This manual was originally composed as part of the Transportation and Civil Engineering (TRAC) Program created by the American Association of State Highway and Transportation Officials (AASHTO). For more information on the original manual, see the complete final report, NCHRP 20-52.

The manual was updated and revised in 2017 by the Center for Technology & Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).
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Executive Summary

This module contains four activities to provide a comprehensive overview of the design and construction of roadways. Concepts are introduced independently in the activities and then pulled together in experimental demonstrations and hands-on projects. Each activity contains the following sections:

1. **Instructor’s Reference.** This section is intended for both instructor and volunteer use and contains an activity summary and preparation information for the activity.
2. **Instructor’s Answer Key & Discussion Ideas.** This section serves as an instructor companion to the *Research Manual* and *Research Notes* and contains all answers to the questions given to students. It also contains suggested points of discussion that relate to the activity.
3. **Research Manual.** This section is intended for student use, and contains all background, setup, and procedure information and instructions for completing the activity.
4. **Research Notes.** This section is intended for student use while working on the activity and lists the same questions found in the *Instructor’s Answer Key & Discussion Ideas* section.

This manual also contains a complete activity overview table, instructor introduction to the module, and a copy of the National Education Standards. Below are summaries and potential volunteer topics for each activity.

**Activity 1: How Much Traffic Can the Road Handle?**

Activity 1 consists of two sections that explain the concept of traffic flow rates at varying traffic densities and also demonstrates how there is a maximum number of cars able to move through a lane within an hour. Activity 1A is a short two-part activity to demonstrate flow rates of popcorn kernels through different funnels. Activity 1B has students determine traffic flow rates from given traffic density and average speed information using *Microsoft Excel*. Activity 1A is appropriate for middle and high school students, and Activity 1B is appropriate for high school students. These activities act as prelab exercises for Activities 2 & 3, respectively.

**Volunteer Topics**

A traffic engineer can discuss the meaning of highway and roadway capacity and, more specifically, how decisions relating to capacity are determined when developing a road agency’s construction and maintenance program. A transit professional can highlight the role of alternative modes of transportation and the difficulties they face with the overcrowded travel ways. A traffic management system (TMS) or Intelligent Transportation System (ITS) professional can describe ways that advanced technology can be applied to get more vehicles through the system without adding capacity.

**Activity 2: Not in My Backyard!**

Activity 2 is a one- to two-class-period, hands-on drawing exercise that asks students to determine how to align a road that will go from point A to point B on a map, given that there is no optimal location for the road. Students consider design consequences, costs, and environmental impacts when deciding where to route the road.
Volunteer Topics

A planner can fascinate students with stories of public hearings where controversy arose regarding a proposed transportation project. An environmental or regulatory background helps one highlight the decision process preceding construction, including the Environment Impact Statement’s role. An administrator can outline the role of public involvement, especially the different personalities of constituents that influence a public meeting, and the importance of good project management to keep construction on schedule and under budget.

Activity 3: How Much Does It Cost?

Activity 3 uses the map from Activity 2 to explain how real estate prices are determined. In this activity students will use Microsoft Excel to create a computer-based model for estimating land prices, and then apply that model to determine the cost of the right-of-way that must be acquired for a roadway.

Volunteer Topics

An economist, financial analyst, planner, safety professional, pavement engineer, right of way specialist, or any person with a strong modeling background is an excellent fit for this activity. Students determine land prices and are introduced to mathematical modeling. Thus, applications of models (curve fitting, regression, etc.) to any area (economics, pavement distress, population growth, etc.) is appropriate. For example, assumptions about the future revenue stream for transportation improvement directly affects the types of projects, regardless of whether they are transit enhancements, road maintenance, or new highway construction that a community can realistically anticipate. A right-of-way specialist may also describe the process of acquiring land.

Activity 4: Construction Estimating

Activity 4 is an exercise in estimating the cost of construction, including labor, equipment, material, overhead, and profit. Using arithmetic, geometric, and problem solving skills, students will walk through the process of estimating a basic construction project.

Volunteer Topics

A volunteer with construction experience would be invaluable, as they could discuss many of the practical applications of estimating and what can happen on job sites that may slow or halt construction. If an estimator from a construction firm can be present, they could go through the process they would use while estimating a large job for their firm.
Instructor’s Introduction

Engineering is not simply about solving problems. It is about solving problems in the most efficient and elegant manner possible, while not creating new problems along the way. In order to come up with the most efficient solution, some amount of prior knowledge is usually needed. Frequently, this knowledge is mathematical or experiential.

For centuries, scientists, mathematicians, and engineers have studied the physical world and recorded their observations. They have derived mathematical formulas that describe the way materials and systems behave. They have also conducted experiments and drawn conclusions from their results. This body of knowledge that has accumulated over time is what engineers study and apply to solve problems every day. This process is what differentiates engineering from tinkering.

Tinkering is what we do when we try to solve problems by relying on trial-and-error. Tinkering can be fun, but it is usually not the most efficient way of solving a problem. Although solutions to engineering problems can sometimes be found by tinkering, these solutions tend to be neither efficient nor optimal.

Engineering can be fun, too. There is a great deal of satisfaction to be gained from approaching a problem theoretically. Typically, an engineer will try to find a set of equations that describe the problem mathematically. These equations will give the engineer clues about how to solve the problem at hand. Using these clues, engineers can arrive at the optimal solution much more quickly than they could have if they had relied on tinkering alone.

As part of the TRAC & RIDES Program it is key to understand where funding comes from and how decisions are made in the world transportation planning/engineering. Transportation plays a huge role in our everyday lives, and Metropolitan Planning Organizations/Transportation Planning Organizations (or MPOs/TPOs) are a critical component of a city’s transportation system. MPOs help plan the future of transportation in a region, and chances are, there is a MPO in your city making decisions that affect all of us and how we get around. MPOs are made up of local elected officials, elected by the people of a city or region, who decide how to spend taxpayer money on transportation projects. MPOs plan all types of transportation, from roads and highways to public transit and bike lanes. Public involvement is very important to decision makers, and your voice matters! Learn more about your local MPO, and find out how you can get involved in planning the transportation system of the future. As you implement any of the TRAC & RIDES modules we suggest you investigate the MPO/TPO in your area and encourage your students to do the same. It will open up a whole new area where students can explore career opportunities in transportation planning and engineering.

Two websites to begin your student’s research:

- Association of Metropolitan Planning Organizations [www.ampo.org](http://www.ampo.org)
- National Association of Regional Councils [www.narc.org](http://www.narc.org)

Transportation assets such as; urban freeways, sidewalks, bicycle lanes, traffic signals, rural two-lane roads, residential streets, and computerized traffic management systems require diverse skills to plan, design, construct, and maintain. These skills include problem solving, civil and systems engineering, economic analysis, communication, and an ability to make decisions given that no alternative is perfect.
Activity 1 covers how a road’s capacity is affected by the design speed of the road, the size of the road, and the closeness with which vehicles can travel. Activity 1 is for the student who asks, “Why can’t everyone just drive faster in order to eliminate a traffic jam?”

During the 1900s, surface transportation in the US focused heavily on roadways. Designers needed a strong grasp on mathematics (geometry, trigonometry, and algebra) to determine the dimensions for a road and to determine whether a proposed horizontal curve was too sharp due to centrifugal force or if the road couldn’t accommodate stopping distances under poor weather. These geometric design skills are still important today, as reflected in Activity 2.

Since the 1960s, the transportation planning process requires that roads not be built in a vacuum; road builders may not lay a road through a community with impunity. Instead, they have to consider the best way to minimize noise pollution, maintain water quality, and preserve existing development. These considerations are also part of Activity 2.

Urbanization has made the acquisition of right-of-way for the road increasingly important in the construction process. An important skill explored in Activity 3 is to model how land costs are influenced by the location of a piece of property as well as the type of development (residential, commercial, or industrial). Mathematical modeling is used in many other careers as well, such as investment banking or weather prediction.

Estimating is a critical technique utilized in construction projects, and many firms will go so far as to hire people who specialize in estimating. Activity 4 demonstrates many of the costs associated with construction by having students estimate labor, equipment, and material costs for a basic construction project, as well as overhead and profit costs.
National Education Standards

Activity 1: How Much Traffic Can the Road Handle?

National Council of Teachers of Mathematics Standards
The algebra standard indicates students should use “mathematical models...including graphs, tables and equations.” Activity 1 has students create and interpret their own graphs from equations that predict traffic speed as a function of the number of cars.

International Technology Education Association Standards
The focus of Activity 1 is the theme “Transportation Technologies: Transportation Processes and Efficiency”. Standard M, “The Designed World” notes “determine capacity of lanes, traffic flow, and potential congestion problems”, computations that are done in this activity.

Activity 2: Not in My Backyard!

National Council for the Social Studies Standards
Strand 8 Science, Technology, and Society: (relationships among science, technology, and society) asks “How can we manage technology so that the greatest number of people benefit from it?” Activity 2 considers the technology to be a new road and asks how that road should be designed, what speed limit should be set, and where it should be placed, given the views of different constituents.

International Technology Education Association Standards
Activity 2 focuses on the theme “Positive and negative impacts of transportation systems”, including congestion and environmental impacts [shown in Activity 2 as congestion delays, displacement of homes and businesses, noise pollution, and water quality.

Activity 3: How Much Does It Cost?

National Council of Teachers of Mathematics Standards
The Data Analysis and Probability Standard indicates that students should “understand scatterplots and use them to display data ... conduct analyses of the relationships between two sets of measurement data ... produce lines that fit the data .... [and] discuss what best fit might mean” Activity 3 focuses on these goodness of fit measures, and while students are not expected to define a residual or an R square value, they see a graphical representation of how they want to minimize residuals.

Activity 4: Construction Estimating
For the full documentation of TRAC and the National Education Standards, see the TRAC/Michigan Education Standards page on the MDOT website: http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html.
Activity 1: How Much Traffic Can the Road Handle?

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructor Prep Time</strong></td>
</tr>
</tbody>
</table>
| **Class Time** | 5 minutes (Activity 1A)  
10 minutes (Activity 1B) |
| **Grade/Class** | 6 - 8 Mathematics / Technology (Activity 1A)  
9 - 12 Mathematics / Technology (Activity 1A & 1B) |
| **Suggested Activity Grouping** | Small groups of two or three (Activity 1A)  
Individual or groups of two (Activity 1B) |
| **Technology** | Low/High Tech |
| **National Council of Teachers of Mathematics Standards** | Algebra: Graphs, tables, and equations |
| **International Technology Education Association Standards** | Transportation processes and efficiency |

**Introduction**

This activity eliminates a common misconception: that the number of vehicles that can pass a certain point in a given time could be increased if every vehicle drove faster. While it is true that speed is a factor in determining traffic flow, there is a limitation to the speed that can be safely traveled. This activity will demonstrate that the free-flow speed will decrease as traffic approaches the capacity of the road.

The popcorn kernels in Activity 1A will demonstrate that once the number of cars reaches a certain point, the free-flow speed begins to decrease. As the volume of traffic continues to increase, the traffic slows down; which eventually leads to a traffic jam, referred to in transportation engineering as “Level of Service F.” The use of a spreadsheet to produce a graph in Activity 1B will demonstrate to students how the optimal speed and capacity of a roadway is determined.

**Note:** Activity 1A prepares students for Activity 2 and Activity 1B prepares students for Activity 3.

**Objective**

Students will learn:

- Two factors that affect the rate of flow: traffic density and traffic speed.
- Limitations of physical models of traffic flow: namely, how popcorn flowing through a funnel does and does not represent traffic moving on a freeway.
Background

There is a limit to every road in which an increase in the speed limit will no longer increase the amount of cars that can travel the roadway at a given time. In addition, increases in speed limits can lead to more severe accidents and less fuel efficiency. Explain to students that whenever they adjust one aspect of a road’s design, they must also consider what other effects will come as a result of that change. Also note that the popcorn example is not a perfect analogy; however, it is useful in understanding the basics of flow and capacity.

Activity Expansion Ideas

In order to gain additional experience with the objectives of this activity, the following online activity may be beneficial. In this online activity, students will be able to control roadway attributes, including the density of traffic, the fraction of truck traffic, and various other settings dependent upon the chosen scenario.

Activity Link:

http://traffic-simulation.de/index.html
Activity 1: How Much Traffic Can the Road Handle?

General Activity Discussion
As this activity progresses, students should have a better understanding of the complexities of road design and why roads cannot simply be made “better.” While there are many more factors that come into play when designing road speed limits, such as the curvature of a road or what is located nearby, for this activity we will assume that the only factor is the flow rate. How would the design speed of a road change if we needed to consider those additional factors?

Activity 1A: Traffic Jam

Part One: Forming a Bottleneck

Questions
1) Which pour caused popcorn kernels to jam more often in the small funnel?
   The faster pour should cause more kernels to jam in the funnel.

2) What impact did the capacity of the funnel have on the popcorn’s ability to flow through?
   The larger capacity funnel allows for more popcorn to flow through over a period of time than the smaller funnel.

3) How can you compare this demonstration to roadways, traffic volume, speed, and traffic jams?
   Roadways = funnel
   traffic volume = kernel volume
   speed = flow (movement) of kernels
   traffic jams = kernel jam in the funnel

   The small funnel would be representative of a road that was designed for a low volume of traffic. There would be slowed traffic, or traffic jams, especially during peak travel hours if more vehicles used the road than what it was designed to handle.

   The large funnel represents a road that was designed for a larger volume of traffic. Therefore, there would be ample road space for travel with minimal, if any, situations of slowed or stopped traffic. With more ability for motion the roadway could have a higher speed limit, as you witnessed with the much quicker flow of kernels.
Part Two: Comparing Flow Rates of Large and Small Funnels

Questions

Note: Answers will vary. Answers given below are based on the sample data shown in the table on p. 20.

1) Compare the average flow rates for the small funnel and the large funnel. Show your work.

Average flow rate for the large funnel \( f_L \) = 100 mL/sec

Average flow rate for the small funnel \( f_s \) = 23.5 mL/sec

The small funnel has a flow rate that is 77% less than the large funnel

Since \( \frac{f_s - f_L}{f_L} = \frac{23.5 - 100}{100} = -0.765 \approx -77\% \)

2) Compare the areas of the funnels. Show your work.

Diameter of the large funnel = 2.3 cm

Diameter of the small funnel = 1.3 cm

Area of the large funnel = \( \pi \left( \frac{2.3}{2} \right)^2 \) = 4.15 cm² since \( 3.14(1.15)^2 \approx 4.15 \)

Area of the small funnel = \( \pi \left( \frac{1.3}{2} \right)^2 \) = 1.33 cm² since \( 3.14(0.65)^2 \approx 1.33 \)

The small funnel has an area that is 68% less than the large funnel

Since \( \frac{Area_{f_s} - Area_{f_L}}{Area_{f_L}} = \frac{1.33 - 4.15}{4.15} = 0.6795 = 68\% \)

3) Is the percentage computed in Question 1 similar to the percentage computed in Question 2?

_______yes _______no

This is the student’s call. The teacher may suggest that being within 10 percentage points should be considered.
4) Suppose that the kernels represent drivers, the funnels represent the width of the roadway, and the smaller funnel represents a work zone or accident that temporarily closes part of the road.

What does your answer in Question 3 suggest about the effect of a lane closure?

If the answer is yes, this means that the effect of closing a lane has a proportional impact on flow rates. For example, if one decreases a road width from two lanes to one lane, then one will decrease the amount of traffic flow by 50%.

If the answer is no, this means that the effect of closing a lane has a disproportionate effect on flow rates. For example, using the computations above, a 68% decrease in capacity caused a 77% decrease in traffic flow.

In practice, it is often the case that a small decrease in roadway capacity has a large decrease in traffic flow. For example, it has been suggested that, in some instances, closing one lane of a three lane highway will decrease capacity by more than 33%. In periods of heavy congestion, even a small obstruction on the shoulder, such as a disabled vehicle, can greatly decrease the traffic flow on a roadway. One can also criticize the popcorn analogy in the sense that drivers are not like popcorn kernels: they will have different reactions in times of traffic turbulence.

5) Was your optimum density at the fastest speed? If not, why do you think this was the outcome?

The optimum density should not be the fastest speed recorded, because, in order to safely drive at that speed, there would need to be less traffic on the road. We used empirical data (data from observations) therefore, a different road may have different results.

Discussion

There are a multitude of factors that make an impact on capacity in real life. Discuss with your students what additional factors were not considered in this activity that could potentially be important. For example, as the speed limit of a road increases, cars need to leave more space between one another, which affects capacity. Additionally, varying road conditions – such as weather conditions or the quality of the roadway surface (potholes, cracking, or other distress) – could affect the flow of traffic. Another potential factor, due to the design, would be width and additional space on the roadway – such as the width of the shoulders – which can affect the speed of traffic.

Activity 1B: Bumper to Bumper Traffic

Questions

1) The traffic density at any particular time is prone to change, causing actual travel speeds to fluctuate. What factors cause the traffic density to change?

Time of day is a major one. Roads are usually busier during the daytime, particularly at times when a large number of people are travelling to and from work. Car accidents and road construction are two other factors that would restrict the flow of traffic and increase the traffic density.
Discussion

When it comes to the flow of traffic, there are several factors that affect the speed limit of the roadway; including the density of traffic explored in this activity. Discussing the ways in which the density of traffic can be controlled would be beneficial to students. Some of the topics of interest would be alternative/public transportation – for example, the bus system, a rail system, carpooling, or riding a bike, as well as limiting access to the roadway. Means of alternative/public transportation create more space on the roadways by taking a large amount of vehicles off the road and placing a large number of people into one vehicle. To add context, a single 40-foot coach transit bus can typically carry 50 people; potentially removing as many as 50 individual cars from the road. As for limiting the access to the roadway, by decreasing the number of locations that vehicles can enter the stream of traffic, the flow of traffic will increase. This result is directly correlated to the decrease in the number of interruptions present on the road; therefore, decreasing the amount of times that traffic will slow.
Activity 1: How Much Traffic Can the Road Handle?

Introduction

An opening, such as a school hallway or a doorway at a crowded movie theater or stadium, cannot accommodate an unlimited number of people in a fixed time frame. Capacity is dependent upon the size of the opening. Roads are similar, but pose a unique problem: as the speed of a car increases, the amount of space between cars must also increase. Traffic engineers cannot always make roads bigger to solve problems related to the capacity. Often these challenges require more creative solutions.

This activity has two parts:

1A: Pouring popcorn kernels through two funnels of differing diameters, and therefore different opening areas, to verify that speed affects the flow rate.

1B: Using spreadsheet software to estimate capacity from speed and density observations.

Objective

In this activity, you will learn:

- Factors that affect the rate of flow: traffic density, traffic speed, and capacity of a roadway.
- Limitations of physical models of traffic flow: namely, how popcorn flowing through a funnel does and does not represent traffic moving on a freeway.

Background

Motorists generally try to maintain some type of distance between their vehicle and the vehicle immediately in front of them, commonly known as headway. People tend to follow with varying headways, which can be affected by their current mood. For example, anger can make one driver place his or her bumper almost immediately behind the vehicle in front of them, regardless of the speed. However, it is generally the case that as the speed of traffic increases, drivers tend to travel with larger headways. Figures 1-1A and 1-1B display examples of small and large headways, respectively.

![Figure 1-1A: Smaller Headways](image1)

![Figure 1-1B: Larger Headways](image2)

As vehicle speed increases, the amount of distance required to come to a stop also increases. This is why the headway when travelling on a 35 mph road is not the same as the headway required for a 70 mph
freeway. Stopping distance is covered in more detail in a different module; however, Figure 1-2 shows how stopping distance increases **exponentially** as the vehicle’s speed increases. While this graph does not perfectly represent every scenario (due to the effect of varying road conditions), it does represent the need for larger breaking distances as speed increases. For more context, State and Federal government agencies – such as MDOT and AASHTO – set design and construction standards to ensure roadway performance for many measures, including stopping distance.

![Figure 1-2: Stopping distance requirements](image)

When vehicles are traveling at a certain speed, some drivers travel with larger headways, while others travel with smaller headways, sometimes unsafely so. The total amount of headway between vehicles on a roadway is a limiting factor for the traffic capacity of the roadway. The capacity is decreased when there is insufficient headway for vehicles to travel safely at the speed limit or when a crash occurs as a result of insufficient headway. Due to these factors, the capacity of a road does in fact have an effective limit, the calculation for which will be explored in Activity 1B.
Materials

Activity 1A

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Popcorn Kernels</td>
<td>1 bag</td>
</tr>
<tr>
<td>Small funnel (1.3 cm opening)</td>
<td>1 per group</td>
</tr>
<tr>
<td>Large funnel (2.3 cm opening)</td>
<td>1 per group</td>
</tr>
<tr>
<td>Stopwatch</td>
<td>1 per group</td>
</tr>
<tr>
<td>Catch containers</td>
<td>2 per group</td>
</tr>
</tbody>
</table>

Activity 1B

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer with Microsoft Excel</td>
<td>1 per student or pair</td>
</tr>
<tr>
<td>Data file: Activity 1 - Flow Rate.xls</td>
<td>1 per student or pair</td>
</tr>
</tbody>
</table>

Note: this activity uses advanced spreadsheet functions. Instructions were completed using Microsoft Excel. Comparable software may be used, however, not all software may contain the functions necessary to complete the exercise.
Activity 1A: Traffic Jam

Procedure

In this activity, you will pour popcorn into a container using two different funnels and pour speeds. The goal is to determine how “traffic jams” are dependent on both the speed and the size of the road. However, these are not the only factors.

Part One: Forming a Bottleneck

1. Measure out approximately 200mL of popcorn kernels. Record the exact volume you measured in your Research Notes.
2. Place the smaller funnel over an empty container. Prepare to time the activity.
3. Student 1 will pour the popcorn kernels slowly into the funnel. (You do not want the kernels to get stuck in the funnel.) Student 2 should begin timing as Student 1 begins to pour the kernels into the funnel (See Figure 1-3A) and stop timing once all the kernels have passed through the funnel.
4. Use the data table in your Research Notes to record the time required to pour all the kernels through the small funnel into the container.
5. Repeat steps 2-4, but this time, pour the popcorn kernels faster so they become jammed in the funnel. As the kernels get stuck, shake the funnel to dislodge them.
6. Now place the large funnel over an empty container and pour the same kernels through the funnel at a moderate and steady rate (See Figure 1-3B). Timing should be performed in the same manner as described in step 3.
7. Use the data table in your Research Notes to record the time required to pour all the kernels through the large funnel into the container, then answer the questions for Part 1.

Figure 1-3A: Popcorn in a Small Funnel

Figure 1-3B: Popcorn in a Large Funnel
Part Two: Comparing Flow Rates of Large and Small Funnels

1. Measure out approximately 400 mL of popcorn kernels. Student 1 should hold the large funnel at a slight angle and block the bottom of the funnel with his/her hand so the kernels will not pass through the funnel. Student 2 should pour the kernels into the large funnel.
2. Student 3 should prepare to time the trial. Once Student 1 and Student 3 are both ready, Student 1 should remove his/her hand from the bottom of the funnel and Student 3 should begin timing. Continue timing until all the popcorn has passed through the funnel.
   *Note:* To reduce jamming, make sure to hold the funnel at an angle.
3. Record the volume and time data in your Research Notes.
4. Repeat steps 1-3 until you have completed 5 trials with the large funnel (use the same 400mL of kernels for each trial). Calculate the flow rate for each trial, then calculate the average flow rate for all 5 trials using the equations given below.
5. Now repeat steps 1-4 with the small funnel.
   *Note:* If the small funnel jams, gently shake the funnel to dislodge the kernels and keep the flow going.
6. Answer the questions in your Research Notes for Part 2.

<table>
<thead>
<tr>
<th>Flow Rate Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q = \frac{V}{t} )</td>
</tr>
<tr>
<td>Where:</td>
</tr>
<tr>
<td>( Q ) = Flow Rate (mL/s)</td>
</tr>
<tr>
<td>( V ) = Volume (mL)</td>
</tr>
<tr>
<td>( t ) = time (s)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Flow Rate Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{avg} = \frac{\sum Q_i}{n} )</td>
</tr>
<tr>
<td>Where:</td>
</tr>
<tr>
<td>( Q_{avg} ) = Average Flow Rate (mL/s)</td>
</tr>
<tr>
<td>( \sum Q_i ) = Sum of flow rates from all trials (mL/s)</td>
</tr>
<tr>
<td>( n ) = number of trials</td>
</tr>
</tbody>
</table>
Activity 1B: Bumper to Bumper Traffic

Setup

Open Microsoft Excel, select File/Open, and navigate to the file entitled Activity 1 - Flow Rate.xls, which can be found in the Design & Construction Module section of the TRAC webpage.

Procedure

This activity will demonstrate how a road has a maximum speed and traffic capacity. At a certain traffic density and speed, a road can support the greatest amount of vehicles per hour.

A traffic study has been conducted on a local county road in order to examine the traffic density and traffic flow rates. The results of this empirical study has been compiled into a table provided to you, the traffic engineer. It is now your job to analyze the data in order to determine the optimal speed limit for this road.

1. The Excel file contains a three-column data table. Calculate the Flow Rate data column by multiplying the given Average Vehicle Speed data column by the corresponding Traffic Density data column. This calculation can be performed in Excel by using the formula bar at the top of the page. Select the first cell underneath the Flow Rate data column, then type ‘=’ into the formula bar. Then, select the first cell under the Traffic Density data column and type ‘*’ into the formula bar (an asterisk represents multiplication in Excel). Then, select the first cell under the Average Vehicle Speed data column and press enter. Excel will do the calculation for you and present the resulting value in the cell.

\[ \text{density} \times \text{speed} = \frac{\text{vehicles}}{\text{mile}} \times \frac{\text{miles}}{\text{hour}} = \frac{\text{vehicles}}{\text{hour}} = \text{flow rate} \]

2. This formula can then be copied to the rest of the cells under the Flow Rate data column, which will cause Excel to perform all the calculations for you. Click on the cell you calculated in the previous step and a green box will appear in the lower right corner of the cell. Drag this green box down the length of the data column and release at the last cell. Excel will automatically perform all of the calculations with the corresponding Traffic Density and Average Vehicle Speed data.

3. Now that you have data in the Flow Rate column, we are going to graph this data with regards to Traffic Density. To do this, highlight the data under the Traffic Density data column. Next, hold down the Ctrl button on your keyboard and highlight all of the data under the Flow Rate data column as well.

4. In the top, left-hand corner of the page, there should be a tab labeled Insert; open this tab. In the Charts section, select Insert Scatter (X,Y) or Bubble Chart, then select Scatter. Figure 1-4 can guide you through this process.

Note: Your x-axis should be the Traffic Density data and your y-axis should be Flow Rate data. If this is not how your graph appears, right-click on the graph and click on Select Data. In the dialog box that appears, click Edit; another dialog box will appear. Select the Traffic Density data under Series X Values and the Flow Rate data under the Series Y Values to make the necessary changes to your graph. Click OK on both dialog boxes to save your changes.
5. To label your axes, click on your graph. In the top right hand corner of the graph, a + sign will appear. Click on this and then place a check mark next to **Axis Titles**. Edit the **Axis Titles** placeholders that appear on your graph to assign them their appropriate labels. Your x-axis should be labeled **Traffic Density (vehicles / mile)** and your y-axis should be labelled **Traffic Flow Rate (vehicles / hour)**. Figure 1-5 can help guide you through this process.

6. Type in a chart title in the **Chart Title** placeholder. Your chart should be titled **Traffic Flow Rates at varying Traffic Densities**.
   
   **Note:** A **Chart Title** placeholder should have appeared when you created your graph. If this did not occur, one can be added by clicking on the + sign again and placing a check mark next to **Chart Title**.
   
7. Click on the + sign again and select the arrow next to **Trendline**, opening a drop-down menu. From that drop-down menu, select **More Options**. A window will open on the right side of your screen. Figure 1-6 can guide you through this process.
8. In the window that appears, select the tab, opening Trendline Options. Select the Polynomial trendline option and change the order to 3. Figure 1-7 can guide you through this process.

You should now have a completed graph of Flow Rate with regards to Vehicle Density, with a trendline that represents the general trend of the empirical data. From this trendline, you can visualize the concept of the maximum road capacity. At a certain traffic density, the road becomes too congested for vehicles to effectively travel at higher rates of speed.
Advanced Steps

We will now calculate what the **optimum** speed limit would be for this road. To do this, we will need to find two things:

a) The overall maximum point on the graph where the slope of the trendline is equal to 0.
b) The corresponding **Flow Rate** and **Traffic Density** at that point. These values will be used to find the optimum speed limit.

1. To find the optimum capacity, click the box in the **Format Trendline** window labeled **Display Equation on Chart**, below where you chose the **Polynomial** trendline option earlier. A formula should appear on your graph.

2. Copy this formula from the graph and paste it into a blank cell. Delete the y from the beginning of the formula, and everywhere that the formula has an x, replace them with the name of a different blank cell. Delete all the spaces present between variables. After this, add in multiplication and exponent symbols to the appropriate locations shown in the example below.
   a. For example, if you placed the formula in cell E31, use cell D31 as the blank cell in your formula. Your formula should be displayed exactly as follows:
      
      \[=0.0046 \times D31^3-1.4674 \times D31^2+123.95 \times D31-768.07\]

   b. It is important that the cell you choose to enter the formula in is empty.

   c. In Excel, an astrick (*) is a multiplication symbol and the carrot (^) indicates an exponent.

3. Now under the **Data** tab, on the far right under **Analysis**, click the **Solver** button. **Note**: You may have to load the Solver Add-In into Excel if you cannot find it. This can be done by following the instructions on the following link:


4. To use the solver, we will set the **Objective** to the cell that we wrote our formula in (E31 in our example), set the solver to find the **Max**, and set the **By Changing Variable Cells** to the blank cell referenced by our equation earlier. (D31 in our example) Then click **Solve**. Figure 1-8 can assist you with this.
5. The cell where you typed the formula earlier (E31 in our example) should now be replaced with a number. This is the maximum flow rate of the trendline equation. The blank cell we referenced in the equation (D31 in our example) should now be replaced with a number as well. This number is the optimum traffic density. Record these values in your Research Notes.

6. Divide the maximum flow rate by the optimum traffic density to achieve the Optimum Speed for that road (this model assumes steady traffic flow). Record this value in your Research Notes and answer the questions about this section.
Activity 1A: Traffic Jam

Part One: Forming a Bottleneck

Record the popcorn volume and the time it takes to pour the popcorn kernels through the small and large funnels.

<table>
<thead>
<tr>
<th></th>
<th>Small Funnel</th>
<th></th>
<th>Large Funnel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume (mL)</td>
<td>Time (s)</td>
<td>Volume (mL)</td>
</tr>
<tr>
<td>Slow Pour</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Fast Pour</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions

1) Which pour caused popcorn kernels to jam more often in the small funnel?

2) What impact did the capacity of the funnel have on the popcorn’s ability to flow through?

3) How can you compare this demonstration to roadways, traffic volume, speed, and traffic jams?
Part Two: Comparing Flow Rates of Large and Small Funnels

Record the volume and time data for each trial in the appropriate row of the table, then calculate the flow for each trial:

<table>
<thead>
<tr>
<th></th>
<th>Large Funnel</th>
<th></th>
<th>Small Funnel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Volume (mL)</td>
<td>Time (s)</td>
<td>Flow (mL/s)</td>
<td>Trial</td>
</tr>
<tr>
<td>Example</td>
<td>400 mL</td>
<td>4 s</td>
<td>100 mL/s</td>
<td>Example</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Average Flow Rate for All 5 Trials</td>
<td></td>
<td></td>
<td></td>
<td>Average Flow Rate for All 5 Trials</td>
</tr>
</tbody>
</table>

Questions

1) Compare the average flow rates for the small funnel and the large funnel. Show your work.

Average flow rate for the large funnel \( f_L \) = mL/sec
Average flow rate for the small funnel \( f_s \) = mL/sec
The small funnel has a flow rate that is \( \frac{f_s - f_L}{f_L} \times 100\% = \) % less than the large funnel

2) Compare the areas of the funnels. Show your work.

Diameter of the large funnel \( \text{diameter}_L \) = cm
Diameter of the small funnel \( \text{diameter}_s \) = cm
Area of the large funnel \( \text{Area}_{L} = \pi \left( \frac{\text{diameter}_L}{2} \right)^2 = \) cm²
Area of the small funnel \( \text{Area}_{S} = \pi \left( \frac{\text{diameter}_S}{2} \right)^2 = \) cm²
The small funnel has an area that is \( \frac{\text{Area}_{S} - \text{Area}_{L}}{\text{Area}_{L}} \times 100\% = \) % less than the large funnel
3) Is the percentage computed in Question 1 similar to the percentage computed in Question 2?

______yes  ______no

4) Suppose that the kernels represent drivers, the funnels represent the width of the roadway, and the small funnel represents a work zone or accident that temporarily closes part of the road.

What does your answer in Question 3 suggest about the effect of a lane closure?

5) Was your optimum density at the fastest speed? If not, why do you think this was?

Discussion Notes
Activity 1B: Bumper to Bumper Traffic

Record the max traffic density, max traffic flow rate, and optimum speed limit in the table below:

<table>
<thead>
<tr>
<th>Max Traffic Density (vehicles/mi)</th>
<th>Max Traffic Flow Rate (vehicles/hr)</th>
<th>Optimum Speed Limit (mi/hr)</th>
</tr>
</thead>
</table>

Questions

1) The traffic density at any particular time is prone to change, causing actual travel speeds to fluctuate. What factors can you think of that will cause the traffic density to change?
Activity 2: Not In My Backyard!

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructor Prep Time</strong></td>
</tr>
</tbody>
</table>
| **Class Time** | 45 minutes for Background section  
45 minutes for Activity |
| **Grade/Class** | 6 - 12 Social Studies / Civics / Geography  
6 - 12 Technology |
| **Suggested Activity Grouping** | Groups of two |
| **Technology** | Low Tech |
| **National Council for the Social Studies Standards** | Strand 8 (Science, Technology, and Society) |
| **International Technology Education Association Standards** | Positive and negative impacts of transportation systems |

**Introduction**
Using a transportation case study, this activity explores the impact of technology on our physical environment. When constructing a new road, the pros and cons are evaluated to ensure quality. The process of evaluation (location and features of the roadway) is equally as important as the end result of the project.

Activity 1A is a useful prelab, but is not required.

**Objective**
Students will be able to:

- Develop a basic framework for evaluating the impacts of two or more alternatives using quantitative and qualitative techniques.
- Identify a technology’s impacts (e.g. the road’s environmental and economic effects).
- Compare alternatives (e.g. the road’s location) while considering community goals.

**Background**
Often community planners will create a document called a 20-year plan, which will outline how a community should expand and improve its infrastructure as it grows. These plans are constantly updated to ensure that the end goal is always improving and progressing. When creating the 20-year plan, the community needs to be involved. In order to accommodate the community, their voice should be heard and considered in the planning process and they should be informed of decisions. This is important because much of the funding results from property taxes, other local taxes, state taxes, and
federal taxes. As part of this process, planners must decide where new improvements, such as roads, will go and must balance the needs of all the people they serve.

**Activity Expansion Ideas**

**Your Community’s 20-Year Plan**

In order to further understand the 20-year plan referenced in this activity, students could conduct research on your local community’s 20-year plan (or 10-year plan) and complete a written report. A suggested layout for the report includes: a brief history of the city, current projects that fulfill portions of the 20-year plan, the forecasted 20-year plan, and the student’s personal opinion of the 20-year plan. During this process, information can be found through internet searches, contacting the community engineer or board (or equivalent), or attending community meetings (where the 20-year plan is on the agenda).

**Land Usage Exploration**

In this activity, different road types and land uses that affect the location and design of a new road are explored. Depending on time constraints, discussion of the characteristics of each land use type and anticipated community reaction could be conducted to supplement the activity.
Activity 2: Not In My Backyard!

General Activity Discussion
This activity first demonstrates how roadway solutions differ depending on specific and diverse needs set forth by the project stakeholders. The second portion of the activity challenges the students to design a road that best fits all these needs with a single solution. Often, road projects are designed and built to meet future needs as well. These needs may not be immediately realized by the project stakeholders and it is therefore the responsibility of the engineers to educate and inform the public about why certain decisions were made. Have a class discussion regarding the process of designing a roadway that best addresses individual project stakeholder interests both now and into the future while doing what is best for the community as a whole.

Research Manual

Questions
Questions have been placed within the Research Manual instead of the Research Notes section in order to help guide students through the engineering process. Students will complete the first five scenarios while addressing these questions; following this, discuss the answers with the students. Students will then have the necessary background information to complete scenario six.

Scenario 1. The road that eliminates the most congestion -
In order to maximize speed when many trucks are in the traffic stream, why might you locate your road on flat land rather than mountains and valleys?

Mountains and valleys will cause cars, and to a much greater extent heavy trucks, to travel more slowly when going uphill. In addition, they will need to burn more gas in order to provide the power required to go up the hill, which will increase emissions and reduce fuel economy.

Scenario 2: The best road for economic development -
Why might the business owners at Strip Mall City prefer to be adjacent to a four lane road with a traffic light rather than a six lane freeway?

If the freeway has no exit ramps near Strip Mall City, then the freeway traffic may simply bypass the mall altogether. An arterial road that has a traffic light at Strip Mall City may cause some drivers to casually stop at the mall, thereby increasing business.

Scenario 3: The best road for the environment -
To reduce runoff that could worsen water quality, which one of the following is it critical to avoid:

a) farmland
b) residences
c) Great Dismal Swamp
d) the Financial and Business District
e) River Run High School

Scenario 4: The cheapest road -

Generally, is land cheaper at (select one):

a) the northern half of the map (rows 1-19)

b) the southern half of the map (rows 20-38)

Scenario 5: Consider only citizen attitudes regarding a new road -

Compare the road locations for Scenarios 1, 2, and 4. Why might the “best” road differ amongst the scenarios?

Each scenario represents a different goal or a different constituency. For example, persons interested in economic development might prefer a road that opens up rural areas, whereas persons more interested in preservation might prefer simply to widen existing facilities.

Research Notes

Questions

1) Determine the total cost of the road by adding the costs of the individual cells.

The cost is $_______ in millions

This will vary by road, but remind students to simply use the data in Table 2-6. The value of doing this comes from comparing answers amongst students in the class and pointing out that students who did two-lane roads (with low design speeds) will generally have lower costs than students who chose six-lane freeways with high design speeds.

2) Determine the environmental impacts by counting the cells inside any buffered areas from step 3 (such as the Snake River).

A total of ________cells are affected by runoff or noise pollution.

The answer will vary for each student. The lesson is that a road can affect an area even if the road does not physically touch the location.

3) Indicate the number of homes and businesses that will be displaced by the road.

_______homes will have to be relocated

_______businesses will have to be relocated

In this simplified process, we are counting each dwelling unit (regardless of size) equally and each business (regardless of size) equally. This simplifies matters but is a bit unrealistic.
4) What percentage of the time will your road have enough capacity to avoid a traffic jam (e.g. breakdown conditions)? See Tables 2-2 and 2-8.

_______% of the time we will not have a traffic jam

Students compare the capacity of their road from Table 2-2 to the percentage of hours shown in Table 2-8, where the capacity exceeds the volume. For example, suppose a student chose the four-lane arterial with a design speed of 50 mph. See the following comparison in Table 2-8. For this particular road, there will be sufficient capacity about 40% of the time. During the remaining 60% of the time, there will be breakdown conditions. (Engineers refer to these breakdown conditions as “Level of Service F.”)

5) Indicate which goal is best achieved by your road. Tables 2-3 and 2-4 may be helpful.

a) move a lot of traffic
b) minimize environmental impacts such as water, runoff, and noise
c) consume as little land as possible
d) increase pedestrian safety
e) encourage economic development in rural areas.

This will relate to the chosen road, and there may be more than one correct answer. For a high-speed freeway, the answer should be (a). For a two-lane, low-speed roadway, the answer may be (c). A road’s location may also influence which of these is chosen; a road connecting rural areas could qualify for answer (e).

6) Indicate which of the following constituents is likely to be the most content with the construction of the road. Table 2-5 may be helpful.

a) Residents (____________________________________name the particular areas)
b) Through-travelers that do not live in the community
c) Small business owners (____________________________________name a few that apply)
d) The Western Forest Preserve Conservation Society
e) The Airport Authority

Encourage students to discuss which of these constituencies would also be unhappy with the decision. For example, if the road goes to the east (far away from the forest preserve) then the Western Forest Preserve Conservation Society in answer (d) will be happy; however, the Airport Authority in answer (e) will be disappointed if a large road does not serve the airport.

7) What can you conclude is the “best” decision for this community if they decide they want a new road?

This activity should convey that there is no single decision that will please everyone. Instead, a community has to consider the different goals it may have and the different constituencies and draw some sort of compromise amongst these (It is true that there can be cases where a new road may satisfy all goals, but often some type of compromise is necessary).
8) The location for a road that is guaranteed to make all citizens happy is probably:
   a) in a rural area (to encourage economic development)
   b) in an urban area (so as to preserve farmland)
   c) in the mountains (to provide a scenic view)
   d) within driving distance of major residential neighborhoods
   e) no location will please everyone

   Answer should be (e) although students may come up with some excellent ideas that justify another
answer; if so, then accept their answer!

9) What mode of transportation was not fully considered in this example but should be considered in
real life?
   a) bicycle
   b) walking
   c) public transportation (buses)
   d) public transportation (light rail or subway)
   e) all of the above

   This activity leaves out a critical lesson: that transportation should truly be multimodal in focus. An
extension of this activity would be to discuss how a combination of transportation options such as
high-speed rail or other transit options could mitigate the need for new road construction.

Discussion

Discuss how any construction project, especially one in a city, has a cost associated with the use of land
or a cost due to the closure time required to perform repairs. If you had to choose which plots of land to
buy, you must consider all of these factors, like land cost and impact on traffic, before making a
decision. Ask students to think about construction projects near them and what factors would have
needed to be considered in order to complete the projects.
Activity 2: Not In My Backyard!

Introduction

Planning for transportation facilities, specifically deciding where, when, and if to construct a new roadway often has no right answers. A road’s location, size, and alignment affect a community’s environment, quality of life, and character. A road may reduce congestion, improve safety, remove through-traffic from residential streets, and encourage economic development, but it can also destroy neighborhoods, increase erosion, and decrease safety.

Even if it is agreed that a road needs to connect two points, the nature of the road itself may be debated. Residents may disagree on the number of lanes, the design speed, the amount of curvature, and the location. In Figures 2-1 and 2-2, a demonstration of this occurrence is depicted. A road in the same location can be built in two different ways, depending on the needs of the area. Some may think that the money spent on new construction should be spent on other transportation expenses instead, such as maintaining existing roads or investing in different modes of transportation (such as bus transit or high-speed rail). Others may argue that if a road is to be built, it should be a high-capacity freeway or an arterial that can accommodate more traffic, as shown in Figure 2-3. Although, others may argue that a road should be aesthetically pleasing, as shown in Figure 2-4.

To construct a road, land must be purchased from private citizens, businesses, or local, state, or federal governments. The total land area for building a road is known as right of way; which includes the land underneath the road bed, as well as additional land that borders the roadway. As areas in the U.S. become increasingly urbanized, acquiring right of way becomes more and more difficult. Not only must a path be planned for a roadway that does not conflict with existing churches, schools, stores, and homes, but one must also ensure that high-speed, high-volume roads, such as freeways, are not too close to existing buildings. For example, a heavily-traveled interstate would not be a welcome addition to a residential area. In fact, the noise and congestion from high-speed roadways has become so unpopular that in many communities, citizens request for no additional streets to be constructed through their neighborhood. The phrase “not in my backyard!” refers to the perspective that a new road...
should not be constructed near a particular area, such as a neighborhood, church, business, school, park, or waterway.

On the other hand, some communities want additional roads to accommodate heavy traffic that may be contributing to congestion. If one road has a lot of traffic, a parallel road can relieve traffic congestion. By relieving this congestion, it becomes possible for people to get to work, home, and shopping quicker and more efficiently. Figures 2-5 and 2-6 display roads with no congestion and a lot of traffic congestion, respectively.

**Objective**

In this activity, you will:

- Develop a basic framework for evaluating the impacts of two or more alternatives using quantitative and qualitative techniques.
- Identify a technology’s impacts (e.g. the road’s environmental and economic effects).
- Compare alternatives (e.g. the road’s location) while considering community goals.
Background

What Road Types are considered?

This activity considers three road types as shown in Figures 2-7: a two lane road (one lane in each direction), a four lane arterial with traffic signals and sidewalks (two lanes in each direction), and a six lane limited access freeway (three lanes in each direction), respectively.

![Figure 2-7A: two lane road](image)

![Figure 2-7B: four lane arterial with signals](image)

![Figure 2-7C: six lane freeway](image)

Several factors influence how well a road moves traffic. Two critical factors considered in this activity considers are design speed (how fast a single vehicle by itself can travel safely) and capacity (how much traffic the road can handle).

How Do Turns Affect the Design Speed?

A road with a larger turning radius, or radius of curvature, can accommodate higher speed traffic than a road with a tighter turning radius. Suppose Road A is being designed to carry traffic at 30 mph (48 km/h) and Road B is to carry traffic at 70 mph (113 km/h). Also, suppose that the road changes direction from north to west (e.g. make a 90 degree turn), as shown in the left half of Figure 2-8. The turning radius for Road B is much larger, as seen in the right half of Figure 2-8. The tangent sections (shown on the vertical and horizontal axes) would require a much larger connecting curve at the higher speed of 70 mph (113 km/h).
Table 2-1 assigns values to each of these minimum turning radii for each design speed. This data shows that if a 70 mph roadway is being designed, then the turning radius needs to be more than double what would be needed for a 50 mph roadway! Therefore, the higher speeds require more land, or right of way, than would be needed for a lower speed road.

**Table 2-1: How Does Design Speed Affect the Minimum Turning Radius?***

<table>
<thead>
<tr>
<th>Design Speed</th>
<th>30 mph</th>
<th>40 mph</th>
<th>50 mph</th>
<th>60 mph</th>
<th>70 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>48 km/h</td>
<td>250 ft</td>
<td>464 ft</td>
<td>76 m</td>
<td>142 m</td>
<td>231 m</td>
</tr>
<tr>
<td>64 km/h</td>
<td>464 ft</td>
<td>758 ft</td>
<td>76 m</td>
<td>142 m</td>
<td>231 m</td>
</tr>
<tr>
<td>81 km/h</td>
<td>758 ft</td>
<td>1,200 ft</td>
<td>366 m</td>
<td>554 m</td>
<td></td>
</tr>
<tr>
<td>97 km/h</td>
<td>1,200 ft</td>
<td>1,815 ft</td>
<td>554 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>113 km/h</td>
<td>1,815 ft</td>
<td>554 m</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Curves use a rate of superelevation of 0.08 and coefficients of side friction appropriate for the design speed.

**How Much Traffic Can a Road Handle?**

The capacity of a roadway is the maximum number of vehicles that can be accommodated by the roadway during an hour, which increases as the number of lanes increases and as the design speed increases. If more vehicles want to use the road than capacity will allow, then “traffic jams” occur (Figure 2-6). Generally, this occurs when more traffic is entering the road than exiting it. Capacities for the three roadway types being considered are given in Table 2-2. Although capacity will vary by situation, we will utilize these capacities for the purpose of the activity.
Table 2-2: Capacity for Different Roadway Types and Design Speeds*

<table>
<thead>
<tr>
<th></th>
<th>30 mph (48 km/h)</th>
<th>50 mph (81 km/h)</th>
<th>70 mph (113 km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Lane Winding Road (no shoulders)</td>
<td>900 vehicles per lane (1,800 vehicles total)</td>
<td>1,300 vehicles per lane (2,600 vehicles total)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>Four-Lane Arterial with traffic signals and Sidewalks</td>
<td>1,300 vehicles per lane (5,200 vehicles total)</td>
<td>1,600 vehicles per lane (6,400 vehicles total)</td>
<td>(not applicable)</td>
</tr>
<tr>
<td>Six-Lane Limited Access Freeway</td>
<td>(not applicable)</td>
<td>2,000 vehicles per lane (12,000 vehicles total)</td>
<td>2,200 vehicles per lane (13,200 vehicles total)</td>
</tr>
</tbody>
</table>

*A number of assumptions are made, but these capacities should suffice for comparison purposes.

**Hint:** If your class performed Activity 1A with the popcorn kernels, then an applicable analogy in this situation is the representation of design speed as how fast one kernel of popcorn travels by itself. Similarly, the capacity represents how many popcorn kernels can flow through the funnel at once without becoming jammed.

**What Type of Road Might a Community Select?**

None of these options are the “best.” A high-speed six-lane freeway is great for moving lots of traffic quickly, but a two-lane winding road is a better choice for using less land and reducing noise. Yet from the perspective of a pedestrian, both of these choices cannot compare to a four lane arterial road with sidewalks. Table 2-3 gives examples of what goals would be best accomplished by each of these roadway types.

Table 2-3: What road type would you select if your only goal were to...

<table>
<thead>
<tr>
<th>Goal</th>
<th>Two-Lane Winding Road (no shoulders)</th>
<th>Four-Lane Road With Traffic Signals and Sidewalks</th>
<th>Six Lane Limited Access Freeway</th>
</tr>
</thead>
<tbody>
<tr>
<td>move the most traffic?</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>move traffic the fastest?</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>build the cheapest road?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>use as little land as possible?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reduce noise?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>increase safety for drivers?</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>increase safety for pedestrians?</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
What Location Might the Community Select?

If one thinks of a community as having a single voice, then a road’s location is influenced by the goals of the community. If Community A wants to keep farmland free from development, it may choose to locate a road only in urbanized areas. Yet if Community B wants to purchase the cheapest land possible for a road (to minimize construction costs), then it may choose that same farmland that community A would have preserved. Consider the following three land uses: rural lakes and mountains, farmland, and urbanized residential and commercial areas, as presented in Table 2-4. Suppose that you only have two choices for each type of land use: placing the road near the land use or far from the land use. The goal of the community affects where the road may be located.

Table 2-4: Where would you locate the road if your only goal were to . . .

<table>
<thead>
<tr>
<th>Goal</th>
<th>Rural Mountains and forest</th>
<th>Farmland</th>
<th>Urbanized areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>provide a scenic view for drivers?</td>
<td>near</td>
<td>near</td>
<td>far</td>
</tr>
<tr>
<td>minimize water runoff impacts?</td>
<td>far</td>
<td>far</td>
<td>near</td>
</tr>
<tr>
<td>stimulate business customers?</td>
<td>far</td>
<td>far</td>
<td>near</td>
</tr>
<tr>
<td>be accessible to local residences and businesses?</td>
<td>far</td>
<td>far</td>
<td>near</td>
</tr>
<tr>
<td>minimize construction costs by finding cheaper, flatter land?</td>
<td>far</td>
<td>near</td>
<td>far</td>
</tr>
<tr>
<td>preserve existing homes and businesses?</td>
<td>near</td>
<td>near</td>
<td>far</td>
</tr>
<tr>
<td>keep rural areas rural?</td>
<td>far</td>
<td>far</td>
<td>near</td>
</tr>
<tr>
<td>stimulate the development of rural areas?</td>
<td>near</td>
<td>near</td>
<td>far</td>
</tr>
<tr>
<td>not generate additional noise for urbanized residents?</td>
<td>near</td>
<td>near</td>
<td>far</td>
</tr>
</tbody>
</table>

What Location Might Different Constituencies Want?

In reality, a community does not speak with a single voice. Different constituents (residents, business owners, and so forth) may have different attitudes regarding what constitutes an ideal location for a road, even if they agree that a new road is needed. A gas station may want to be immediately adjacent to a road and have a traffic signal installed in order to encourage customers to stop by, whereas a prospective homeowner may reject such a location because of the noise that is generated. Table 2-5 shows some possible reasons for why different constituents may disagree on where the road should be placed. The information provided is a simplification of reality, as there are more choices and factors to consider than those shown.
### Table 2-5: Attitudes Regarding the Location of a Roadway

<table>
<thead>
<tr>
<th>Constituency</th>
<th>This constituency probably wants to be located...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport operator</td>
<td>Close to the entrance/exit of a high capacity freeway that can transport goods and services directly.</td>
</tr>
<tr>
<td>Factory owner</td>
<td></td>
</tr>
<tr>
<td>Military Base</td>
<td></td>
</tr>
<tr>
<td>Large shopping mall</td>
<td></td>
</tr>
<tr>
<td>Fast Food Restaurant</td>
<td>On a high volume arterial road with a traffic signal, encouraging traffic (and, therefore, customers) to “drop in” (see Figure 2-9). Being near a freeway entrance is also desired.</td>
</tr>
<tr>
<td>Mini-Mall, Gas Station,</td>
<td></td>
</tr>
<tr>
<td>Supermarket</td>
<td></td>
</tr>
<tr>
<td>Bed and Breakfast</td>
<td>On a quiet two lane road with low volumes, in order to minimize pollution and noise.</td>
</tr>
<tr>
<td>Apple Orchard</td>
<td></td>
</tr>
<tr>
<td>Lake Resort</td>
<td></td>
</tr>
<tr>
<td>Residential Area</td>
<td>Located on a quiet, low-volume, low-speed road (see Figure 2-10). Some residents would like a higher speed road to be within a few minutes’ drive of their home; others prefer the opposite.</td>
</tr>
<tr>
<td>Golf course</td>
<td>A location that will attract many customers, such as an arterial road that links the course to businesses or residences.</td>
</tr>
</tbody>
</table>

**Figure 2-9: Potential Location for Businesses Seeking to Attract Drive-By Customers**

**Figure 2-10: Potential Location for Residents**
Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-part map of the study area</td>
<td>1 copy per group</td>
</tr>
<tr>
<td>Transparent road tangent templates</td>
<td></td>
</tr>
<tr>
<td>Two-lane road</td>
<td>4 per group</td>
</tr>
<tr>
<td>Four-lane arterial</td>
<td>4 per group</td>
</tr>
<tr>
<td>Six-lane freeway</td>
<td>4 per group</td>
</tr>
<tr>
<td>Circular curve tool (30 mph (48 km/h), 50 km/h)</td>
<td>1 set per group</td>
</tr>
<tr>
<td>Sticky notes</td>
<td>As needed</td>
</tr>
<tr>
<td>Scotch tape</td>
<td>As needed</td>
</tr>
<tr>
<td>Pencils</td>
<td>As needed</td>
</tr>
<tr>
<td>Optional (Not Supplied)</td>
<td></td>
</tr>
<tr>
<td>Three different colored markers</td>
<td>As needed</td>
</tr>
<tr>
<td>Ruler</td>
<td>As needed</td>
</tr>
<tr>
<td>Calculators</td>
<td>As needed</td>
</tr>
</tbody>
</table>

Setup

Preparing the Map

Work in groups of two. Prepare your map by taping the two individual sheets together. (The map is divided into a top and bottom half, each printed out an 11 X 17-inch sheet of paper). Tape the maps together such that row 20 (on the bottom map) immediately follows row 19 (on the top map). Discuss the history of the community and the problem it faces, as described below.

History of the Community

The northern half of this community is more heavily developed than the southern half. Except for Shrimp Lake in the northwestern corner and the farmland to the northeast, most of the northern land is occupied. A historic district, centered around cell L5, was constructed over a century ago; where residents enjoy central park (located just to the west), the bicycle trails linear park (just to the north) and Paradise Theaters (just to the east). After World War II, the community grew rapidly with a series of strip malls built just south of the historic district and large-scale community projects, such as MegaMart Superstore, a premier hospital, and Soundblaster Stadium, were built to the east where open land was readily available. The relocation of several renowned financial investment companies to the eastern financial and business district in the 1960s and 1980s spurred the need for residential housing, a large amount of which is clustered near the center of the map, between rows 13 and 19. Following this, schools, a golf course, athletic fields, and other amenities were developed.

In the 1980s and 1990s the southern half of the community started to develop, although, much more slowly. The southern land is more rural than the northern land for several reasons. First, unlike most of the northern portion, the southern land is somewhat mountainous: Hidden Valley (centered at X23) and Windy Mountain (L35). The terrain is quite steep, causing construction to be prohibitively expensive. Another factor that has kept the southern lands pristine has been their sheer distance from the urbanized portion of the community. Aside from the Lake Side Resorts and farming, there are not many jobs in the area. Finally, the southern lands have several federally protected areas: Snake River and the Forest Preserve. These locations are favorite spots for hikers and kayakers from all over. Other
protected areas in the community include the Great Dismal Swamp and the Forest of Gloom, aptly named as a result of the amount of hikers that get lost every year.

**The Problem Facing the Community**

Traffic congestion is increasing on all the roads shown on the map. Not only has new development to the east generated traffic, but an increasing amount of non-residents have been traveling through the community. In fact, the greatest need for travel is from the southwest corner (A38, near US 8) to the northeast corner (Z1). The community has decided they want to construct a new road, although the citizens have to decide how the southwest and the northeast quadrants should be connected: extending existing roads, widening roads, or building a brand new facility.

**Procedure**

We shall consider five different scenarios to help determine where the road should be placed:

1. The fastest possible road that eliminates the most congestion
2. The road that encourages economic development
3. The road that is best for the environment
4. The road that is the cheapest
5. A road that minimizes impacts regarding existing homes and businesses

Then, a sixth and final scenario, is to design the “best road” that you think is a good compromise of speed, environmental considerations, economic development considerations, cost, and impact on existing homes and businesses.

Short questions (multiple choice and short answer) are provided with each scenario. For the first five scenarios, it is recommended that you spend about five minutes per scenario and answer the questions. Your instructor will determine if you will discuss these scenarios as a class or in small groups. Scenario 6 should be tackled by each group independently.

**Scenario 1. The road that eliminates the most congestion**

1. Suppose your only goal is to eliminate traffic congestion by increasing capacity. Use Table 2-2 to identify which road types (two-lane, four-lane arterial, or six-lane freeway) and which design speed (30 mph, 50 mph, and 70 mph) are best to eliminate congestion.

   ____ total lanes  ____ design speed

2. Decide where this road should be located. Select the appropriate two, four, or six lane roadway template. For now, connect the road tangent templates end to end until the road goes from A38 in the lower left corner to Z1 in the upper right corner.

3. Finally, connect the tangent sections with the appropriate circular curves, as illustrated in Figures (2-11 A-C) below. One can have sharper curves (e.g. a smaller turning radius) for lower speed roads, whereas higher speed roads require a larger curve, as shown in Figure 2-11D.
In order to maximize speed when many trucks are in the traffic stream, why might you locate your road on flat land rather than on mountains or in valleys?

Scenario 2: The best road for economic development

1. Suppose you have only two goals. First, you want to encourage more customers to visit the Mega Mall of America and the airport, both of which are losing business because of heavy traffic congestion. Second, you want to make jobs accessible to residents near Lake Side Resort. Use Table 2-2 to identify the number of lanes (two, four, or six) and the design speed you think are appropriate.

   ____ total lanes       ____ design speed

2. Decide where the road should be located, by using the appropriate tangent road templates and then connecting those sections via the appropriate curves.

Tip: If a tangent section is too long, you may shorten it so long as you do not alter its width.

Why might the business owners at Strip Mall City prefer to be adjacent to a four lane road with a traffic light rather than a six lane freeway?
Scenario 3: The best road for the environment

1. Suppose your only goal is to reduce noise pollution and runoff. Accordingly, you would like a low-volume road that discourages high speed traffic, especially trucks. Use Table 2-2 to identify the number of lanes (two, four, or six) and the design speed you think is appropriate.

   ____ total lanes   ____ design speed

2. Decide where the road should be located, by using the appropriate tangent road template and then connecting those sections via the appropriate curves.

   To reduce runoff that could worsen water quality, which one of the following is it critical to avoid:
   a) farmland
   b) residences
   c) Great Dismal Swamp
   d) the Financial and Business District
   e) River Run High School

Scenario 4: The cheapest road

1. Suppose your only goal is to build the most inexpensive road possible. You opt for a two-lane facility with a 30 mph design speed. You also decide to add to existing roads as much as possible rather than build a new road from scratch.

2. Connect the two-lane tangent road templates end to end so that there is a complete path from A38 to Z1. For areas where there is no road already, lightly pencil in a sketch of the road.

Table 2-6 shows the cost of each land use type by cell.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Cost Per Square (in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacant</td>
<td>$1</td>
</tr>
<tr>
<td>Wetlands or Forest</td>
<td>$5</td>
</tr>
<tr>
<td>Residential</td>
<td>$10</td>
</tr>
<tr>
<td>Commercial or Public Building</td>
<td>$50</td>
</tr>
<tr>
<td>Airport or Military base</td>
<td>$200</td>
</tr>
</tbody>
</table>

Generally, is land cheaper at (select one):

a) the northern half of the map (rows 1-19)
b) the southern half of the map (rows 20-38)
Scenario 5: Consider only citizen attitudes regarding a new road

1. Count the number of homes and businesses that were destroyed by the road you chose under scenario 1 and scenario 4 and record the data in Table 2-7.

<table>
<thead>
<tr>
<th>Number of homes affected</th>
<th>Scenario 1: Fastest Road Possible</th>
<th>Scenario 4: Cheapest Road Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of businesses affected</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compare the number of homes and businesses affected by Scenario 1 and 4. Keeping in mind the effect of your design decisions on homes and business by creating the fastest and cheapest roads would you do anything different?

Scenario 6: Design your own road

1. Your goal is to design the “best” road for connecting cells A38 and Z1. You want to choose the best road type, design speed, and location so that you please everybody: taxpayers who want a cheaper road, residents who want a road close to their homes but not through their homes, drivers who want a road that is fast, pedestrians who want to be able to walk safely, the airport authority who wants direct access, and other stakeholder desires you may think of. While considering the “best” road design, you should essentially compromise between all of the previous scenarios to implement an optimal design.

2. Assuming you decide to build a brand new road you will have to resolve:
   a) where the road should be located (e.g. the path it should follow from A38 to Z1)
   b) what type of road should be implemented (two-lane, four-lane arterial, or six-lane freeway)
   c) what the appropriate design speed of the road should be

3. On the surface, your goal seems simple: you have to determine where the road should be placed so that it connects cells A38 and Z1. Then, the community can purchase the necessary land, known as right of way. In practice, however, this means you have to resolve issues a, b, and c.

4. Answer the questions about your road in the Research Notes section.
Activity 2: Not In My Backyard!

Questions

1) Determine the total cost of the road by adding the costs of the individual cells.

   The cost is $_______ in millions

2) Determine the environmental impacts by counting the cells inside any buffered areas from step 3 (such as the Snake River).

   A total of ________ cells are affected by runoff or noise pollution

3) Indicate the number of homes and businesses that will be displaced by the road.

   _______ homes will have to be relocated

   _______ businesses will have to be relocated

4) What percentage of the time will your road have enough capacity to avoid a traffic jam (e.g. breakdown conditions)? See Tables 2-2 for capacity values and 2-8 for hourly demand.

   ______% of the time we will not have a traffic jam

<table>
<thead>
<tr>
<th>Table 2-8: Hourly Demand for the Road with Sample Capacity Evaluation for 50 mph Arterial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours of the Day</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>7:00 - 8:00 am</td>
</tr>
<tr>
<td>10:00 - 11:00 am</td>
</tr>
<tr>
<td>1:00 - 2:00 pm</td>
</tr>
<tr>
<td>4:00 - 5:00 pm</td>
</tr>
<tr>
<td>6:00 - 7:00 pm</td>
</tr>
</tbody>
</table>
5) Indicate which goal is best achieved by your road. Tables 2-3 and 2-4 may be helpful.
   a) move a lot of traffic
   b) minimize environmental impacts such as water runoff and noise
   c) consume as little land as possible
   d) increase pedestrian safety
   e) encourage economic development in rural areas

6) Indicate which of the following constituents is likely to be the most content with the construction of the road. Table 2-5 may be helpful.
   a) Residents in _________________________________ (name the neighborhood)
   b) through travelers that do not live in the community
   c) small business owners such as ____________________________ (name some examples)
   d) The Western Forest Preserve Conservation Society
   e) the Airport Authority

7) What can you conclude is the “best” decision for this community if they decide they want a new road?

8) The location for a road that is guaranteed to make all citizens happy is probably
   a) in a rural area (to encourage economic development)
   b) in an urban area (to preserve farmland)
   c) in the mountains (to provide a scenic view)
   d) within driving distance of major residential neighborhoods
   e) no location will please everyone
9) What mode of transportation was not fully considered in this example but should be considered in real life?
   a) bicycling
   b) walking
   c) public transportation (buses)
   d) public transportation (light rail or subways)
   e) all of the above

Discussion Notes
Activity 3: How Much Does It Cost?

### Activity Summary

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructor Prep Time</strong></td>
<td>15 minutes</td>
</tr>
</tbody>
</table>
| **Class Time**           | 45 minute activity  
                          45 minute discussion and questions |
| **Grade/Class**          | 9 - 12 Mathematics |
| **Suggested Activity Grouping** | Groups of two |
| **Technology**           | High Tech     |
| **National Council of Mathematics Teachers Standard** | Data analysis and probability |

### Introduction

This activity uses common tools in the workplace to develop a mathematical model to estimate the value of land. Students will estimate right-of-way costs for different pieces of property using Microsoft Excel. Students will classify property by land use and location and then predict the selling price of these properties using a mathematical model they develop themselves.

### Objective

Students will create, evaluate, and use a mathematical model that predicts a dependent variable (such as land costs) as a function of an independent variable (such as location or land use type).

### Background

Since the land that roads are built on is not free, the cost of the land is a critical consideration when building. While the cost in rural areas may be smaller, there is likely less demand in areas with less people. In this activity, the students will investigate how these costs vary and how each project has pros and cons associated with it.

Give each group of students the map that was used in Activity 2. The answers to the next four questions may either be written on the board or discussed aloud. Their goal is to prepare students to develop a model that predicts land price as a function of location.

### Activity Expansion Ideas

Have students explore real estate values of different properties in your area to better understand the factors behind price determination. For example, students could use a realtor’s website to compare the cost of waterfront property to what is available in a neighborhood, business district, or next to an airport. The possibilities are endless, so challenge students to look past the obvious. Students could deliver an oral report of their findings to the class.
Activity 3: How Much Does It Cost?

Questions

1) Suppose you compare the actual cost of land to the estimated value. How will they compare?
   The model we created is based on the best fit of the data. Therefore, it may not perfectly represent all the data but approximates the trend. Extrapolating beyond the dataset used to make the line may result in greater error between the estimate and actual values.

2) What limitations do you see from modeling value with a line of best fit?
   We are limited by the data supplied, so our model can only approximate a price based on past sales and cannot adjust for changes in the market. For example, if another mall opened on the other side of town, land prices around that new mall would increase. However, our model would not be able to account for that until a significant number of plots of land had been sold.

3) What factors that were not considered in this activity might play a role in determining the value of a plot of land?
   Factors such as the zoning, conditions of the land, or nearby attractions not considered could affect the land price.

4) What would the estimated value of a commercial plot of land located 3 cells above and 3 cells right of the prime cell be?
   The cell we are estimating is V10. This cell has the coordinates of (22, 10). The prime cell is L5. This cell has the coordinates of (12, 5). The y equation is the trendline formula from the Commercial Land Graph and the x equation is the distance formula presented in the background section of the Instructor’s Reference section.

\[
y = 29206x^{-1.995}
\]

\[
x = \sqrt{(row - 5)^2 + (column - 12)^2}
\]

\[
11.2 = \sqrt{(10 - 5)^2 + (22 - 12)^2}
\]

\[
$236.49 = 29206(11.2)^{-1.995}$
\]
5) Compare your estimate to the actual cost for the cell in Question 4. How accurate is the estimated value? (The actual price is found in the CellCost column.)

Actual price = $289.21
Estimated price = $236.49

\[
\frac{|236.49 - 289.21|}{289.21} \times 100 = 18.2\%
\]

While the model does approximate the correct price, it is not a perfect match. Specifically, as the distance to the prime cell decreases, the accuracy of the model decreases since there is less data available at those locations.

6) What steps could be taken to improve the accuracy of the model?

More data points, especially for locations closer to the prime location, would increase the accuracy of the model.

Discussion

When construction is considered for real-world application, there are a variety of additional factors that must be considered. For example, the best design from an engineering standpoint is not necessarily the same design that would be the best from a political standpoint. Consider what factors are applicable to the decision of when and where to build roads.
Activity 3: How Much Does It Cost?

Introduction
This activity uses Microsoft Excel to explore how land prices change based on location and introduces basic price modeling. Land will be characterized based on use and location, which will form the basis of the model.

Objective
In this activity, you will create, evaluate, and use a mathematical model that predicts a dependent variable (such as land cost) as a function of an independent variable (such as location or land use type).

Background
Many empirical relationships, such as the value of a house with respect to its size and location, the salary one receives with respect to one’s abilities and the market, or the fuel economy of a vehicle given its weight, are probabilistic. The relationship is not exact; rather there is some natural variability in the answer. For example, two homes may be located in the same neighborhood, be for sale at a time when the economy is doing well, and be of similar construction, yet their prices may be different. This is because the multitude of factors affecting the home price are variable.

The opposite of a probabilistic relationship is a deterministic relationship where the answer is exactly known, such as the relationship $\text{Force} = (\text{mass})(\text{acceleration})$. Despite the intrinsic variability in selling a plot of land, it is possible to create a model that will approximate the value based on a number of factors.

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-part map of the study area</td>
<td>1 copy per student pair</td>
</tr>
<tr>
<td>Computer with Microsoft Excel</td>
<td>1 per student pair</td>
</tr>
<tr>
<td>Data file: Activity 3 – Price and Location.xls</td>
<td>1 per student pair</td>
</tr>
</tbody>
</table>

Note: Instructions were completed using Microsoft Excel. Comparable software may be used, however, not all software may contain the functions necessary to complete the exercise.

Setup
Your job is to forecast what the “missing” land value would be using what you know about the existing land value. To achieve this, you can develop a mathematical model that forecasts the value as a function of the location and the type of property.

Open Microsoft Excel, select File/Open, and navigate to the file entitled Activity 3 – Price and Location.xls, which is located in the Design & Construction Module section of the TRAC webpage.
The file contains three data sets:

- **Vacant Land**: contains only cells with either farmland or no structures
- **Commercial Land**: contains only cells that are used commercially
- **All Land**: contains all cells regardless of the type of land

Examine the **All Land** data set. The **All Land** data set is organized as follows with each row representing a cell on the map:

- **Land use** indicates one of five possible land uses for the cell (see Figure 3-1 which corresponds to the large maps you used for Activity 2):
  1. vacant or farmland (v)
  2. environmental areas (e): lakes, rivers, wetlands, forest, mountains, or valleys
  3. residential area (r)
  4. commercial or public area (c): businesses, roads, resorts, gas stations, malls, parks, or The Old Town Canal
  5. airport or military base (a)
- **Cell cost** indicates the actual cost of the land in each cell.

The two other datasets, **Vacant Land** and **Commercial Land**, are subsets of the **All Land** data set. Now open the **Vacant Land** dataset.

---

**Figure 3-1: Color-Coded Map of Land Uses**
Part One: Determine Distance of Each *Vacant* Cell from Prime Location

**Procedure**

To begin, we will assume that the mall is at cell L5, and that everyone wants to own land near the mall, as we move away from this cell, prices will decrease.

1. In the *Vacant Land* tab, create a new column titled *Distance*. Click on the first cell in this column.
   a. Insert the formula “=SQRT((B2-5)^2+(C2-12)^2).” This formula uses the Pythagorean Theorem to determine the actual distance based on vertical and horizontal movement.
   b. Cell distance from prime location = √((cell row − 5)^2 + (cell column − 12)^2)
   c. Because the location of the mall is L5, we subtract 5 and 12 (since L is the 12th letter in the alphabet).
2. Copy and paste the cell down the column to apply this formula to the remainder of the cells.

You should now have a column that shows the distance of each cell from the prime location, L5.

Part Two: Determine a Model for the Cost of *Vacant Land*

**Procedure**

Now, we will analyze the cost of land and how it changes with distance from the prime cell. To do this, we will graph the *Cell Cost* data against *Distance* data that we just calculated.

1. Make sure that you are in the *Vacant Land* tab.
2. Highlight all of the data in the *Cell Cost* column. In the top, left-hand corner of the page, there should be a tab labeled *Insert*; open this tab. In the *Charts* section, select *Insert Scatter (X,Y) or Bubble Chart*, then select *Scatter*. Figure 3-2 can guide you through this process.

![Figure 3-2: Inserting a Scatter Plot](image)

3. Now, right click on the graph you created and click *Select Data*. In the dialog box that appears, click *Edit*; another dialog box will appear. Highlight all of the *Distance* data under *Series X Values*. Click OK on both dialog boxes to save your changes.
4. To label your axes, click on your graph. In the top right hand corner of the graph, a + sign will appear. Click on this and then place a check mark next to *Axis Titles*. Edit the *Axis Titles* placeholders that appear on your graph to assign them their appropriate labels. Your x-axis should be labeled *Distance to Prime Location* and your y-axis should be labelled *Property Value*.
5. Type in a chart title in the *Chart Title* placeholder as well. Your chart should be titled as *Property Values of Vacant Land vs. Distance to the Prime Location*.
Note: A Chart Title placeholder should have appeared when you created your graph. If this did not occur, one can be added by clicking on the + sign again and placing a check mark next to Chart Title.

Now we will use this data to approximate a formula for how much a piece of vacant land would cost.

6. Click on the + sign on your graph again and select the arrow next to Trendline, opening a drop-down menu. From that drop-down menu, select More Options. A window will open on the right side of your screen.

7. In the window that appears, select the tab, opening Trendline Options. Select the Power trendline option.

8. Place a check in the box titled Display Equation on Chart. Your graph should now appear as shown in Figure 3-3.

![Property Values of Vacant Land vs. Distance to the Prime Location](chart.png)

Figure 3-3: Appearance of completed Vacant Land Graph

From this data, we can conclude that it is more expensive for land closer to the prime cell. Be aware that normally there would be significantly more factors in determining the price of a plot of land.

As indicated in the graph, as the distance from cell L5 decreases, the price increases, however the trendline continues to increase towards infinity as the distance becomes smaller. Obviously there is a limit to how much someone would pay for the land, which is not represented on this graph.
Part Three: Determine Distance from Each Commercial Cell from Prime Location

Procedure

We will now determine the distance from the prime cell again, only this time using the data in the Commercial Land tab. Additionally, we will adjust the location of cell L5 for use in Part Four.

1. In the Commercial Land tab, create a new column titled Distance, click on the first cell, and insert the formula “=SQRT((B2-5)^2+(C2-12)^2).”
2. Copy and paste the cell down the column to apply this formula to the remainder of the cells in the column.
3. In the Excel sheet, change the location of cell L5 from row 5 column 12 to row 5.5 and column 12.5 so that the distance value for this cell increases above zero. (We will see in Part Four why this is necessary).

<table>
<thead>
<tr>
<th>col</th>
<th>row</th>
<th>column</th>
<th>cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>5.5</td>
<td>12.5</td>
<td>116</td>
</tr>
</tbody>
</table>

*Note:* If “the 5.5” that you entered in appears as a “6,” do not panic. The value “5.5” is still stored. Excel is simply showing a rounded value with no decimals. The same is true with “12.5” and “13.”

You should now have a column that shows the distance of each cell from the prime location, L5, and an adjusted L5 cell for use in Part Four.

Part Four: Determine a Model for All Commercial Land

Procedure

Follow the steps performed in Part Two to create a graph of the Property Value vs. Distance to the Prime Location for the Commercial Land data, with the addition of the following corrections.

1. Change the title of this graph to Property Values of Commercial Land vs. Distance to the Prime Location.
2. This time when you add a trendline, your graph will shrink as shown in Figure 3-4. This is because Excel assumes the property values will continue to increase to infinity as the distance to the Prime Location nears zero. To fix this issue, right click on the y-axis and select Format Axis.

*Note:* If you did not change cell L5 to (5.5, 12.5) in Part Three, a trendline will not appear at all.
3. In the window that appears, set the Maximum Bound to 40,000 as shown in Figure 3-5. Your graph should look like the one presented in Figure 3-6.
You may notice that the trendline formula in this graph is not as neat as the trendline formula found for the Vacant Land graph. This is because the line of best fit is as the name implies: a best fit, not a perfect fit. As the line of best fit approaches a distance of zero away from the prime location, the model becomes less and less accurate, and more error is introduced. To adjust for this error, a limit should be placed on the equation. When calculating the cost of a cell, the maximum price should be set at $36,000 (You do not need to make a correction for this activity).

Due to this error, if you use this formula to calculate the property value of a cell you already know the actual value of, the value you achieve with the equation will be slightly different than the actual value. You will also notice that the formula is more accurate the farther away from the prime location you are, as there are more data points on the graph at farther distances.
Activity 3: How Much Does It Cost?

Questions

1) Suppose you compare the actual cost of land to the estimated value. How will they compare?

2) What limitations do you see from modeling value with a line of best fit?

3) What factors that were not considered in this activity might play a role in determining the value of a plot of land?
4) What would the estimated value of a commercial plot of land located 3 cells above and 3 cells right of the prime cell be?

5) Compare your estimate to the actual cost for the cell in Question 4. How accurate is the estimated value? (The actual price is found in the CellCost column.)

6) What steps could be taken to improve the accuracy of the model?
Activity 4: Construction Estimating

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor Prep Time</td>
</tr>
<tr>
<td>Class Time</td>
</tr>
<tr>
<td>Grade/Class</td>
</tr>
<tr>
<td>Suggested Activity Grouping</td>
</tr>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>National Science Education Standards</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Introduction
The importance of construction estimating cannot be overstated. It is a critical part of the bidding process for construction contracts. Based on a project design, the estimator must determine costs for each portion of the job in order to place an accurate bid. If a bid is too high, the contractor may lose the contract. If the bid is too low and the contractor is awarded the job, then costs will be higher than anticipated and the profit margin will be lower, or even negative. The success of many companies is directly related to the skill of their estimators. Since the conditions of each job varies greatly from the location, availability of supplies, and weather, construction estimates are as much an art as a science.

In this activity, students will estimate the cost to install a bollard. Working in pairs, they will calculate the labor, equipment, and material costs of the installation, as well as incorporate the overhead and profit. This will require students to use geometric formulas, unit conversions, and critical thinking.

Objective
In this activity, students will:

- Apply arithmetic, geometric, and problem-solving skills to estimate the cost of a basic construction project.
- Break down the costs of a construction project, including overhead and profit.

Background
Estimating requires an understanding of field work, so the students will be at a disadvantage since they do not have this information. This does not mean that they cannot find the correct answer; however, they will have to use their problem solving skills to do so. It may be helpful to step through what information they need, such as the materials and labor. Demonstrating how to expand the necessary information into costs may also be helpful to students.
Activity Expansion Ideas

To demonstrate the ambiguity of estimating, the teacher or volunteer could fill a container with uniform objects, such as candy or marbles, count the number of items in the container, and allow students to submit an “estimated” number of how many they believe are in the container. Upon announcing the winner, students should be informed of how estimating on the job sometimes has to be done on the spot. This requires field technicians, engineers, or construction workers to estimate progress and set a timeline based on experience. For example, on a pipeline job, they may need to estimate the remaining cubic yards of material to be dug, the time for the pipe crew to place the pipe, and the time to properly backfill the hole, all of which would be done by looking at progress and applying math equations, if necessary. By estimating this information, they can easily determine whether the timeline of the project will remain on track or not. As previously mentioned, this knowledge comes with experience and time spent in the field.
Activity 4: Construction Estimating

General Activity Discussion

The correct price breakdown of the bollard is as shown below, however, student’s estimates will likely vary. The most difficult part of this activity for the students will be to determine how much time it will take for the workers to dig the hole. Since most students probably have never installed a bollard themselves, they must make educated guesses to estimate this time. According to estimating standards, this should take 1.6 hours for two workers and a backhoe. In addition to estimating the time, the students must correctly calculate the material dimensions and convert the concrete volume into cubic yards. The most expensive material cost of the bollard will be the steel pipe, whereas the concrete is relatively cheap. The 15% for “Overhead and Profit” is applied to the subtotal of the other costs. Students may argue that the job could be accomplished in either less time or with less people; however, these answers are based off industry standards for installation of bollards.

<table>
<thead>
<tr>
<th>Item</th>
<th>Actual Cost</th>
<th>Estimated Number of Units</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$40/hour/laborer</td>
<td>2 laborers @ 1.6 hours</td>
<td>$128</td>
</tr>
<tr>
<td>Equipment Rental</td>
<td>$115/hour</td>
<td>1.6 hours</td>
<td>$184</td>
</tr>
<tr>
<td>Concrete</td>
<td>$75/yard³</td>
<td>0.511 yard³</td>
<td>$38.33</td>
</tr>
<tr>
<td>Steel Pipe</td>
<td>$2.07/linear inch</td>
<td>87 inches</td>
<td>$180.09</td>
</tr>
<tr>
<td><strong>Subtotal of Labor, Equipment, and Materials</strong></td>
<td></td>
<td></td>
<td><strong>$530.42</strong></td>
</tr>
<tr>
<td>Overhead</td>
<td>5% of subtotal</td>
<td></td>
<td>$26.52</td>
</tr>
<tr>
<td>Profit</td>
<td>10% of subtotal</td>
<td></td>
<td>$53.04</td>
</tr>
<tr>
<td><strong>Total Estimated Cost for Bollard Construction and Installation</strong></td>
<td></td>
<td></td>
<td><strong>$609.98</strong></td>
</tr>
</tbody>
</table>

Cost Breakdown:

*Labor:*

\[
1.6 \text{ hrs} \times \frac{$40}{\text{hr} \times \text{laborer}} \times 2 \text{ laborers} = $128
\]

*Equipment Rental:*

\[
1.6 \text{ hrs} \times \frac{$115}{\text{hr}} = $184
\]
Concrete:

- **Volume:**
  \[ V = \pi r^2 h \]
  \[
  \left( \pi \left( \frac{8 \text{ in} + 8 \text{ in} + 8 \text{ in}}{2} \right)^2 \right) \times \left( 4 \text{ ft} \times \frac{12 \text{ in}}{ft} \right) + \left( \pi \left( \frac{8 \text{ in}}{2} \right)^2 \times \left( 3.5 \text{ ft} \times \frac{12 \text{ in}}{ft} \right) \right) = 23,825.84 \text{ in}^3
  \]
  \[
  23,825 \text{ in}^3 \times \frac{yd^3}{46,656 \text{ in}^3} = 0.511 yd^3
  \]

- **Cost:**
  
  \[
  0.511 yd^3 \times \frac{\$75}{yd^3} = \$38.33
  \]

Steel Pipe:

- **Length:**
  \[
  \left( 4 \text{ ft} \times \frac{12 \text{ in}}{ft} \right) - 3 \text{ in} + \left( 3.5 \text{ ft} \times \frac{12 \text{ in}}{ft} \right) = 87 \text{ in}
  \]

- **Cost:**
  \[
  87 \text{ in} \times \frac{\$2.07}{\text{in}} = \$180.09
  \]

**Subtotal (without Overhead & Profit):**

\[ $128 + $184 + $38.33 + $180.09 = $530.42 \]

**Overhead:**

\[ $530.42 \times 0.05 = $26.52 \]

**Profit:**

\[ $530.42 \times 0.10 = $53.04 \]

**Total Estimated Cost:**

\[ $530.42 + $26.52 + $53.04 = $609.98 \]
Questions

1) **What was the most difficult part of this construction estimating activity?**
   
   Answers here will vary for each student.

2) **What could be done to standardize construction estimates?**
   
   Construction firms often have their own historical production rates which are the amount of work a crew can perform in a set amount of time. They use these rates to determine how much time should be required for each job and base their price on that.

   In addition, existing estimating standards, such as *RS Means*, provide average prices for various crews and tasks, along with location factors.

3) **What assumptions were made in this exercise that could not be made for a full size project?**

   In this exercise, factors such as setup and teardown costs were not considered, as well as permit costs, site prep, availability of equipment and workers, and potential hazards such as buried and overhead utilities.

   Also, it is assumed that materials could be purchased to the exact quantity needed, and that labor times did not need to be rounded to a billable increment. In reality, materials are sold in certain quantities, and labor time is rounded up to certain intervals. Steel members are often purchased to the nearest 2-inch increment, concrete is usually batched in certain increments, and labor costs are usually recorded in certain billable increments.

Discussion

Discuss student answers to questions 2 and 3. Let them express the answers they developed, and then discuss other listed answers that they did not bring up.

In addition to discussing the questions, it may be beneficial to expand on a topic that is touched on in this activity: overhead (the costs associated with bidding, payroll, accounting, computers, software, and utilities). Overhead is one portion of the overall project that is quite important, but is easily overlooked by people not familiar with the operation. Some of the potential questions to present to the students to spark discussion could be: What happens to profit if overhead is estimated too low?
Activity 4: Construction Estimating

Introduction

Estimating is one of the most important techniques used by contractors in determining a bid price for a construction project. In fact, accurate estimates are so important, many contracting firms hire specialists just for this task. The estimator determines the necessary amount of materials and labor for a project to estimate the cost, which can total millions, or even hundreds of millions, of dollars.

Objective

In this activity, you will:

- Apply arithmetic, geometric, and problem-solving skills to estimate the cost of a basic construction project.
- Break down the costs of a construction project, including overhead and profit.

Background

The importance of estimating cannot be overstated, as it is a critical part of the bidding process for construction contracts. Based on a project design, the estimator must estimate costs for each portion of the job in order for the firm to place an accurate bid on the job. If a bid is too high, the contractor may lose the contract. If the bid is too low and the contractor is awarded the job, then costs will be higher than anticipated and the profit margin will be lower, or even negative. The success of many firms is directly related to the skill of their estimators. Since the site condition of each job varies greatly based on location, availability of supplies, and weather, construction estimates are as much an art as a science.

The basic idea of estimating is calculating the necessary amount of labor and materials to finish a project. All physical aspects (direct costs) of a project must be paid for, such as each worker, piece of equipment, and construction material. In addition, companies must pay for a variety of overhead costs (indirect costs), such as office supplies and equipment, insurance, and utilities. In order to accurately estimate the total cost, you must know the cost of labor, equipment, and material, as well as additional costs from overhead and profit. Since you must estimate all of this information, the end price will usually not exactly match the estimate; however, it is possible to come very close.

This activity will focus on estimating the cost of a single bollard. Bollards are traffic devices designed to keep traffic from passing a certain point. You have likely seen examples of these bollards around buildings or in parking lots. While they may seem relatively short from the surface, it is important to remember that they are often buried 3-4 feet underground and surrounded with concrete. Figure 4-1 displays bollards after installation.
Figure 4-1: Installed Bollards (concrete footings are buried in ground)

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>As needed</td>
</tr>
<tr>
<td>Calculator</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

Procedure

Estimate the cost to install a bollard at a construction site. Use the prices for material, equipment, labor, overhead, and profit listed in Table 4-1, and the dimensions of the bollard shown in Figure 4-2, to complete this task. Perform your calculations on a separate sheet of paper and record your estimates in the space provided in your Research Notes. Attach your calculations to the Research Notes.

Table 4-1: Bollard Construction and Installation Costs

<table>
<thead>
<tr>
<th>Bollard Construction and Installation Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Cost</td>
</tr>
<tr>
<td>Labor</td>
<td>$40 / hour / laborer</td>
</tr>
<tr>
<td>Equipment Rental</td>
<td>$115 / hour</td>
</tr>
<tr>
<td>Concrete</td>
<td>$75 / yard³</td>
</tr>
<tr>
<td>Steel Pipe</td>
<td>$2.07 / linear inch</td>
</tr>
<tr>
<td>Overhead</td>
<td>5% of subtotal</td>
</tr>
<tr>
<td>Profit</td>
<td>10% of subtotal</td>
</tr>
</tbody>
</table>
1. Start by estimating the cost of labor and equipment. To do so, you must decide how long you believe it will take for the laborers to install the bollard and how many laborers this work will require. When estimating these values, field experience can be very useful for determining how long certain tasks take to perform and how many laborers are necessary. However, you must make an educated guess. For reference, the process for installing these bollards is as follows:
   a. Dig a 4-foot-deep hole in the ground using a backhoe (a backhoe is a piece of construction equipment that has a loader in front and a small excavator in back).
   b. Use the backhoe to lift the bollard into the hole.
   c. Backfill soil overtop of the bollard’s base using the backhoe.
   d. Compress the soil with a plate compactor to hold the bollard’s base firmly in place (a plate compactor is a small but heavy, vibrating piece of equipment that forces soil beneath it to compact).
2. After estimating labor and equipment costs, estimate the cost of materials. Use the dimensions of the bollard in Figure 4-2 and your knowledge of geometry to determine the quantities of concrete and steel pipe required. Recognize that the apostrophe symbol (’) represents feet, and the quotation symbol (“”) represents inches. The concrete is purchased by volume and steel is purchased by length; compute the concrete volume in cubic yards and the steel length in linear inches. Useful unit conversions and equations are given below:

<table>
<thead>
<tr>
<th>Unit Conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 foot = 12 inches</td>
</tr>
<tr>
<td>1yd³ = 46,656in³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume of a Cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V = \pi r^2 h$</td>
</tr>
</tbody>
</table>

Where:
- $V$ = volume of a cylinder (in³)
- $r$ = radius of cylinder (in)
- $h$ = height of cylinder (in)
3. Once you have estimated the cost of labor, equipment, and material, the sum of these values should be calculated to achieve a subtotal cost.
4. Use this subtotal cost to estimate the cost of overhead and profit. Overhead is estimated as 5% of the subtotal, and profit is estimated as 10% of the subtotal.
5. After calculating these costs, add them to the subtotal to achieve the overall cost of installation.
6. Then, answer the questions in your Research Notes.
Figure 4-2: Bollard Dimension Drawing (drawing is not to scale)
Activity 4: Construction Estimating

Bollard Estimate

Record your project estimate in the space provided.

<table>
<thead>
<tr>
<th>Item</th>
<th>Actual Cost</th>
<th>Estimated Number of Units</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$40/hour/laborer</td>
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<td></td>
</tr>
<tr>
<td>Steel Pipe</td>
<td>$2.07/linear inch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Subtotal of Labor, Equipment, and Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Percentage of Subtotal</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Profit</td>
<td>10%</td>
<td></td>
</tr>
</tbody>
</table>

Total Estimated Cost for Bollard Construction and Installation

Questions

1. What was the most difficult part of this construction estimating activity?

2. What could be done to standardize construction estimates?
3. What assumptions were made in this exercise that could not be made for a full-size project?

Discussion Notes
Appendix A: Document Links

NCHRP 20-52
The NCHRP 20-52 final report details the completion of the original TRAC PAC 2 program, including the original manual.

TRAC/Michigan Education Standards
Link: http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html
The Michigan Education Standards are outlined in terms of how TRAC meets the benchmark goals. This page includes the standards for 6th, 7th, and 8th grades as well as high school standards. Both the TRAC modules and bridge building competition are listed.
Appendix B: Glossary of Terms

**Arterial:** A larger road used in cities and urban areas that is designed to carry a large number of cars coming from smaller roads into highways.

**Congestion:** The state of being overcrowded. (i.e. so crowded with traffic or people that freedom of movement is prevented.)

**Exponentially:** When something is increasing or decreasing at a growing rate of change. On a graph this would be represented as a curve that continuously becomes steeper or shallower.

**Force:** A push or pull acting upon an object as a result of the object’s interaction with another object.

**Optimum:** Most likely to result in a favorable outcome; best option.

**Tangent:** A line or plane that intersects with a circle or curve at exactly one point. This line or plane runs at a 90° angle to the radius of the circle or curve.
This manual was updated and revised in 2017 by the Center for Technology and Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).