The Relationship between Suicide Rates and Mental Health Provider Ratio

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Abstract
This project is an analysis of the relationship between suicide rates and mental health provider ratio within the United States. Data from 2018 are collected for each state regarding its suicide rate, mental health provider ratio, and percent of population unable to receive treatment for mental health problems. An initial analysis is made using suicide rates and mental health provider ratio, with no correlation being found. A second analysis is conducted, using multiple linear regression with the percent of individuals within each state who were unable to access treatment for their mental health problems being the confounding variable. Controlling for the percent of individuals within each state who were unable to access treatment for their mental health problems provided a significant correlation between suicide rate and mental health provider ratio ($R^2 = .961$). This allows for further analysis, using integration to determine the average suicide rate using the equation of the trendlines for the graphs of both the unadjusted and adjusted data. The average suicide rate for the unadjusted graph is 16.32 per 100,000. For the adjusted graph, this number is 16.07 per 100,000. Findings imply that access to mental health providers and treatment availability decreases the amount of suicides within the United States.

Keywords
suicide rate, mental health provider ratio, multiple linear regression, matrix operations, average value of a function

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**PROBLEM STATEMENT**

The mental health crisis within the United States involving suicide may be correlated with a lack of mental healthcare workers, so this concept should be analyzed.

**MOTIVATION**

The mental health crisis in the United States is one of great importance, as rates of mental illness is relatively high. The effect of having mental health problems can be catastrophic for individuals, leading to many drastic consequences. Of these consequences is suicide, a major cause of death within the United States that has been increasing since 1999 (Stone et al., 2018). The United States struggles with this concept, which has led to a call for an increase in the amount of mental healthcare providers available (Walker et al., 2015). Access to mental healthcare providers would in theory, be crucial in reducing the amount of suicides. Thus, this paper aims to address how access to mental healthcare providers can affect suicide rates, by providing a mathematical analysis of how the ratio of mental healthcare workers within different regions affects suicide rates using data from. From this, implications regarding the reason for high suicide rates can be inferred.

**MATHEMATICAL DESCRIPTION AND SOLUTION APPROACH**

To begin, data are collected from Mental Health America regarding the mental health provider ratio within each state in 2018 (Mental Health in America - Access to Care Data 2018, n.d.). Data are also collected from the CDC regarding the rates of suicide for each state (Stats of the State - Suicide Mortality, 2020). The mental health provider ratio displays how many people
there are per one mental health provider. The suicide rate displays how many suicides there are per 100,000 individuals. For both values, the lower the number the better. This is displayed in Table 1 of the Appendices. The values are arranged into Figure 1 shown below:

**Figure 1**

![Graph showing Suicides Per 100,000 vs. Mental Health Service Ratio](image)

From Figure 1, no major trend is found within the data. Since there is a lack of statistical trend, multiple linear regression has to be used to account for a potential confounding variable. The confounding variable that is controlled for is the percent of individuals within each state population who do not have the ability to receive mental health treatment. See Appendices, Table 2.

To control for access to mental health treatment, data are converted into matrices for a multiple linear regression calculation. The suicide rate is variable Y, X₁ is the mental health provider ratio, and X₂ is the percent of individuals who are unable to access treatment for their mental health problems. The multiple linear regression equation is: \( y = b_0 + b_1X_1 + b_2X_2 \). The intercept is \( b_0 \), while \( b_1 \) and \( b_2 \) are the regression coefficients for both the mental health provider
ratio and the percent of individuals who are unable to access treatment, respectively. To continue the multiple linear regression calculation, matrix $X$ is generated:

**Matrix $X$ (50 × 3)**

|   |   |    |
|---|---|----|
| 1 | 200 | 45.9 |
| 1 | 240 | 41.4 |
| 1 | 250 | 51.2 |
| 1 | 260 | 43.7 |
| 1 | 270 | 56.3 |
| 1 | 280 | 57.2 |
| 1 | 290 | 49.3 |
| 1 | 300 | 63.9 |
| 1 | 310 | 52.5 |
| 1 | 350 | 61.2 |
| 1 | 350 | 52.0 |
| 1 | 350 | 57.3 |
| 1 | 360 | 55.6 |
| 1 | 360 | 52.3 |
| 1 | 380 | 56.2 |
| 1 | 390 | 49.0 |
| 1 | 410 | 48.1 |
| 1 | 420 | 56.4 |
| 1 | 440 | 57.5 |
| 1 | 460 | 53.7 |
| 1 | 460 | 50.6 |
| 1 | 470 | 63.5 |
| 1 | 490 | 50.2 |
| Value 1 | Value 2 | Value 3 |
|--------|--------|--------|
| 490    | 59.5   |        |
| 510    | 44.3   |        |
| 510    | 54.8   |        |
| 550    | 52.2   |        |
| 560    | 50.6   |        |
| 580    | 66.0   |        |
| 580    | 53.3   |        |
| 580    | 53.7   |        |
| 580    | 58.2   |        |
| 600    | 52.4   |        |
| 600    | 58.1   |        |
| 600    | 53.2   |        |
| 630    | 52.9   |        |
| 640    | 55.6   |        |
| 660    | 54.3   |        |
| 680    | 58.3   |        |
| 730    | 53.0   |        |
| 730    | 55.4   |        |
| 750    | 61.7   |        |
| 780    | 57.7   |        |
| 820    | 45.6   |        |
| 820    | 57.8   |        |
| 850    | 58.5   |        |
| 900    | 57.3   |        |
| 950    | 53.8   |        |
| 1070   | 60.4   |        |
| 1260   | 54.0   |        |
The first column of the matrix represents $b_0$, or the intercept. The second column is the mental health provider ratio, or $X_1$, and the third column is the percent of individuals who are unable to receive mental health treatment. The equation for matrix $b$ is: $b = (X'X)^{-1}(X'Y)$. For the next step, matrix $X$ is needed to be transposed:

$Matrix\, X'$ (3 $\times$ 50, entries are presented vertically)

Then matrix $X$ and matrix $X'$ are multiplied together, being sure to multiple matrix $X'$ as the first matrix, and matrix $X$ as the second:

$Matrix\, X'X$ (3 $\times$ 3)

Then to complete the first half of the formula for matrix $b$, the inverse of matrix $X'X$ is taken:
Matrix \((X'X)^{-1}\) (3 × 3)

\[
\begin{array}{ccc}
2.263166185 & 0.00003432265 & -0.04161335489 \\
0.00003432265 & 0.00000041872267 & -0.000004807005 \\
-0.04161335489 & -0.000004807005 & 0.000813562549
\end{array}
\]

Then for the other half of the equation for matrix \(b\), matrix \(X'\) is multiplied by matrix \(Y\) (50 × 1):

Matrix \(X'Y\) (3 × 1)

\[
\begin{array}{c}
822.5 \\
440889 \\
44697.22
\end{array}
\]

Now matrix \((X'X)^{-1}\) and matrix \((X'Y)\) are multiplied together in order to get matrix \(b\):

Matrix \(b\) (3 × 1)

\[
\begin{array}{c}
16.58539054 \\
-0.002019162285 \\
0.01764416058
\end{array}
\]

The first value of matrix \(b\) represents the intercept \(b_0\). The second value represents the regression coefficient for \(X_1\), or the Mental Health Provider ratio. Then the third value represents the regression coefficient for \(X_2\), or the percent of individuals without the ability to receive treatment. This allows for the generation of the equation for the adjusted \(y\)-values:

\[
y = 16.58539054 + (-0.002019162285)X_1 + (0.01764416058)X_2.
\]
The equation allows for the creation of a table with the adjusted y-values for suicide rate, as well as mental health provider ratio. The table is displayed as Table 3 in the Appendices. This is graphed in Figure 2 below:

Figure 2

![Graph showing the relationship between Suicides Per 100,000 and Mental Health Provider Ratio. The trendline displays a significant trend, meaning that the data correlate when the confounding variable of individuals without access to mental health services, is removed. The data show a difference in suicide rate as mental health provider ratio changes, suggesting that access to healthcare is a significant factor when determining rates of suicide.

To further analyze the data, the equations of the trendlines are investigated. To do so, integrals of the trendlines are found to determine the average number of suicides within the range of the mental health provider ratio: 200-1260. The polynomial trendlines to the second degree are used for this calculation, as the linear trendlines are the same for both.
Trendline for Suicides Per 100,00 vs. Mental Health Provider Ratio (Without Adjustment):

\[ f(x) = 19.6 - 0.00975x + 0.00000612x^2 \]

\[ F(x) = \int_0^x f(t) dt = 19.6x - 0.004875x^2 + 0.00000204x^3 \]

\[ f_{ave} = \frac{1}{(1260-200)} \int_{200}^{1260} f(x) dx \]

\[ f_{ave} = \left[ \frac{1}{(1260-200)} \right] [ F(1260) - F(200)] \approx (21037.2 - 3741.32)/1060 \approx 16.317 \]

suicides per 100,000

Trendline for Suicides Per 100,000 vs. Mental Health Provider Ratio (With Adjustment):

\[ f_A(x) = 17.4 - 0.00162x - 0.000000229x^2 \]

\[ F_A(x) = \int_0^x f_A(t) dt = 17.4x - 0.00081x^2 - 0.00000007633x^3 \]

\[ f_{A(ave)} = \frac{1}{(1260-200)} \int_{200}^{1260} f_A(x) dx \]

\[ f_{A(ave)} = \left[ \frac{1}{(1260-200)} \right] [ F_A(1260) - F_A(200)] \approx (20485.3 - 3446.99)/1060 \approx 16.074 \]

suicides per 100,000

**DISCUSSION**

The initial linear regression without any adjustments to the obtained data resulted in insignificant findings between suicide rates and mental health provider ratio. Multiple linear regression was required in order to find a correlation between suicide rates and mental health provider ratio, by accounting for a confounding factor. The confounding factor that was used was the percent of individuals within each state who were unable to access treatment for their mental health problems. After accounting for this the percent of individuals within each state who were unable to access treatment for their mental health problems, a correlation between suicide rates and mental health provider ratio was found, with an \( R^2 \) value of .961. From the adjusted data,
there appeared to be no major difference within suicide rates when mental health provider ratio increased, however the graph did display a slight downwards trend as mental health provider ratio increased. This makes sense, as adjusting for individuals who did not have the ability to receive treatment allows the data to be viewed as if everyone is able to receive treatment, thus the effect of mental health provider ratio should be minimal on the adjusted graph. After calculating the average F value of the graphs using the equation of the polynomial trendline to the second degree, it was discovered that the average suicide rate was 16.32 per 100,000 before adjustment, while it was 16.07 after adjustment. Findings suggest access to mental health providers may decrease the suicide rate by 1.5%, if everyone has access to mental health providers.

There are many limitations to this investigation. The most glaring limitation is that there are many other confounding variables not addressed. This is especially present when investigating the adjusted graph, in which the suicide rate decreased as the mental health provider ratio increased, meaning that the more people per mental health provider, then the lower the suicide rate. Other limitations include the analysis of the polynomial trendline to the second degree, which provides values that do not quite fit the data. Overall however, it appears as though the rate of suicide decreases when everyone has access to mental health care, with the average suicides theoretically decreasing.

**CONCLUSION AND RECOMMENDATIONS**

This project analyzes the relationship of suicide rates per 100,000 within each state, with the ratio of mental health providers (amount of people per mental health provider). Data are collected from 2018 from databases regarding these two factors for each state (Stats of the State -
Suicide Mortality, 2020); (Mental Health in America - Access to Care Data 2018, n.d.). From these data a graph is generated, but no strong correlation is displayed. Then data regarding the percent of the population within each state unable to receive treatment for mental health problems are collected from a database, and a multiple linear regression is used, controlling for the percent of the population unable to receive mental health treatment (Mental Health in America - Access to Care Data 2018, n.d.). The adjusted graph displays a correlation between suicide rate and mental health provider ratio, with an $R^2$ value of .961. Analysis using integration displays the average suicide rate for the unadjusted and adjusted graph. The average suicide rate for the unadjusted graph is 16.32 per 100,000, while the average suicide rate for the adjusted graph is 16.07 per 100,000. This implies that access to mental health providers would generate a decrease in suicide within the population.

For further analysis, it is recommended to account for other confounding variables. This includes variables such as the rate of individuals who are unable to receive treatment due to insurance or financial issues, rather than a general unable to receive treatment category. Type of mental healthcare provider could also have been specified, in order to provide a more dynamic analysis.
## NOMENCLATURE

| Symbol | Description |
|--------|-------------|
| Y      | The matrix of values related to suicide rates per 100,000 |
| $X_1$  | The matrix of values related to Mental Health Provider Ratio (amount of individuals per mental health provider) |
| $X_2$  | The matrix of values related to the percent of individuals who were unable to receive treatment for mental health problems |
| X      | The matrix of values that includes the values for the intercept, Mental Health Provider Ratio, and the percent of individuals who were unable to receive treatment for mental health problems, respectively |
| X’     | The transposed matrix X |
| X’X    | The transposed matrix X’ multiplied by matrix X |
| Symbol | Description |
|--------|-------------|
| $\begin{pmatrix} X'X \end{pmatrix}^{-1}$ | The inverse of the transposed matrix $X'$ multiplied by matrix $X$ |
| $X'Y$ | The transposed matrix $X'$ multiplied by matrix $Y$ |
| $b$ | The matrix related to the coefficient values for multiple linear regression |
| $b_0$ | The intercept of the multiple linear regression equation. |
| $b_1$ | The regression coefficient for the values of the Mental Health Provider ratio |
| $x_1$ | The values of the Mental Health Provider ratio |
| $b_2$ | The regression coefficient for the percent of individuals unable to receive treatment |
| $x_2$ | The values of the percent of individuals unable to receive treatment |
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## APPENDICES

### Table 1

| State            | Mental Health Provider Ratio | Suicides Per 100,000 |
|------------------|------------------------------|----------------------|
| Massachusetts    | 200                          | 9.9                  |
| Maine            | 240                          | 18.5                 |
| Oregon           | 250                          | 19                   |
| Vermont          | 260                          | 18.8                 |
| Oklahoma         | 270                          | 20                   |
| New Mexico       | 280                          | 25                   |
| Rhode Island     | 290                          | 9.5                  |
| Alaska           | 300                          | 24.6                 |
| Connecticut      | 310                          | 10.6                 |
| California       | 350                          | 10.9                 |
| Wyoming          | 350                          | 25.2                 |
| Colorado         | 350                          | 21.9                 |
| Washington       | 360                          | 15.9                 |
| Missouri         | 360                          | 19.5                 |
| Utah             | 380                          | 22.2                 |
| New Hampshire    | 390                          | 19.4                 |
| Montana          | 410                          | 24.9                 |
| New York         | 420                          | 8.3                  |
| State            | Code | Rate |
|------------------|------|------|
| Nebraska         | 440  | 13.4 |
| Michigan         | 460  | 15   |
| Delaware         | 460  | 11.4 |
| Hawaii           | 470  | 11.9 |
| North Carolina   | 490  | 13.7 |
| Maryland         | 490  | 10.2 |
| Minnesota        | 510  | 13.1 |
| Arkansas         | 510  | 18.3 |
| Idaho            | 550  | 23.9 |
| Kentucky         | 560  | 17.5 |
| Nevada           | 580  | 20.8 |
| Illinois         | 580  | 11.3 |
| Kansas           | 580  | 19.3 |
| New Jersey       | 580  | 8.3  |
| Wisconsin        | 600  | 14.8 |
| Louisiana        | 600  | 15.1 |
| Pennsylvania     | 600  | 14.9 |
| Ohio             | 630  | 15.3 |
| North Dakota     | 640  | 19.2 |
| South Dakota     | 660  | 19.3 |
| South Carolina   | 680  | 15.4 |
| Virginia         | 730  | 14   |
| Indiana          | 730  | 16   |
| State       | Suicides Per 100,000 | Mental Health Provider Ratio | % With No Treatment |
|-------------|----------------------|------------------------------|---------------------|
| Florida     | 750                  | 15.2                         |                     |
| Tennessee   | 780                  | 16.6                         |                     |
| Iowa        | 820                  | 15.5                         |                     |
| Mississippi | 820                  | 13.8                         |                     |
| Arizona     | 850                  | 19.2                         |                     |
| Georgia     | 900                  | 14.6                         |                     |
| West Virginia | 950               | 21.2                         |                     |
| Texas       | 1070                 | 13.7                         |                     |
| Alabama     | 1260                 | 16.5                         |                     |

Sources:
(Mental Health in America - Access to Care Data 2018, n.d.)
(Stats of the State - Suicide Mortality, 2020)

Table 2
| State          | Suicide Rate | Mental Health Providers | Suicide Rate |
|---------------|--------------|--------------------------|--------------|
| Connecticut   | 10.6         | 310                      | 52.5         |
| California    | 10.9         | 350                      | 61.2         |
| Wyoming       | 25.2         | 350                      | 52.0         |
| Colorado      | 21.9         | 350                      | 57.3         |
| Washington    | 15.9         | 360                      | 55.6         |
| Missouri      | 19.5         | 360                      | 52.3         |
| Utah          | 22.2         | 380                      | 56.2         |
| New Hampshire | 19.4         | 390                      | 49.0         |
| Montana       | 24.9         | 410                      | 48.1         |
| New York      | 8.3          | 420                      | 56.4         |
| Nebraska      | 13.4         | 440                      | 57.5         |
| Michigan      | 15           | 460                      | 53.7         |
| Delaware      | 11.4         | 460                      | 50.6         |
| Hawaii        | 11.9         | 470                      | 63.5         |
| North Carolina| 13.7         | 490                      | 50.2         |
| Maryland      | 10.2         | 490                      | 59.5         |
| Minnesota     | 13.1         | 510                      | 44.3         |
| Arkansas      | 18.3         | 510                      | 54.8         |
| Idaho         | 23.9         | 550                      | 52.2         |
| Kentucky      | 17.5         | 560                      | 50.6         |
| Nevada        | 20.8         | 580                      | 66.0         |
| Illinois      | 11.3         | 580                      | 53.3         |
| State         | Rate  | Population | Suicide Mortality |
|--------------|-------|------------|-------------------|
| Kansas       | 19.3  | 580        | 53.7              |
| New Jersey   | 8.3   | 580        | 58.2              |
| Wisconsin    | 14.8  | 600        | 52.4              |
| Louisiana    | 15.1  | 600        | 58.1              |
| Pennsylvania | 14.9  | 600        | 53.2              |
| Ohio         | 15.3  | 630        | 52.9              |
| North Dakota | 19.2  | 640        | 55.6              |
| South Dakota | 19.3  | 660        | 54.3              |
| South Carolina | 15.4 | 680      | 58.3              |
| Virginia     | 14    | 730        | 53.0              |
| Indiana      | 16    | 730        | 55.4              |
| Florida      | 15.2  | 750        | 61.7              |
| Tennessee    | 16.6  | 780        | 57.7              |
| Iowa         | 15.5  | 820        | 45.6              |
| Mississippi  | 13.8  | 820        | 57.8              |
| Arizona      | 19.2  | 850        | 58.5              |
| Georgia      | 14.6  | 900        | 57.3              |
| West Virginia| 21.2  | 950        | 53.8              |
| Texas        | 13.7  | 1070       | 60.4              |
| Alabama      | 16.5  | 1260       | 54.0              |

Sources:
(Mental Health in America - Access to Care Data 2018, n.d.)
(Stats of the State - Suicide Mortality, 2020)
Table 3

| Adjusted Suicide Rate Per 100,000 | Mental Health Provider Ratio |
|----------------------------------|-----------------------------|
| 16.99142505                     | 200                         |
| 16.83125984                     | 240                         |
| 16.98398099                     | 250                         |
| 16.83145816                     | 260                         |
| 17.03358296                     | 270                         |
| 17.02927109                     | 280                         |
| 16.86969059                     | 290                         |
| 17.10710372                     | 300                         |
| 16.88576866                     | 310                         |
| 16.95850637                     | 350                         |
| 16.79618009                     | 350                         |
| 16.88969414                     | 350                         |
| 16.83950745                     | 360                         |
| 16.78128172                     | 360                         |
| 16.8097107                      | 380                         |
| 16.66248112                     | 390                         |
| 16.60621813                     | 410                         |
| 16.73247304                     | 420                         |
| 16.71149837                     | 440                         |
| Value         | Time |
|--------------|------|
| 16.60406731  | 460  |
| 16.54937041  | 460  |
| 16.75678846  | 470  |
| 16.48173788  | 490  |
| 16.64582857  | 490  |
| 16.33725409  | 510  |
| 16.52251777  | 510  |
| 16.39587647  | 550  |
| 16.34745419  | 560  |
| 16.57879101  | 580  |
| 16.35471017  | 580  |
| 16.36176784  | 580  |
| 16.44116656  | 580  |
| 16.29844718  | 600  |
| 16.3990189   | 600  |
| 16.31256251  | 600  |
| 16.2466944   | 630  |
| 16.27414201  | 640  |
| 16.21082135  | 660  |
| 16.24101475  | 680  |
| 16.04654258  | 730  |
| 16.08888857  | 730  |
| 16.15966353  | 750  |
| Number          | Value |
|----------------|-------|
| 16.02851202    | 780   |
| 15.73425119    | 820   |
| 15.94950995    | 820   |
| 15.90128599    | 850   |
| 15.77915488    | 900   |
| 15.61644221    | 950   |
| 15.49059419    | 1070  |
| 14.99403073    | 1260  |

Sources:
(Mental Health in America - Access to Care Data 2018, n.d.)
(Stats of the State - Suicide Mortality, 2020)