Stuck in Traffic?

This urban driving exploration is designed to develop students’ reasoning and sense-making skills as they analyze a set of data related to transportation issues in a metropolitan region. Students will work in collaborative groups to create graphs, compare and contrast the graphs, and use the results to discuss and interpret data related to urban transportation. Where appropriate, students will use linear functions to model the data, explain the meaning of the mathematical model for the data set, and use the model to make predictions. Use the file All-Urban-Areas-Graph.pdf to preview the data, graphs, and linear regressions for each data set.

TEACHER NOTES

Suggested answers are in red. Instructional notes are in blue and are preceded by the hand icon. These two features do not appear in the student edition.

Classroom Materials
Select the appropriate option(s) for creating graphs in the classroom:
• Graph paper; a graphing calculator, an electronic device with a spreadsheet, or graphing software
• An online graphing tool is available at http://www.geogebratube.org/student/m136787 and is discussed in task 5.

Supplemental Files
• Student Edition.doc
• All-Urban-Areas-Graph.pdf
• Data-by-Individual City.zip

Acknowledgment: Texas A & M Transportation Institute (http://mobility.tamu.edu/ums/)
Suggestions for Use

Teachers of students in grades 5–7 may want to use the data to focus on graphing in the coordinate plane and making conjectures about future values for each data set (questions 1–8). Teachers of students in grades 8 and above may want to continue the activity to include modeling linear functions and using the model to predict future values.

Before You Begin

Download the file All-Urban-Areas-Graph.pdf. Click on the name of the city to jump to the data for the region. The next page of the document displays the graph of each data set. Select the data for the metropolitan region closest to you and additional regions using the following tips:

- Six data sets have been provided for each urban area. Determine if students will construct the graphs individually or with a partner. Each urban area data set contains six columns of data. Determine the required number of urban areas for each class; for example, twenty-four students working with a partner would require twelve graphs, or two urban areas.
- Select the closest region and at least one data set from a significantly smaller or larger region.
- Select a data set from a different state. The gasoline price data is the state average, so selecting cities from a single state will have the same data for gasoline price.
- View the graphs in the file All-Urban-Areas-Graph.pdf. Each graph shows linear regression models for use in selecting data sets and determining if student answers are reasonable. In some cases, the linear regression is not a good fit for the data.
- Data sets and graphs for each urban area are provided in individual files. The data set page can be printed, cut into sections, and distributed to students.

Multiple-Group Collaboration

After creating the graph, students will meet with all other students who are graphing data from the same urban area. After a discussion, they will regroup with other students working with the same data column from the different urban areas. Ultimately, all students with a population graph will meet together; for example, those working with Freeway Miles Driven will meet together; and so on.

Answers provided for most questions are sample answers. Teachers may use the graphs provided for each urban area to evaluate the answers provided.

Overview of the Data

The Urban Mobility Report is a product of the Texas A & M Transportation Institute (http://mobility.tamu.edu/ums/). Data have been collected annually for many urban areas of the United States since 1982. The institute studies various methods to ease traffic congestion in large cities. Data for each year and additional data are reported on the Texas A & M website.

About the Data

- Population (000): The population of the metropolitan region is reported in thousands (as indicated by the 000) for each year. A value of 510 in the population column represents 510,000 people.
- Freeway Daily Vehicle Miles of Travel (000) is the total number of freeway miles driven daily in thousands. A freeway is a restricted-access road (with entrance and exit ramps), such as interstates or other roads without such controls as stoplights. A value of 1,705 would indicate 1,705,000 freeway miles were driven each day.
- Freeway Lane Miles: The number of freeway lane miles is calculated by multiplying the number of lanes by the number of miles of road. A freeway with 4 lanes of travel in each direction for 20 miles would result in 8 lanes multiplied by 20 miles, or 160 lane miles of freeway.
- Public Transportation Annual Passenger Miles (million) is the total number of annual passenger miles, in millions, traveled using public transportation. A value of 1,024 in this column represents 1,024,000,000 miles.
- Average State Gas Cost is the average cost of a gallon of gasoline in the state for the year.
- Annual Delay Per Commuter is a yearly sum of all the per-trip delays for persons commuting during peak periods (6–10 a.m. and 3–7 p.m.).
Anyone driving in a large urban area has experienced periods when traffic jams result in a longer than normal time to reach a destination. In this activity, you will use data provided by the Texas A & M Transportation Institute for a metropolitan area close to you. As a researcher, you will graph the data, analyze the graph, and investigate reasons why travel is becoming more difficult. You will also explore possibilities for reducing the time to travel in an urban area.

**Task 1: Understanding the Data**

1. Consider the column headings in the data that your teacher has distributed to you. Population is the number of people in the urban area, but what does the (000) mean? What does a value of 1024 in the population column represent?

   The (000) indicates that the population value should be multiplied by 1,000. The value of 1,024 will be 1,024,000 people.

2. Proceed through each set of data for the urban area. What does each column of data represent?

   See “About the Data” on page ii.

**Task 2: Graphing and Modeling the Data**

Teachers with Internet-accessible devices may want to incorporate Task 5: Exploring Lines of Best Fit into this task.

Construct the graph using the number of years after 1990 as the value for the independent axis, or x-axis. Use the data to select an appropriate scale for the dependent axis, or y-axis.

Teachers of younger students may decide to use the actual year as the x-axis value with additional space on the right side of the graph. For all others, using years after 1990 as the x-axis value may be easier. The first data point will always have an x-value of 3. If students begin the graph using 1993 as the first x-value, a model will contain a negative y-intercept, which lacks meaning when the linear model is explained.

3. Graphing multiple data sets requires advance planning. What are the essential parts of a graph? How is the scale of the graph selected?

   The graph should include a title with an urban area and data category. Each axis should include units. When possible, the y-axis scale should be the same across multiple graphs of similar data sets.
Using the same y-axis scale makes comparisons of the data easier. Using a different scale is acceptable because students will see that visual comparisons can lead to errors if the scales are not the same. Allowing the use of different scales will provide an opportunity to discuss the misleading nature of some graphs. However, graphing each category (population, freeway miles driven, etc.) from all urban areas using the same scale is preferable with younger students.

Group students on the basis of the data set they will be graphing. For example, all students graphing freeway lane miles should work together. Group members should determine if it is possible to use a common scale and construct the graphs for each city and category.

4. Look at the graph of your data. How would you describe your graph? Is there a pattern? Does the graph always follow this pattern?

Examples: The number of public transit miles in Omaha decreased until 1995. From that point forward, it has increased.

The number of freeway lane miles in Laredo, Texas, increased until 1999 and has been relatively constant at just less than 80 lane miles of freeway since 1999.

The cost of gasoline in Akron, Ohio, was relatively constant until 2002. The price increased until reaching its peak in 2008 and had declined slightly by 2011.

Encourage students to use precise language by including the urban area and data title in the explanation of their graph. Students should not compare the rate of change visually unless the vertical axis scales are the same or the rate of change has been calculated.

5. Describe the impact of the change in your data set on an urban area. If the data set is increasing (or decreasing) over time, what impact does it have on driving in the area?

Increases in the cost of fuel may mean fewer miles driven, resulting in less congestion and increased usage of public transportation systems.

A decrease in the commuter delay time would result in fewer gallons of fuel being burned, and less time would be spent waiting in traffic, allowing for more time at work or home. The outcome would be positive for the urban area.

Increases in the number of miles driven may lead to more delays and longer commute times. Increased commuting time would have a negative impact on the area.

6. Compare and contrast the data.

The price of gas in all cities was relatively constant until 1999. After 1999, the cost of gasoline increased each year until a maximum was reached in 2008. In 2011, the price of gasoline was about the same as 2008 in Allentown.

7. What does the graph suggest will happen in future years? Answers will vary.


Although many of the data sets are linear, certain graphs tend to have greater variability in the data. Discussion may be needed to assist students in selecting points resulting in a reasonable model. The line should pass as close to the middle of the data as possible. If the first part of the data has a pattern and the second part of the data has a different pattern, use a model that best represents the latter portion of the data. Other data sets appear to increase and decrease over time without much change. A horizontal line is a possible line of best fit. Suggestions for teachers of grades 5–7:

1. Students may plot projected points for years 2014 and 2017. Ask them to explain their reasoning in selecting the points.

2. Select a reasonable y-value that the data set will approach in the next few years. Use the graph to predict the year when the value will be reached. For example, when will the number of freeway miles driven daily in Omaha reach 7,000,000? For additional information, see the teacher note for question 13. Conclude the exploration; the remaining tasks will require the use of algebra skills.

9. Explain the meaning of each of the data points.

In the example data set Akron Ohio Delay Hours per Commuter, the point (12, 31) indicates that twelve years after 1990, or in the year 2002, the average commuter in Akron experienced thirty-one hours of delay. The point (21, 23) indicates that in the year 2011, the number of hours of delay had decreased to twenty-three hours.
the data sets. A value of 40,082 in the Freeway Miles Driven Daily column for Washington, D.C., means that 40,082,000 miles are driven on the freeway each day of the year. A value of 2,489.7 in the public transportation column means that 2,489.7 million—or 2,489,700,000—passenger miles were traveled during the year.

10. Select two data points representing the line of best fit. Find the rate of change including units. Compare the rates of each urban area.

In the example data set Akron Ohio Delay Hours per Commuter, the points (12, 31) and (21, 23) were selected. The rate of change is $-\frac{8}{9}$ hours per year, or approximately $-53$ minutes per year. Each year after 2002, the amount of commuter delay decreases by about $53$ minutes each year.

The data set Freeway Miles Driven Daily is typically the most difficult for students to understand. The linear regression for the Washington, D.C., metropolitan area shows a rate of change of $561.32$ (thousands) per year. This means that the number of miles driven daily increases by $561,320$ each year. One year from today, drivers will travel $561,320$ more miles on the freeways than they do today. Meanwhile, the number of lane miles of freeway is increasing by about $17$ miles each year, the population is increasing by about $66,476$ people each year, and passengers will travel about $72$ million more miles each year.

A common student misconception is that the rate of change occurs every three years. Students may believe the growth occurs every three years because the data are provided in three-year intervals.

11. Find the $y$-intercept of the line of best fit. Explain the meaning of the $y$-intercept. Compare the $y$-intercepts of each urban area.

The $y$-intercept is the value of $y$ when $x$ is zero. In this case, $x$ represents the number of years after 1990. The $y$-value is the number of annual hours of commuter delay. The mathematical model indicates that the value in 1990 should have been about $42$ hours. Looking at the data set provided, this is clearly not the case. However, we attempted to fit a model to the data from 12 to 21 years after 1990. The linear model predicts that if the pattern had been decreasing each year at hours per year, the number of hours of delay in 1990 would have been $61$ hours.

Task 3: Explaining the Model

Group students by urban area. For example, all students with data from Louisville should be grouped together. Question 13 requires the teacher to select appropriate values for each urban area data set. Use the teacher data graphs to find an appropriate future value for each data set.

12. Use the model to predict the value for the given data set in the year 2025. For example, what is the predicted population of Louisville in 2025?

The $x$-value is the number of years after 1990. The year 2025 is $35$ years after 1990. Substitute $35$ for the $x$-value in the equation and solve for $y$.

13. Use the model to predict the year when the following will occur in Louisville:

a. When will the population reach ________ million people?

b. In what year will the number of miles driven daily reach ________ million miles daily?

c. When will there be ________ lane miles of freeway?
d. In what year will there be _______ million miles traveled on public transportation?

e. In what year will gas cost $6 per gallon? _______

f. In what year will a commuter experience _________ hours of delay?

To solve for the year, replace the $y$-value in the model with the given value and solve for $x$. The answer is $x$ years after 1990.

The population, freeway miles driven, and public transportation miles will require conversion before substituting into the function. Population in the table is reported in thousands. Convert the given population to match the units listed in the table. A population of 1.2 million is 1,200,000, or 1,200 thousands. Substitute 1,200 for the $y$-value in the equation and solve for $x$. Similarly, the number of freeway miles driven would need to be divided by 1,000, and the number of public transportation miles would need to be divided by 1 million before substituting into the model.

14. How are the data sets related? How could a change in one category affect another category? For example, how might a decrease in the number of public transportation miles available change the commuter delay hours?

If the number of public transportation miles decreases, the number of vehicles on the road would likely increase, resulting in more miles being driven and creating more hours of traffic delay.

Increasing the number of lane miles may result in more miles of road, allowing more vehicles to travel on the roads at the same time, resulting in less congestion and fewer delay hours.

Increasing fuel costs may result in people driving fewer miles or using public transportation as an alternative.

As the population grows, more people will be driving, resulting in more miles driven and/or more miles of public transportation. Each of these could have an impact on the number of hours of delay.

Source: http://mobility.tamu.edu/mip/strategies-pdfs/added-capacity/technical-summary/adding-new-lanes-or-roads-4-pg.pdf

15. Is it possible to build our way out of traffic congestion? Can we build enough roads? What options exist to reduce traffic congestion?

In most cases, building enough roads to eliminate the problem is not practical. Drivers in Kansas City will be driving 363,000 more miles each day next year than they are this year. During the same period, only 27 miles of road will be built. The congestion occurs over a wide area, making it impossible to build enough roads where they are needed. Building roads requires acquiring land that is already occupied, which can take many years. Road construction is expensive; one lane mile of road often costs from $2–10 million or more.

Researchers are working with a variety of strategies to minimize delays, including making “smart” traffic signals, which monitor traffic and adjust the timing of traffic lights. Cities can work to increase rider-ship on public transportation, and companies can adjust work hours so travel does not have to occur at peak hours.

**Task 4: Comparing and Contrasting the Data**

Group students by data set. For example, students with graphs of gasoline cost should work together.

16. Compare and contrast the rate of change and $y$-intercepts for the data set in each urban area. If the urban areas are to be ranked in terms of growth in each category, how could the ranking be determined? Are there times when rate of change is not a good measure? What other measures can be used?

The rate of change will provide a quick reference point as long as the $y$-values are comparable. However, if the $y$-values are significantly different, the rate of change will be inaccurate. Two cities may increase the number of freeway lanes by 10 miles per year. If one city currently has 500 lane miles and the other has 800 lane miles, which city will see the greatest impact in the additional roadway? Using the percent change may be a better method to rank the growth. Use the rate of change and the most recent $y$-value to calculate the percent change. Using the chart below, find the percentage of the most recent amount of the rate of change. For example, the percent increase in freeway miles driven per year in Kansas City would be $363/21701 \times 100 \approx 1.7\%$. The number of miles driven per year is increasing by about 1.7% of the total miles driven in 2011.
Task 5: Exploring Lines of Best Fit

Explore the data set using graphing software at http://www.geogebratube.org/student/m136787.

- In the appropriate input box, enter the number of data points to be graphed.
- Enter the first data point in input box P1, the second point in input box P2, and so on.
- Use the checkbox to show the line. Using the selection tool, move the points on the line to approximate the points used in determining the mathematical model in questions 8–10.
- Check the box marked “Show slope and y-intercept.”

17. How does the online linear model compare with the model developed in questions 8–11? Student answers should be very similar in both models, assuming the data points have been entered correctly and the linear model is calculated correctly.

18. The mean square error (MSE) is a statistical measure of how close the line fits the data points. To calculate it, find the difference between the value calculated from the linear function and the actual value. Click the “Show error & MSE” checkbox on the page. The signed length assigned to each segment is the difference of the actual value minus the calculated value. To find the MSE, square each error value and find the sum of the squares. Divide the sum by the number of data points. The result is the MSE. Why do you think the errors are squared? Squaring the error makes all error values positive; the mean square error decreases the impact of small errors and increases the impact of larger errors.

19. With the “Show error & MSE” check box selected, move the points of the line of best fit to minimize the MSE. Observe the graph of other data sets with the smallest MSE. Describe characteristics of a line of best fit. What strategies could you use for choosing a line of best fit on a graph? The line passes through as many points as possible or passes as close to as many points as possible. The number of data points above and below the line of best fit should be about the same.

The MSE is calculated from all graphed data points. If students have nonlinear data, such as the Akron, Ohio, data in task 2, discuss strategies that might be used to produce a better fit. Students may need to use a subset of the data. A discussion of outliers may also be appropriate in some data sets.

The table below is included as an aid for teachers.

<table>
<thead>
<tr>
<th>City</th>
<th>Increase in Freeway Miles Driven per Year (000)</th>
<th>Freeway Miles Driven 2011 (000)</th>
<th>Increase as % of 2011 Miles Driven</th>
<th>Increase in Freeway Lane Miles</th>
<th>2011 Freeway Lane Miles</th>
<th>Increase as % of 2011 Freeway Lane Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>947</td>
<td>49,501</td>
<td>1.9</td>
<td>45</td>
<td>2,970</td>
<td>1.5%</td>
</tr>
<tr>
<td>Chicago</td>
<td>1,061</td>
<td>62,791</td>
<td>1.7</td>
<td>48</td>
<td>3,500</td>
<td>1.4%</td>
</tr>
<tr>
<td>Kansas City</td>
<td>363</td>
<td>21,701</td>
<td>1.7</td>
<td>27</td>
<td>2,096</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

According to the table above, the number of miles driven daily in both Kansas City and Chicago is increasing at a rate of 1.7% per year. Atlanta is increasing the number of miles driven at the slightly higher rate of 1.9%. The percent increase in miles driven is greater than the percent increase of the number of lane miles in all three cities. The number of freeway lane miles constructed is not increasing at the same rate as the number of freeway miles driven. Building roads at the current rates will not alleviate congestion problems.
Did you know that . . .

- traffic planners call a plan of action to improve traffic flow a treatment?

- coordinating traffic lights on the basis of volume of traffic can have a significant reduction in delay time? Keeping high-volume traffic moving through longer green lights allows more vehicles to pass through intersections. When a light cycles from red to yellow to green, traffic is stopped in all directions for a period of time. Having fewer cycles of the traffic light in a given period increases the length of time that vehicles are passing through the intersection.

- entrance ramp meters regulate the flow of traffic on freeway entrance ramps? They are designed to create more space between entering vehicles so those vehicles do not disrupt the traffic flow already on the freeway.

- motorists calling on their cell phones are often the way a stalled vehicle or a crash is reported, but monitoring closed circuit cameras enable the responses to be more effective and better targeted? Shortening the time to detect a disabled vehicle can greatly reduce the total delay caused by an incident.

- providing smooth traffic flow and reducing collisions are the goals of a variety of individual treatments that make up a statewide or municipal access management program? Typical treatments include consolidating driveways to minimize the disruptions to traffic flow, median turn lanes or turn restrictions, acceleration and deceleration lanes, and other approaches to reduce potential collision and conflict points.

- the authors traveled one-half mile in one hour in a shuttle van during the development of this exploration?

Can you . . .

- investigate strategies for increasing traffic flow and decreasing congestion in urban areas that do not involve building more roads?

- find the cost for building a lane-mile of interstate highway in your region?

- look for treatments being used in your area to decrease traffic congestion? Are roundabouts an effective replacement for intersections?

- use a city or state webcam to monitor traffic flow? Does the timing of the stoplights change at different times of day or based on the number of vehicles passing through the intersection?

- investigate the effectiveness of High Occupancy Vehicle (HOV) lanes or High Occupancy Toll (HOT) lanes?

Sources

http://d2dtl5nlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012-appx-b.pdf

Texas A & M Transportation Institute. http://mobility.tamu.edu/ums/