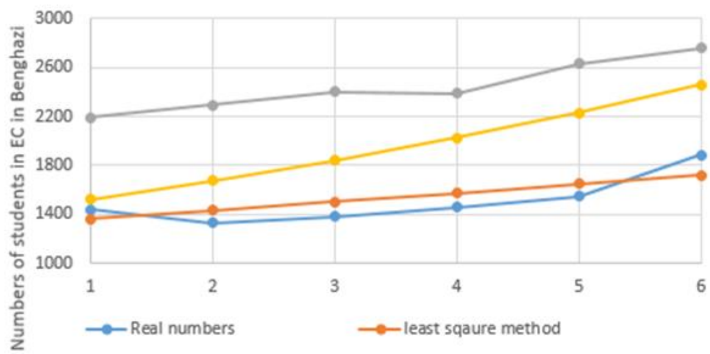

Figure 6. Predicted students number using the forecasted methods

It is clear from (Figure 6) that the least squares method offers the most accurate depiction of the student population's reality.

3.6. Forecasting Error

The objective of model evaluation is to diagnose and determine how far actual results deviate from the estimated values. The difference between expected and actual figures is referred to as forecast error. Although forecast error is an unavoidable aspect of the process, the goal of forecasting is to minimize the magnitude of this error. For this purpose, three standard metrics used to compare and assess the quality (reliability and performance) of different methods were employed in order to identify the most precise of solution. The mean absolute percentage error (MAPE), the root mean square error (RMSE) and the mean absolute deviation error (MADE) are defined by the formulas, respectively.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|A_i - F_i|}{A_i}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(A_i - F_i)^2}{n}}$$

$$\text{MADE} = \frac{\sum_{i=1}^{n}|A_i - F_i|}{n}$$

Where A_i – actual value, F_i – forecasted value.

The statistical coefficients of the three methods were calculated and the results are shown in (Table 6).

Table 6 Values of the statistical coefficients.

Method	$MAPE$	$RMSE$	MADE
Exponential Change method	0.298132274	493.2880329	452.695
Logistic method	0.632828301	944.7648214	938.7583333
Least square method	0.07595577	119.0517352	115.0983333

The finding in (Table 6) imply that the Least Square method is more accurate as compared to the Exponential Change method and the Logistic methods. Indeed, the Least Square method provides lower MAPE, RMSE, and MADE than the other two methods used, proving itself as the best approach for the predicted student numbers.

4. Results

The analysis of figures 2, 3 and 5 indicates that both the logistic method and the exponential change method are inadequate for making predictions, as they significantly overestimate actual outcomes and their graphical representations diverge considerably from real data trends. The curve of the exponential change method shows that during the first semesters, Equation (1) gives relatively accurate approximation of reality, but with the increase in the forecasting period, this accuracy decreases sharply. This shows a significant risk when using either technique to forecast student enrollment. However, the least squares method suggestions greater accuracy in estimates, and the resulting curve closely aligns with actual data trends. Particularly, the predictions generated by the least squares method are slightly higher than the actual figures. This is indicating its likely efficacy for forecasting student enrollment at the Education College of Benghazi. Moreover, as verified by the data in Tables 2, 3, and 4, the mean absolute percentage error (MAPE) for the least squares method is 0.076, which is considered acceptable.

In contrast, the logistic method and the exponential change method reveal Mean Absolute Percentage Error (MAPE) values of 0.633 and 0.298, respectively. These figures indicate a substantial deviation from actual outcomes, as lower values in Table 6 indicate a more effective forecasting approach. The Mean Absolute Deviation Error (MADE) for the least squares method was recorded at 115.098, while the exponential change method yielded a value of 452.695, and the logistic method reached 938.758. This shows that the least squares method outperforms the exponential change method in forecasting student enrollment at the Education College of Benghazi. Additionally, the data in Table 6 shows

that the logistic method is unsuitable for predicting student enrollment at the Education College of Benghazi, as indicated by its significantly high accuracy coefficients.

Based on the calculated error coefficients, it is evident that the results from both the exponential change and logistic methods, as shown in Table 6, are significantly higher than those obtained from the least squares method. The mean absolute percentage error (MAPE) in relation to the least squares method is 7.6% and therefore can be considered to have an acceptable standard error not exceeding 10% [13]. Hence, it is appropriate to apply this method to the forecast of student enrolment. However, the Mean Absolute Percentage Error (MAPE) for the exponential change method is 29.9%, while the logistic method has a MAPE of 63.3%. As a result, these two methods are not recommended for forecasting student enrollment at the education college of Benghazi.

Furthermore, we could predict student enrollment for the Education College of Benghazi for 2023, 2024, and 2025 using three forecast models as shown in (Table 7). The study's findings are similar to the findings of the study conducted by [13]. MAPE is considered acceptable with the least squares method, while the Exponential Change method yields moderate actuality and the Logistic method is the least effective.

These results stress that the chosen method should depend on the data properties and specific needs. This paper has clearly shown that the use of the least squares method produces significantly improved forecasts when applied to student enrollment at the Education College of Benghazi, compared to using the exponential change or the logistic methods.

Table 7. Predicted students number in (2023-2025)

Semester	**Semester**	**Predicted students number**

	number	Exponential Change method	Logistic method	Least square mothed
Spring (2023-2024)	16	2458.46	2757.79	1716.566
Fall (2024-2025)	17	2706.83	2886.85	1787.275
Spring (2024-2025)	18	2980.29	3021.73	1857.984

5. Conclusion

The predicted students' number plays a crucial role in planning and resource allocation for educational institutions. The research presents the exponential change method, logistic method, and least squares method models for predicting college enrollment. The least squares method confirmed the highest percentage of accuracy at 92% with low forecast errors. These models were then utilized to make forecasted enrolment levels for the Education College of Benghazi over the next three semesters. This information is essential for administrators at the Education college of Benghazi to make decisions regarding class sizes, faculty requirements, and infrastructure needs.

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