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 and Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).
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Executive Summary

This module contains five activities to provide students an understanding of technology applications in Traffic Engineering, as well as understand the factors behind reaction time and stopping distance. Concepts are introduced independently in the activities and then pulled together in experimental demonstrations, hands-on projects, and computer-based simulations. 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: Calculating Reaction Time**

In Activity 1, the concept of reaction time is taught to students through the application of linear motion. Students are challenged to determine their own reaction time based on their ability to catch a meter stick accelerating at a constant rate due to gravity. This data can be used to understand how accidents occur due to driver reactions. Not only does reaction time affect braking distance and stopping distance, but it is also used to set the duration of yellow lights on a traffic signal.

**Volunteer Topics**

A traffic engineer can discuss how far a car travels in a second and reinforce the importance of drivers not being distracted while they are driving or following the car in front of them too closely. A Public Safety Officer could discuss the impact that distracted driving (i.e. cellphone use while driving) and reckless driving can have on yourself and the people around you. They could also discuss the importance of safe driving and how distracted driving can affect driving ability.

**Activity 2: Braking Distance and Friction**

Activity 2 studies the concept of braking distance by exploring the relationship between kinetic energy of a moving car and work done to bring the car to a stop. Students will calculate the coefficient of friction of different surfaces based on this relationship and the braking distance of the Maglev car. This concept is also related to why cars require space for safe driving and why braking distance varies in different weather conditions.
Volunteer Topics

* A *mechanical engineer* could talk about the procedure used to test the braking distance of vehicles and how road conditions affect braking distance.

**Activity 3: Setting Yellow Light Time**

In Activity 3, the concept of linear motion is applied to the duration of the yellow light time on a traffic signal by tying together reaction time and braking distance. Students will learn why yellow lights last as long as they do and the problems that occur if yellow lights last too long or not long enough.

Volunteer Topics

* A *Traffic and Safety Engineer* can discuss the different stages of a traffic signal and the assumptions that go into the design of traffic signals.

**Activity 4: Programming Logic for Traffic Systems**

Activity 4 introduces students to software programming, as it applies to traffic technology. Students will be exposed to the basics of programing logic and they will learn how to organize flowchart diagrams based on traffic technology scenarios, functions, and logical statements.

Volunteer Topics

This activity is designed to build problem solving and logic skills. A *programmer* could discuss complex coding techniques or discuss how to apply programming logic to more complex scenarios.

**Activity 5: Shortest Path**

Activity 5 explores how modern map applications determine the quickest route between two locations. Students will use *Microsoft Excel* to calculate the quickest route on a maze based on the distance between different path options. Students will work through a guided example then attempt a more complex maze on their own.

Volunteer Topics

* A *mobile app developer* or *traffic engineer* could discuss the complexities of developing a map application and adding data such as traffic volumes, road closures, and road construction into route decisions.
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)

In this module, students will learn about driver response times and vehicle braking distances in Activities 1 and 2, respectively. This will allow them to understand some considerations that go into traffic technology planning, especially the duration of yellow lights on traffic signals; which is explored in Activity 3. Delving into a programmer’s point of view of traffic signals, Activity 4 explains logical statements and programming language. Activity 5 will have students use Microsoft Excel to learn how map applications determine the quickest route to a destination.
National Education Standards

Standards for Technology Literacy

- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 9: Students will develop an understanding of engineering design.
- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

National Science Education Standards

Grades 5 – 8

Science as Inquiry

- Use appropriate tools and techniques to gather, analyze, and interpret data.
- Use technology and mathematics to improve investigations and communications.
- Think critically and logically to make the relationships between evidence and explanations.
- Formulate and revise scientific explanations and models using logic and evidence.

Grades 9 – 12

Physical Science Content Standard B

Motion and Forces

- Its position, direction of motion and speed can describe the motion of an object. That motion can be measured.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object’s motion.

Science as Inquiry

- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Motion and forces: Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects.

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: Calculating Reaction Time

<table>
<thead>
<tr>
<th>Activity Summary</th>
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<tbody>
<tr>
<td>Instructor Prep Time</td>
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<tr>
<td>Class Time</td>
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<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>
</tbody>
</table>

Introduction

In this activity, students will learn the steps humans go through when reacting to a situation (perception, identification, emotion, and volition), since people cannot react instantaneously to an event. In order to demonstrate the process, students will determine their own reaction time through the application of linear motion. Students will catch a meter stick constantly accelerating due to gravity, and calculate their reaction time based on the constant acceleration distance equation. Not only does reaction time affect braking distance and stopping distance, but it is also associated with the duration of yellow lights on a traffic signal.

Objective

In this activity, students will:

- Use the linear motion equations to determine their reaction time.
- Understand the importance of reaction time while driving.

Background

The measured reaction times will vary and will be less than the reaction time associated with an unexpected event. These times represent how long it takes to react to an expected outcome. In our daily lives, it takes more time to react to complex, unexpected scenarios.

Activity Expansion Ideas

When analyzing and evaluating reaction time, there are many variables that play into the matter. Some of these variables are uncontrollable, such as age, distractions, and personality type. Students may be curious how these different factors may play into their own reaction time. In this activity expansion, students can determine the typical age associated with their reaction time.
The following link tests reaction time by placing the students in a driving simulation and asking them to press a key when they see a stop sign flash on the screen. Their reaction time is measured in milliseconds and displayed along with the typical age of a person having the same reaction time. Try having students conduct this test without any indication of what they will see on the screen and then have them try a couple more times. They should see that their reactions times lower as they adjust to their situation and become familiar with the layout of the simulation. When they are done with the simulation they can click at the bottom of the screen to see a graph of how the typical age was determined.

Complete the short activity by following this link:

https://www.justpark.com/creative/reaction-time-test/
Activity 1: Calculating Reaction Time

Questions

1) What was the average reaction time of your group?

Be sure students have followed the example calculation and have not made any math errors. For example, if the ruler falls 0.15 m before they catch it, the reaction time should be calculated as follows:

\[ x = v_0t + \frac{1}{2}at^2 \]

\[ t = \frac{2x}{a} \]

\[ t = \frac{2(0.15m)}{9.81 \text{ m/s}^2} = 0.175s \]

2) What aspects of determining reaction time are not included in this method? What would you change in order to address these issues?

This only determines how fast you can close your hand in a situation where you are expecting to do just that. In real life, our reactions are often more complicated, as are the situations that cause them. To account for this, there would need to be a variety of situations to react to—ones that the participant is not prepared for.

3) Based on what you learned, why is it important to leave space between cars when driving?

Since one will not react instantaneously to the behavior of the drivers around them, the space between cars allows for more time to react.

Discussion

Ask students how their reaction time could change based on what they are doing. Would their reaction time while watching a movie be different from what it would be while they were driving? Also, ask them how different feelings, such as being drowsy or angry, would affect their reaction time and decision-making process.

Concerning reaction time, another topic to touch on would be the effects of texting or cellphone-use while driving. Providing statistics for accidents in your state involving cellphone-use while driving could make the situation more real and relatable. In addition to providing statistics and facts, showing videos of cellphone-related crash survivors could create an impact as well and create a foundation for discussion. Regardless of cellphones being one of the biggest contributors to distracted driving, there are a plethora of other things in and around the vehicle that can result in distracted driving: changing the radio station, having a conversation, being exposed to noise in the car, etc.

Link for video about cellphone-related driving:
https://www.youtube.com/watch?v=E9swS1VL6Ok
Activity 1: Calculating Reaction Time

Introduction

If you were walking down the street and someone threw a ball at you, you (along with most people) would likely move out of the way or try to catch the ball. People cannot react instantaneously to an event because there is a number of steps that must be taken first. You must evaluate the situation, determine the potential options, make a decision, and allow your brain to tell your muscles to perform the required action. The duration of this process is known as reaction time.

Your reaction time affects your performance in many everyday activities – such as driving a car, playing sports, or catching a ball. Reaction time is a critical part of your everyday life, and in this activity, we will use the principles of constant acceleration to determine your reaction time.

Objective

In this activity, you will:

- Use the linear motion equations to determine your reaction time.
- Understand the importance of reaction time while driving.

Background

At this point, you may be asking yourself, what is traffic technology? Traffic technology is a series of innovations implemented on roadways to help make them safer and more efficient. Some common examples of traffic technology are traffic signals and radar speed displays; although, these examples are just the tip of the iceberg. Throughout this module, you will explore how this technology influences roadway use and increases safety. However, before we can understand how traffic technology works, we must first understand the drivers behind the wheel.

Human reaction time is approximately 0.1 to 0.2 seconds. Reaction time causes actions to be somewhat delayed and varies between people. For example, reaction time is what separates a good goalie from a fantastic goalie because decisions need to be made in a split second; therefore, a good reaction time is the difference between a goal and a save. This is also true in day-to-day life, such as when you are behind the wheel of a car. In order to avoid a crash, a driver must react to an incident and stop the car. Physical factors – such as friction and velocity – affect the car’s ability to stop, but do not apply until the driver has reacted to the situation and has taken action by applying the brakes.

The human response to events can be described in a four-step sequence: perception, identification, emotion, and volition. The first step, perception, is to notice a problem. For example, an object of some type is suddenly in front of the driver when it wasn’t there before. The second step, identification, is to understand the problem. In this case, the driver might identify (understand) that the object in front of them is a deer. The third step, emotion, is to make a decision about what to do: hit the brakes, scream, or do nothing. The fourth step, volition, is to take action, such as stepping on the brake to avoid hitting the deer. Although human beings react so quickly that they may not consciously think through these four steps, there is a small amount of time that is required before an action can occur. These four steps are known as “PIEV” (perception, identification, emotion, and volition) or, simply, perception-reaction time.
When driving is involved, most people have a perception-reaction time of 1.5 seconds or less. In other words, a driver traveling at 100 km/h (60 mph) who sees a deer and suddenly chooses to apply the brakes could travel at 100 km/h (60 mph) for 1.5 seconds before the car even begins to slow down. During this 1.5 seconds, the car will have traveled about 40 meters (132 feet). When it comes to unfamiliar situations, perception-reaction time will generally increase. For roadways to be relatively safe, it is critical to understand how perception-reaction time can vary among people and situations.

Reaction-perception time can also be greatly affected by distracted driving, such as driving while using a cellphone. Cellphone use takes the driver’s focus away from the road, and increases the driver’s reaction time, as they now have to look up from their phone before their PIEV response can begin. In some states, texting or making a phone call is illegal and could result in a ticket. In addition to cellphone use, distracted driving can also result from carrying a conversation, having a distracting passenger, or changing the radio station. All of these examples may seem mundane, but could be the lead factor in a car accident.

**Sample Problem**

We will use the concept of gravitational acceleration to determine how fast your reaction time is. Based on the concept of constant acceleration, the following formula shows the distance an object falls over a known time at a constant acceleration.

<table>
<thead>
<tr>
<th><strong>Constant Acceleration Distance Formula</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$x = v_0 t + \frac{1}{2}at^2$</td>
</tr>
</tbody>
</table>

Where:
- $x$ = distance fallen
- $v_0$ = initial velocity
- $t$ = time
- $a$ = acceleration due to gravity (9.81 m/s²)

Note that this formula contains $v_0$, which is the initial velocity. Since the object starts from rest in this activity, our initial velocity is 0, and we can remove this term from the formula. If we take this formula and rearrange it to solve for our unknown variable (time) and remove the initial velocity, we get the following:

$$x = \frac{1}{2}at^2$$

$$t = \frac{2x}{a}$$

For example, if a ruler was caught 0.15 m after it was dropped (remember to convert from cm to m) and we know that acceleration due to gravity is 9.81 m/s², then we can determine the reaction time:
\[
    t = \sqrt{\frac{2(0.15m)}{9.81 \text{ m/s}^2}} = 0.175s
\]

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Meter Stick</td>
<td>1 per group</td>
</tr>
</tbody>
</table>

Procedure

Work in groups of 3 or 4 for this activity. Your group should take turns dropping the meter stick, catching the meter stick, and recording data.

1. Student #1 should hold the beginning of the meter stick above Student #2’s open hand. The meter stick should have the 90 cm line even with Student #2’s thumb. Student #3 should note that the meter stick’s initial position is 90cm.
2. Student #1 should tell Student #2 to get ready, but not tell them when they are going to release the meter stick. Student #1 should then release the meter stick, and Student #2 should close his or her hand to catch it.
3. Student #3 should note where student #2 caught the meter stick and calculate the distance traveled (i.e. initial number (90 cm) − ending number = distance traveled).
   **Example:** If the meter stick began at 90 cm from the top, and you catch it at 75 cm, then the distance traveled will be 15 cm.
4. Repeat the activity until you have recorded three trials for each student in your group.
5. Proceed to the Research Notes section to complete that data table and answer the questions.
Activity 1: Calculating Reaction Time

Data Sheet

<table>
<thead>
<tr>
<th>Student Initials</th>
<th>Distance Ruler Dropped (m)</th>
<th>Average Dropped Distance (m)</th>
<th>Reaction Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
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</tbody>
</table>

Questions

1) What was the average reaction time of your group?

2) What issues do you think this method has of determining reaction time? What would you change in order to address these issues?
3) Based on what you learned, why is it important to leave space between cars when driving?

Discussion Notes
Activity 2: Braking Distance and Friction

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

Introduction

In this activity, students will apply the relationship between the kinetic energy of a car in motion and the work done on the car when braking, due to friction. Students will observe the braking distances of the Maglev car coming off the Maglev track onto different surfaces, and use this braking distance to calculate the coefficient of friction for the surface using the given relationship between work and energy.

Note: This activity can be performed as a class demonstration. Have the students take turns releasing the car and taking the measurements. Have each student record the class data and perform calculations individually.

Objective

In this activity, students will:

- Examine the factors that determine how much distance a moving car needs to stop.
- Observe how friction varies on different roadway materials and conditions.

Background

When using the equation presented to the students in this activity, it is pertinent to understand that the equation is based on ideal braking conditions. To add context, ideal braking conditions refers to the assumption that all kinetic energy will be converted directly into work. In reality, there are other factors that come into play when determining braking distances. For example, a car could be braking while moving up a hill, which would transfer some kinetic energy into potential energy, reducing the braking distance. The car is also converting some kinetic energy into thermal energy through the friction of the brakes on the wheels, which slightly reduces the braking distance.
These are a few examples of other energy outputs in this equation. The equation given to students is appropriate in a classroom setting; although, it should be made known to the students that it is an idealization of complex concepts.

**Activity Expansion Ideas**

The experimental portion of this activity could be expanded by testing the braking distance on a wider variety of surfaces. Instead of cardboard and wax paper try other commonly available materials like a placemat, sheet of plastic, or a carpet square.

As many students have minimal to no experience driving, it can sometimes be difficult for them to gauge the significance behind braking distance. As the speed of a vehicle increases, the necessary braking distance increases exponentially. The first link provided below allows students to input a vehicle speed and watch a vehicle brake in order to visualize the stopping distance. This simulation is based on ideal braking conditions. The second link allows the students to control more aspects of the situation to deviate for the ideal braking conditions, including the response time of the driver, distractions, and the weather conditions.

Links:

(1) [http://www.mrmont.com/games/brakingdistance.html](http://www.mrmont.com/games/brakingdistance.html)

(2) [http://www.stoppingdistances.org.uk/](http://www.stoppingdistances.org.uk/)
Activity 2: Braking Distance and Friction

Questions

1) Which surface allowed the car to stop sooner? Why?

   The cardboard should stop the car sooner, since it has a larger coefficient of friction.

2) What effect does increasing or decreasing the velocity of a car have on the braking distance?

   The kinetic energy of the vehicle—which is given by the formula $KE = \frac{1}{2} mv^2$—is one way to understand required braking distance. Since velocity is squared, any changes to the velocity will have a significant effect on the total kinetic energy. The trend of the change in velocity can be described as exponential. Therefore, a car traveling at a high velocity requires an exponentially longer braking distance than a car traveling at a lower velocity.

3) Think about your answers from Question 2. What factors do you think influence the determination of speed limits? Consider speed limits in neighborhoods, school zones, downtown areas, high-traffic shopping areas, highways, freeways, etc.

   Speed limits are lower in areas where braking is more commonly expected. For example, a downtown area would have a low speed limit because many people are trying to find parking or waiting for cars to pull out, causing drivers to brake frequently. On a highway, the speed limits are higher as there are less reasons for drivers to stop suddenly.

Discussion

As stated in the background of the instructor reference, the equations used in this activity are based on ideal braking conditions. Due to the assumptions drawn in the activity, discussion on why the distances calculated do not always reflect what would be measured on an actual road would be beneficial. Some questions that could be touched on during the discussion of this topic are: What assumptions did we make in order to solve these problems? How would you adjust the solution if you could not make these assumptions?

As a reminder of Activity 1, reiterating the importance of reaction times on stopping distance would aid in the students drawing connections amongst the material presented. Resulting from response time, the vehicles travel an additional distance before beginning to brake. Make note that the sum of the distance traveled during the drivers’ reaction time combined with the braking distance equals the total stopping distance of the vehicle. Knowing your stopping distance based on the variable conditions is important while driving to avoid accidents.
Activity 2: Braking Distance and Friction

Introduction

A car is traveling down a country road when, suddenly, the driver notices the road is closed ahead. The driver presses on the brakes, resulting in the car coming to a stop. The distance that the car requires to come to a complete stop is called the braking distance, which is the focus of this activity. You will observe the braking distances of the Maglev car after exiting the Maglev track onto different braking surfaces. In addition, the braking distance will be used to determine the force of friction that the braking surface exerts on the car.

Objective

In this activity, you will:

- Examine the factors that determine how much distance a moving car needs to stop.
- Observe how friction varies on different roadway materials and conditions.

Background

In order to calculate braking distance, we must first understand the relationship between work done on a braking vehicle and the kinetic energy of the vehicle in motion. Work done on a braking vehicle is the product of the friction force and the distance required for the vehicle to stop (braking distance). The friction force is defined by the gravitational force of the car (Force = mass * gravitational acceleration) multiplied by the coefficient of friction – a parameter that changes based on the roadway surface.

Kinetic energy is defined as half of the mass of the vehicle multiplied by the square of velocity. Since energy is conserved by the Law of Conservation of Energy, we can conclude that the energy required to bring the vehicle to a stop is equal to the energy of the vehicle in motion. Thus, the kinetic energy of the vehicle in motion can be set equal to the work required to bring it to a stop. This relationship can be expressed as the formula shown below.

<table>
<thead>
<tr>
<th>Braking Distance Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{2}mv^2 = \mu mgd )</td>
</tr>
</tbody>
</table>

Where:

- \( m \) = mass of the car
- \( v \) = velocity of the car prior to braking
- \( d \) = braking distance
- \( \mu \) = coefficient of friction
- \( g \) = acceleration due to gravity (9.81 m/s\(^2\) or 32.2 ft/s\(^2\))
We can rearrange this formula to solve for the braking distance, as shown below:

\[ d = \frac{v^2}{2\mu g} \]

We can also rearrange this formula to solve for the coefficient of friction, as shown below:

\[ \mu = \frac{2dg}{v^2} \]

This formula will allow us to model the braking distance of our maglev car; however, in practical traffic scenarios, there are other factors that influence braking distance as well. In order to better understand braking distance, the simplification of this formula is provided based on an ideal environment. Other factors that influence braking distance (along with a multitude of other concepts and formulas) are covered in transportation design manuals; for example, AASHTO’s *A Policy on Geometric Design of Highways and Streets*, commonly referred to as the “Green Book”. Civil engineers use the AASHTO Green Book to make informed design decisions for their projects on a regular basis.

Imagine driving on a dry road on a sunny day compared to driving on a wet road on a rainy day. Even if the car is driving at the same speed, the coefficient of friction is different due to the road condition. When comparing these two conditions, it is determined that there will be a larger distance required to come to a stop on a wet road. From the AASHTO Green Book, we can determine that the coefficients for wet and dry roads are 0.4 and 0.7, respectively. Using the formula for braking distance and the different coefficients of frictions, the amount that the braking distance will change can be determined. For this example, let’s assume we are driving 55 mph, or 80.67 ft/s.

\[ d = \frac{v^2}{2\mu g} \]

Dry road:
\[ d = \frac{(80.67 \text{ ft/s})^2}{2(0.7)(32.2 \text{ ft/s}^2)} \approx 144.4 \text{ ft} \]

Wet road:
\[ d = \frac{(80.67 \text{ ft/s})^2}{2(0.4)(32.2 \text{ ft/s}^2)} \approx 252.6 \text{ ft} \]

As you can see, at this speed, the difference in braking distances between a wet and dry road is 108.2 feet. It can be concluded that the condition of the surface clearly makes a significant difference in how quickly a car can stop.

Frictional force is independent of the area of contact. This is why if you have two objects with the same mass, but one is half as long and twice as tall as the other, they will still experience the same amount of friction when dragged along a surface (Figure 2-1). Since the frictional force is directly related to the braking distance you will find that two 5-inch maglev cars stacked on top of each other will have the same braking distance as one 10-inch maglev car.
Figure 2-1: Friction force and contact area

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>Maglev Track</td>
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<tr>
<td>Photogate</td>
<td>1</td>
</tr>
<tr>
<td>LabQuest 2</td>
<td>1</td>
</tr>
<tr>
<td>Maglev Car</td>
<td>1</td>
</tr>
<tr>
<td>Cardboard</td>
<td>1 piece</td>
</tr>
<tr>
<td>Wax Paper</td>
<td>1 sheet</td>
</tr>
</tbody>
</table>

Setup

Set up the lab equipment as shown in Figure 2-2 using the following instructions.

1. Position the Maglev track so that one end is raised on a support and one end is resting on a flat surface, such that it creates an inclined slope. The maglev track should be inclined so that the car will move down the track without being pushed.
2. At the end of the track, lay down either the cardboard or the wax paper on the flat surface to simulate different surfaces for the Maglev car to brake upon. Make sure that the surface material extends far enough past the end of the track to allow the maglev car to come to a stop.
complete stop on its own. Also make sure that one end of the surface material is laid under the track, so that the maglev car has a smooth transition from the ramp onto the “road”.

We will use the photogate to determine the velocity at the point where the maglev car leaves the track and begins to slow. During the trials, the LabQuest 2 device will record the instantaneous velocity based on data provided by the photogate.

3. Position a chemistry stand at the end of the track and attach the photogate to it, as shown in Figures 2-3 and 2-4.

![Figure 2-3: Chemistry Stand Components](image)

4. Position the chemistry stand and photogate at the end of the track (see Figure 2-4).

![Figure 2-4: Chemistry Stand and Photogate Setup](image)
5. Connect the photogate to the DIG port (located on the top of the LabQuest 2 device under the rubber protector) using the provided cable. Once connected, the LabQuest 2 should recognize what sensor is attached.
   a. Use the stylus to select the Sensors tab on the LabQuest 2 device (see Figure 2-5).

   ![Figure 2-5: LabQuest 2 Setup](image)

   b. Choose Data Collection from the drop-down menu (see Figure 2-6) and set it up as follows (see Figure 2-7):
      i. Mode: Photogate Timing
      ii. Photogate Mode: Gate
      iii. Enter the length of the maglev car (in meters).
      iv. Choose to end data collection with the stop button. (This means you will press play to begin and stop to end timing and data collection.)
      v. Hit OK to save input parameters.

   ![Figure 2-6: LabQuest 2 Data Collection](image)
6. Select the Table menu from the upper right hand corner in order to view the velocity results in table format (see Figure 2-8).

**Figure 2-8: LabQuest 2 Table Tool**

**Procedure**

We will use the lab equipment and the braking distance formula to determine the coefficient of friction of the braking surface. The Maglev car will be released from the top of the track. The velocity data gathered by the LabQuest 2 and the recorded braking distance of the Maglev car will be used to calculate the coefficient of friction. This process will be performed on two different braking surfaces, with three trials performed on each surface.

1. When you’re ready to release the car, select the play button in the lower left hand corner of the LabQuest 2 (as shown in Figure 2-8).
2. Release the Maglev car. Watch it move down the track and come to a stop on the braking surface.
3. Record the instantaneous velocity, $v$, of the car as it exits the track from the LabQuest 2 (as shown in Figure 2-9). Record this value in your Research Notes.
4. Measure the distance (in meters) from the end of the ramp to where the car came to a complete stop on the surface material. Record the measured distance in your Research Notes.

5. Repeat steps 2 - 4 two more times for a total of three trials. After three successful trials, select the Stop button in the lower left hand corner of the LabQuest 2. Average the distance and velocity data from the three trials.

![Figure 2-9: LabQuest 2 Results](image)

6. Repeat Steps 2 - 5 with the second surface material (cardboard or wax paper), making sure to position it under the end of the track and extending far enough to allow the maglev car to come to a complete stop on its own.

**Note:** When you select play, you will overwrite and discard the previous collection of data (see Figure 2-10). Be sure you have recorded your data from the first set of trials before you discard the collected data from the LabQuest 2.

![Figure 2-10: Overwrite and Discard Data](image)
7. Using the collected data, determine the coefficient of friction between the bottom of the Maglev car and the two different surface materials using the following rearrangement of the braking distance formula:

$$\mu = \frac{2dg}{v^2}$$
Activity 2: Braking Distance and Friction

Data Sheet

<table>
<thead>
<tr>
<th>Material</th>
<th>Velocity (m/s)</th>
<th>Distance (m)</th>
<th>Coefficient of Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wax paper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions

1) Which surface allowed the car to come to a stop sooner? Why?

2) What effect does increasing or decreasing the velocity of a car have on the braking distance?
3) Think about your answers from Question 2. What factors do you think influence the determination of speed limits? Consider speed limits in neighborhoods, school zones, downtown areas, high-traffic shopping areas, highways, freeways, etc.

Discussion Notes
Activity 3: Setting Yellow Light Time

### Activity Summary

<table>
<thead>
<tr>
<th><strong>Instructor Prep Time</strong></th>
<th>10 minutes</th>
</tr>
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<tbody>
<tr>
<td><strong>Class Time</strong></td>
<td>30 minutes</td>
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<tr>
<td><strong>Grade/Class</strong></td>
<td>9 - 12 Beginner</td>
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<tr>
<td><strong>Suggested Activity Grouping</strong></td>
<td>Individual</td>
</tr>
<tr>
<td><strong>Technology</strong></td>
<td>Low Tech</td>
</tr>
</tbody>
</table>

#### National Science Education Standards

- Appropriate tools
- Technology & mathematics
- Think Critically
- Motion & forces
- Standard 8
- Standard 9
- Standard 10

### Introduction

In this activity, students will learn about the design calculations of traffic signals, or more specifically, they will learn how to calculate the duration of a yellow light. Students will learn the variables involved in this calculation, study examples, and then apply what they have learned to solve a problem.

### Objective

In this activity, students will:

- Learn about the factors that affect yellow light time (such as reaction time from Activity 1)
- Determine the optimal time for a yellow light using the yellow light timing equation.

### Activity Expansion Ideas

Students could delve into the dangers of intersections. This would be a good opportunity for students to research the conflict points (or possible collision points of vehicles) in a regular 4-way intersection and compare it to the conflict points of a roundabout. Encourage them to research ways other than roundabouts that transportation and traffic engineers either are or could make intersections safer. Keep in mind that some of the solutions – including roundabouts – don’t include a traffic signal at all.
Activity 3: Setting Yellow Light Time

Questions

1) How long does the yellow light last? (Round answer to one decimal place)

\[ Y(v) = T_{pr} + \frac{1.47v}{2d_r + 2Gg} = 1s + \frac{1.47 \times 30 \text{ mph}}{2(10 \text{ ft/s}^2) + 2(0.03)(32.2 \text{ ft/s}^2)} = 3.0s \]

2) How long does it take for the police officer to come to a stop? (Round answer to one decimal place)

\[ Y(v) = T_{pr} + \frac{1.47v}{2d_r + 2Gg} = 1.5s + \frac{1.47 \times 30 \text{ mph}}{2(14 \text{ ft/s}^2) + 2(0.03)(32.2 \text{ ft/s}^2)} = 3.0s \]

3) Should the police officer come to a stop or proceed through the intersection? Why?

The police officer should come to a stop because even though they might react slower than the assumed design reaction time their deceleration is greater and causes their total stopping time to be within the 3.0 second yellow light duration.

4) Why do you think that the grade of a road leading up to a traffic light is a factor in what the yellow light duration should be?

If cars are traveling downhill (negative grade), gravity is accelerating the car. Therefore, the amount of time they will need to stop increases and the yellow light duration will need to be longer. Opposite of this, if a car is traveling uphill (positive grade), gravity is decelerating the car. Therefore, the amount of time they will need to stop decreases and the yellow light duration can be shorter.

5) What factors present on a roadway could be dangerous to drivers traveling through an intersection?

Answers may vary. A few examples would be weather conditions and sight distances. Certain weather conditions, such as snow and rain, lower the rate at which drivers are able to decelerate, which could increase the likelihood of accidents at this intersection. Additionally, intersections without proper sight lines can cause longer reactions to the approaching intersection, which could lead to the driver not stopping in time.

Discussion

As students calculate the yellow light times in the activity, talk about the criteria for selecting the ideal yellow light time and the required actions within that time. For example, some criteria that is taken into account is the volume of traffic, the patterns of traffic, and the design speed of the road. If yellow light times are too long, what might happen to drivers’ response to them? In turn, what might happen if the time is too short?
Activity 3: Setting Yellow Light Time

Introduction
As a car travels down a road, it approaches a traffic light. As the car nears the light, the light turns from green to yellow, and the driver is faced with a decision: are they close enough to continue through the intersection or should they prepare to stop? This decision is highly dependent on how long the light stays yellow. In this activity, the method for determining traffic light times and the impact this time has on the average driver will be explored.

Objective
In this activity, you will:
- Learn about the factors that affect yellow light time (such as reaction time from Activity 1).
- Determine the optimal time for a yellow light using the yellow light timing equation.

Background
In order to calculate the sequencing of a traffic system, several variables must be addressed and understood. These include:
- Reaction Time: How quickly can drivers react and put their foot on the brake?
- Deceleration: How quickly can the car slow down?
- Grade: How steep is the road leading to the intersection?
- Velocity: How fast is the car moving?

The changing of a traffic light can be broken down into three phases:
1. **Green**: The traffic is free to go.
2. **Yellow**: Depending on which is safer, drivers either come to a stop or continue through the yellow light. Drivers often make this decision based on the braking distance—the distance the car will travel once the driver has applied the brakes. When drivers are closer to the intersection than the required braking distance, they should continue through the light; if they don’t, then they could end up stopping in the intersection, potentially causing an accident. A yellow light should never go longer than 5 seconds. If it does, drivers tend not to “respect” it and the chance of an accident increases.
3. **All Red**: This is when the traffic lights for all the lanes are red (i.e., no one has a green or yellow light).

The Institute of Transportation Engineers (ITE) uses the following formula to calculate yellow light durations:
Activity 3: Setting Yellow Light Time

### Yellow Light Duration Formula

\[
Y(v) = T_{pr} + \frac{1.47v}{2d_r + 2Gg}
\]

Where:
- \(d_r\) = deceleration (ft/s²)
- \(g\) = acceleration due to gravity (32.2 ft/s²)
- \(G\) = grade (expressed as a decimal)
- \(v\) = velocity (mph)
- \(T_{pr}\) = reaction time (seconds)
- \(Y\) = yellow light duration (seconds)

This formula can be used to set the timing of yellow lights so that there is enough time for drivers to clear the intersection if they are close to it when the light turns yellow, as well as enough time for approaching cars to safely slow to a stop. However, the timing cannot be long enough that approaching drivers choose to ignore the yellow light altogether and accelerate to make it through the intersection, which creates the potential for an accident.

Not every driver has the same reaction time and not every vehicle can decelerate at the same rate, so averaged values are often selected for these variables when using this formula. Standard (averaged) values used for reaction time and deceleration are taken as 1 second and 10 ft/s², respectively. These standard values are often used in design, when specific data for these variables at an intersection is unknown.

**Sample Problem 1:**

Imagine an intersection with an approaching northbound road that has a grade of +2% and a design speed of 35 mph. The average reaction time of drivers approaching this intersection has been found to be 1.5 seconds, and the average rate of deceleration has been found to be 13 ft/s². What should the yellow light duration be for this northbound road? (Note: Standard values of reaction time and deceleration are not used here, as specific intersection data is available.)

To begin, we will write down what information we know:

\[
\begin{align*}
d_r &= 13 \text{ ft/s}^2 \\
g &= 32.2 \text{ ft/s}^2 \\
G &= +2\% = 0.02 \\
v &= 35 \text{ mph} \\
T_{pr} &= 1.5 \text{ s}
\end{align*}
\]

Put this information into the formula, it appears as shown below:

\[
Y(v) = 1.5s + \frac{1.47 \times (35 \text{ mph})}{2 \times (13 \text{ ft/s}^2) + 2 \times (0.02) \times (32.2 \text{ ft/s}^2)} = 3.4 \text{s}
\]
According to the formula, the yellow light duration for the northbound road at this intersection should be set at 3.4 seconds.

**Sample Problem 2:**

Imagine that a four-way intersection is in the design phase, and you, as the engineer, are asked how long the yellow light should last. The roads that intersect both have a design speed of 40 mph. One road was built on flat ground, while the other is located on a hill with a ±5% grade. Using the standard values for reaction time and deceleration, how long would the yellow lights last for both the flat road and the one on the hill?

Recall that the standard values for reaction time and deceleration are 1 second and 10 ft/s², respectively. Again, we will write down what information we know:

\[
\begin{align*}
\text{d}_r &= 10 \text{ ft/s}^2 \\
g &= 32.2 \text{ ft/s}^2 \\
G_{\text{flat}} &= 0\% = 0.00 \\
G_{\text{hill}} &= \pm 5\% = \pm 0.05 \\
v &= 40 \text{ mph} \\
T_{\text{pr}} &= 1 \text{ s}
\end{align*}
\]

You may have noticed the ± symbol in front of the 5%; this symbol stands for both plus and minus. In our example, driving on the inclined road in one direction means you are traveling uphill at a grade of +5%, while driving on the inclined road in the other direction means you are traveling downhill at a grade of -5%. When calculating yellow light durations, the goal should be to select the safest duration. In this case, the safest duration occurs when traveling downhill (resulting in a larger yellow light duration than when traveling uphill).

Calculate the yellow light duration for the road on flat ground:

\[
Y(v) = 1s + \frac{1.47 \times (30\text{mph})}{2 \times \left(10\text{ ft/s}^2\right) + 2 \times (0.00) \times \left(32.2\text{ ft/s}^2\right)} = 3.2s
\]

Next, calculate the yellow light duration for the road on the hill (using the -5% grade):

\[
Y(v) = 1s + \frac{1.47 \times (30\text{mph})}{2 \times \left(10\text{ ft/s}^2\right) + 2 \times (-0.05) \times \left(32.2\text{ ft/s}^2\right)} = 3.6s
\]

From our calculations, we can see that the yellow light should be lit for 3.2 seconds when traveling in either direction on the flat road, and should flash for 3.6 seconds when traveling either direction on the hill.

Use what you have learned to determine answers to the scenario provided in the procedure section.
Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity 1 Data</td>
<td></td>
</tr>
<tr>
<td>Pencils</td>
<td>1 per person</td>
</tr>
<tr>
<td>Paper</td>
<td>As needed</td>
</tr>
<tr>
<td>Calculators</td>
<td>1 per person</td>
</tr>
</tbody>
</table>

Procedure

Imagine a police car traveling down a road with a +3% grade at 30 mph, approaching an intersection as shown in Figure 3-1. The traffic light is initially green, but as the police car gets closer to the intersection, the light suddenly turns yellow. Assuming the road designers used standard values for reaction time and deceleration (1 second and 10 ft/s², respectively), how long will the yellow light last?

Imagine that the police officer is scanning the area for crime, and does not react to the yellow light for 1.5 seconds. If the police car has a deceleration rate of 14 ft/s², how long will it take for the vehicle to reach a stop?

Based on your answers to these questions, should the police car continue through the intersection or come to a stop? Why?

Show your work and record your answers in the space provided in the Research Notes section.

Figure 3-1: Scenario Site Depiction
Activity 3: Setting Yellow Light Time

Questions

1) How long does the yellow light last? (Round answer to one decimal place)

2) How long does it take for the police officer to come to a stop? (Round answer to one decimal place)

3) Should the police officer come to a stop or proceed through the intersection? Why?
4) Why do you think that the grade of a road leading up to a traffic light is a factor in what the yellow light duration should be?

5) What factors present on a roadway could be dangerous to drivers traveling through an intersection?
Activity 4: Programming Logic for Traffic Systems

<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>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

Introduction

In this activity, students will be introduced to software programming logic, learn basic programming concepts, and apply these concepts for traffic engineering purposes. They will look at basic flowcharts to understand the logical arrangement of IF-THEN-ELSE and LOOP statements, then organize flowcharts to apply what they’ve learned.

Objective

In this activity, students will:

- Learn basic programming logic and complete logic flowcharts.
- Develop an understanding of the software programming process.
- Gain experience with problem solving/design processes that engineers use.

Background

As the world becomes more reliant on technology, being technologically literate is increasingly important in every field. Basic programming logic not only can be used in a large variety of applications, but it also applies to most branches of engineering. Understanding computer programming logic will give students a head start on comprehending more advanced programming topics in college engineering programs.

Activity Expansion Ideas

Engineers use computer programming to complete many of their day to day tasks. Creating spreadsheets, especially ones with advanced functions, requires the same logical thinking skills required by computer programmers. Spreadsheets such as Excel also have the ability to program macros for completing tasks. Macros use a form of the BASIC computer language. Students could research how programming logic is used within spreadsheets by looking at some of the advanced functions that are
available. They could also look into the history of some of the programming languages that are commonly used by engineers, such as Visual Basic for Applications (VBA) used by Microsoft Excel.
Activity 4: Programming Logic for Traffic Systems

Logic Challenge 1

Start

IF Crosswalk Button is Pushed

True → Turn Light Yellow

False → Turn Light Red for 10 seconds

Light Turns Green

End
Logic Challenge 2

Start

IF Intersection traffic signal is red
True
Car drives through red light
True
End
False
Car waits for light to turn green
False
Car is pulled over
End

Car drives through intersection
Logic Challenge 3

Start Count

IF 24-hours have passed

IF Sensors are driven over

Add one vehicle to traffic count

Wait for vehicle to cross sensor

IF Vehicle is travelling over 40mph

Record that car is speeding

Record that car is travelling below speed limit
Questions

1) What are the benefits associated with creating flowcharts for programming logic before beginning actual programming?

By creating flowcharts, programmers can organize their logical statements, test their logic, and check for errors before writing a program’s code. This saves the programmer time and effort in the future, as they can correct any errors before they’re input into the program’s code, where they are more difficult to find and correct.

2) LOOP statements are very powerful tools; however, it is important that they are set up correctly. What mistake could lead to a program running indefinitely?

It is possible to create a LOOP where the condition being analyzed cannot be satisfied, which will cause the program you are writing to run indefinitely, or crash. One must make sure that the condition of a LOOP can be satisfied, or else the computer will try to use the available processing power attempting to solve an unsolvable problem.

3) When looking at software you use often – such as video games or phone apps – what logical statements can you find in this software?

Answers will vary for this question. A sample answer is provided:

While playing a video game, if the player needs to open a locked door, the game will ask IF the “player has correct key.” If you indeed do have the key, THEN the game will perform the action “open door,” or ELSE it will “do nothing.”

Discussion

Discuss other programming concepts not covered in this activity that might be found in a more complex program code. An example of this would be a GOTO statement, which directs the program to go to a certain location within the program if a certain condition is met. Another example would be a CALL statement, which causes the program to run another program within it before proceeding. This statement is useful in organizing a program code by creating smaller programs that perform certain functions and are written separately. All of the smaller programs are then compiled and organized in a comprehensive format, making it easier to maintain. The CALL statement can be combined with IF/THEN/ELSE statements to replace GOTO statements. Both of these are examples of the concept of conditional execution of different branches in the code.

Ask students if they can think of any non-programming applications of Boolean logic and flowcharts. For example, some instructional guides provide flowcharts to explain a process in a visually appealing format. Also, schedules, such as a construction schedule or an academic schedule, can be organized by the use of flowcharts. Other examples include cooking directions, vehicle maintenance procedures, and step-by-step gameplay hints for videogames.
Activity 4: Programming Logic for Traffic Systems

Introduction
The use of computer-based technology in today’s world is astounding. Many of the things we use every day are controlled by computer software. Traffic technology is no exception; software programs control the traffic systems that guide drivers along crowded roadways and help keep people safe. This activity will introduce you to the programming logic that allows this software to function properly, teach you basic programming concepts, and allow you to apply these concepts to traffic technology scenarios.

Objective
In this activity, you will:
- Learn basic programming logic and complete logic flowcharts.
- Develop an understanding of the software programming process.
- Gain experience with problem solving/design processes that engineers use.

Background
Many traffic systems, such as traffic lights, use basic computer logic to decide what actions to take and when to take them. The logic that computers use is called Boolean Logic, which is a form of algebra in which all values are reduced to either TRUE or FALSE. For example, the statement “five is greater than four” can be analyzed on a true or false basis by the computer. In this case, the statement is true; the result is used to process the next procedure.

While there are many different software programming languages used today, many basic programming concepts are universal because nearly every programming language uses Boolean Logic. One of the most important of these concepts is the IF-THEN-ELSE logical statement (often referred to simply as an IF statement); which says that “IF a statement is true, THEN perform an action, ELSE perform another action.” For example, if you needed to decide whether or not to wear a jacket, the computer logic version of that decision would be “IF the temperature is less than 50 degrees Fahrenheit, THEN wear a jacket, ELSE do not wear a jacket.”

When writing the operating code for a program, it is critical to plan the logical statements in advance to ensure that the program makes sense and avoids errors. Flowcharts are useful to perform this task. Generally, programmers lay out a complex series of logical statements used in a program prior to typing a single line of code. This allows the programmer to organize the logical statements, test their logic, and check for errors. Considering that computer programs often contain thousands of lines of code, it is important to have a plan before writing the code. Once the flowchart is completed and the logical statements are arranged in an organized, functioning manner, then the programmer will write the code.

In this activity, you will practice using Boolean logic by analyzing and organizing flowcharts for traffic engineering purposes. Table 4-1 displays some common, shapes found in flowcharts, each one is used to indicate a certain function for the computer to perform.
Table 4-1: Common Flowchart Shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Terminal" /></td>
<td>Terminal</td>
<td>Typically represents either the beginning or the end of a flowchart.</td>
</tr>
<tr>
<td><img src="image" alt="Process" /></td>
<td>Process</td>
<td>Represents an action or function to be performed.</td>
</tr>
<tr>
<td><img src="image" alt="Decision" /></td>
<td>Decision</td>
<td>Represents a decision point. Logical statements are presented in these.</td>
</tr>
</tbody>
</table>

In the example shown below, an IF statement is used to determine whether a driver should be issued a speeding ticket on a road with a speed limit of 65 mph. Table 4-2 shows the logical considerations of the IF statement and Figure 4-1 displays the logical procedure of the IF statement using a flowchart. The algorithm presented by the flowchart will govern whether a speeding ticket will be issued.

Table 4-2: Logical Considerations of Issuing a Speeding Ticket

<table>
<thead>
<tr>
<th>Speed While Traveling (mph)</th>
<th>Action to be Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 65</td>
<td>Issue Ticket</td>
</tr>
<tr>
<td>65 or less</td>
<td>No Ticket</td>
</tr>
</tbody>
</table>

Figure 4-1: Flowchart illustrating a basic IF statement
Let us now revise this example and create a more complex algorithm. Our new algorithm will say, "IF Condition 1 is true, THEN perform the first function, ELSE perform a new IF statement checking Condition 2." IF statements can be imbedded or “nested” within each other to perform very complex, logical computations. In this scenario, a second function has been added to assign a ticket if the motorist is traveling too slowly, as shown in Table 4-3 and Figure 4-2.

**Table 4-3: Logical Considerations of Issuing a Speeding Ticket with Additional Lower Limit**

<table>
<thead>
<tr>
<th>Speed While Traveling</th>
<th>Action to be Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 65</td>
<td>Issue Ticket</td>
</tr>
<tr>
<td>40 - 65</td>
<td>No Ticket</td>
</tr>
<tr>
<td>Less than 40</td>
<td>Issue Ticket</td>
</tr>
</tbody>
</table>

![Figure 4-2: Flowchart illustrating a nested IF statement](image)
Now, let’s look at a more advanced concept called a LOOP statement (often referred to simply as a LOOP). A LOOP statement is used when you need to repeat a section of code, until a certain condition is met. For example, if we were to look at a LOOP based on eating a bag of candy, it would look something like Figure 4-3.

![Figure 4-3: Flowchart illustrating a basic LOOP statement](image)

Following this logic, you will eat the candy until the condition “bag = empty” is true, at which point you will throw away the bag. These LOOP statements can have a significant amount of content within them, including IF statements, or even other LOOP statements. Imagine that now, instead of eating the candy alone, you wanted to share it evenly with your friend. A LOOP for this situation would look something like Figure 4-4.

![Figure 4-4: Flowchart illustrating a LOOP statement with a nested IF statement](image)
In this situation, when you first open the bag neither you or your friend will have any candy, so you will take one piece for yourself. Then you will check that there is still candy in the bag, since you have one piece and your friend has none you will give one piece to your friend. You will repeat this process until the bag of candy is empty and the program ends. An IF statement has been nested inside a LOOP statement to perform this function. With LOOP statements, you can create a series of checks that allow you to program a number of complex situations.

Now that we have learned about the logical steps that computer programs follow, you will create programming flowcharts based on a series of traffic control system problems.

**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scissors</td>
<td>1 per person or group</td>
</tr>
<tr>
<td>Paper</td>
<td>As needed</td>
</tr>
<tr>
<td>Pens/pencils</td>
<td>As needed</td>
</tr>
<tr>
<td>Tape or glue</td>
<td>Per person or group</td>
</tr>
</tbody>
</table>

**Procedure**

On the following pages, a series of logic challenges are presented. Each logic challenge has its own independent set of flowchart pieces that need to be cut out and arranged on a blank sheet of paper in the correct order. To determine the correct order, you should apply your knowledge of Boolean logic, IF/THEN/ELSE, and LOOP statements. Follow the instructions listed below to complete this task.

**Note:** You should only cut out the flowchart pieces for the problem you are working on.

1. Read the problem statement and review the figure for each logic challenge.
2. Cut out the flowchart pieces provided with the logic challenge.
3. Arrange the pieces in the order you believe to be correct. Use the IF and LOOP statements to create a logical order for the functions to follow.
4. After you arrange the pieces, draw lines to connect each block. Be sure to indicate TRUE and FALSE conditions on appropriate arrows.
5. Once you have drawn the arrows, glue or tape the pieces down.

Once you have completed each logic challenge, attach your solutions to the *Research Notes* section and answer the questions within your *Research Notes*. 
Activity 4: Programming Logic for Traffic Systems

Logic Challenge 1

The pedestrian in Figure 4-5 is attempting to cross the roadway at the crosswalk, and hits a button at the base of the traffic signal. Pressing this button indicates to the traffic signal’s program that someone is attempting to cross the roadway, which will turn the traffic light red for a set amount of time, allowing the pedestrian time to cross. Use the included IF statement and functions to create a logic flowchart describing the steps your code would take to help the pedestrian safely cross the intersection.

Figure 4-5: Site Depiction of Logic Challenge 1
Start

IF Crosswalk Button is Pushed

Turn Light Yellow

Turn Light Red for 10 seconds

Light Turns Green

End
Logic Challenge 2

A red car is approaching a T intersection at the same time as a police officer, as shown in Figure 4-6. The driver of the red car is in a hurry and does not see the officer. The driver of the red car is contemplating running the light if it turns red in which case the officer will issue a ticket. Create a flowchart with the supplied functions that show the potential outcomes of this situation. Note that there are two different end points in this example, based on whether or not the driver stops at the intersection.

Figure 4-6: Site Depiction of Logic Challenge 2
This page intentionally left blank.
Start

Car waits for light to turn green

End

IF Intersection traffic signal is red

IF Car drives through red light

Car drives through intersection

Car is pulled over

End
This page intentionally left blank.
Logic Challenge 3

A traffic counter is used to collect traffic volume data and the speed at which traffic is traveling on a roadway. This traffic counter records data by use of two pneumatic sensors placed on the roadway, as shown in Figure 4-7. When a car drives over the first sensor, a timer is initiated and the traffic counter adds one vehicle to the traffic count. When the car drives over the second sensor, the timer ends. Using the recorded time and the known distance between sensors, the traffic counter’s program is able to process the velocity of the car and record it. Modern technology allows collection of this data using other tools as well.

Imagine the traffic counter used in Figure 4-7 is placed on a road with a speed limit of 40mph. The traffic counter is set to separate data by the amount of traffic passing the sensor in a 24-hr period. Develop a flowchart of this traffic counter’s operation.
This page intentionally left blank.
Activity 4: Programming Logic for Traffic Systems

Start Count

End Count

Record that car is speeding

Record that car is travelling below speed limit

Add one vehicle to traffic count

Wait for vehicle to cross sensor

IF Sensors are driven over

IF 24-hours have passed

IF Vehicle is travelling over 40mph
Questions

1) What are the benefits to creating flowcharts for programming logic before beginning actual programming?

2) LOOP statements are very powerful tools; however, it is important that they are set up correctly. What mistake could lead to a program running indefinitely?

3) When looking at the software you use often – such as video games or phone apps – what logical statements can you find in this software?

Discussion Notes
Activity 5: Shortest Path

**Activity Summary**

<table>
<thead>
<tr>
<th>Instructor Prep Time</th>
<th>10 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Time</td>
<td>50 minutes</td>
</tr>
<tr>
<td>Grade/Class</td>
<td>9 – 12 Advanced</td>
</tr>
<tr>
<td>Suggested Activity Grouping</td>
<td>Individual or groups of two</td>
</tr>
<tr>
<td>Technology</td>
<td>High Tech</td>
</tr>
<tr>
<td>National Science Education Standards</td>
<td>Appropriate tools Technology &amp; mathematics Think critically</td>
</tr>
</tbody>
</table>

**Introduction**

This activity gives students an understanding of how map applications, such as *Google Maps* or *MapQuest*, provide users the quickest route to a destination. Students will use *Microsoft Excel* to examine this process. A guided example will help students grasp the basics, then they will apply their knowledge to an individual assignment.

**Note:** Before the students begin work, install the solver function on the computers by following the instructions in the link below. **THIS EXCEL TOOL IS REQUIRED FOR THIS ACTIVITY.**


**Objective**

In this activity, students will:

- Learn how a map application on their phone or computer determines the shortest possible route.
- Gain experience with spreadsheets and programming logic.

**Background**

Programming experience is beneficial to allow one to organize complex data sets, perform numerous computations simultaneously, and present information in a comprehensive format. Many college engineering curriculums require that students familiarize themselves with programming functions during the first couple years of school, as many later classes use programming applications to solve a variety of problems.
Activity Expansion Ideas

In order to examine some other factors that are used by map applications to determine the quickest route to a destination, students could explore the Mi Drive app or the Mi Drive website from the Michigan Department of Transportation. This application displays traffic incidents, current flows of traffic, construction projects, as well as other information, such as the location of roadside parks. For students located in states other than Michigan, the Waze app or the Waze website can be used to analyze traffic data and road information. Allow students to take the time to look at the app and/or website and pair it with a map application like Google Maps to determine what the fastest route to a destination would be at a certain time of day.

Mi Drive website link: [http://www.michigan.gov/drive](http://www.michigan.gov/drive)

The Waze website link: [https://www.waze.com/livemap](https://www.waze.com/livemap)
Activity 5: Shortest Path

An Excel file labeled “Activity 5 – Shortest Path Solved.xls” is provided in the Traffic Technology Module section of the TRAC webpage. This file displays the answers to both the Guided Example and the Individual Assignment. The table below displays the answer to the Individual Assignment maze. The quickest route should be “Start-B-E-G-End,” as indicated by the values of 1 in the Y/N column, and displayed in the solved maze image on the following page. The Total cell displays the overall distance of this path, which should be 14.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>A</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Start</td>
<td>B</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Start</td>
<td>C</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>D</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>E</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>B</td>
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<td>0</td>
</tr>
<tr>
<td>C</td>
<td>E</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>E</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>F</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>G</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>H</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>G</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>End</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
<td>End</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>G</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>End</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>
If students are stuck on an intermediate step, the following equations can be checked. The equation that should be placed in the Total cell is as follows:

=SUMPRODUCT(C2:C20,D2:D20)

The equations that should be placed in the Net Flow column are as follows:

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Net Flow</th>
<th>Starting/Ending Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>SUMIF(A$2:A$20,F2,D$2:D$20)-SUMIF(B$2:B$20,F2,D$2:D$20) = 1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>SUMIF(A$2:A$20,F3,D$2:D$20)-SUMIF(B$2:B$20,F3,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>SUMIF(A$2:A$20,F4,D$2:D$20)-SUMIF(B$2:B$20,F4,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>SUMIF(A$2:A$20,F5,D$2:D$20)-SUMIF(B$2:B$20,F5,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>SUMIF(A$2:A$20,F6,D$2:D$20)-SUMIF(B$2:B$20,F6,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>SUMIF(A$2:A$20,F7,D$2:D$20)-SUMIF(B$2:B$20,F7,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>SUMIF(A$2:A$20,F8,D$2:D$20)-SUMIF(B$2:B$20,F8,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>SUMIF(A$2:A$20,F9,D$2:D$20)-SUMIF(B$2:B$20,F9,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>SUMIF(A$2:A$20,F10,D$2:D$20)-SUMIF(B$2:B$20,F10,D$2:D$20) = 0</td>
<td></td>
</tr>
<tr>
<td>End</td>
<td>SUMIF(A$2:A$20,F11,D$2:D$20)-SUMIF(B$2:B$20,F11,D$2:D$20) = -1</td>
<td></td>
</tr>
</tbody>
</table>

The Solver function windows should appear as shown on the following page.
Activity 5: Shortest Path

Solver Parameters

Set Objective: SC$21

To: Min

By Changing Variable Cells: SDS2:SDS20

Subject to the Constraints:

$GS2:GS11 = SI2:SI11

Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Add Constraint

Cell Reference: $GS2:GS11 = SI2:SI11

Constraint: =SI2:SI11

Add Cancel
Data Sheet

<table>
<thead>
<tr>
<th>Shortest Route (Example: Start-A-B-End)</th>
<th>Shortest Route Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start – B – E – G – End</td>
<td>14</td>
</tr>
</tbody>
</table>

Questions

1) What additional factors for determining the shortest route to a destination were not taken into account for this activity?

We only looked at the shortest route in terms of distance. We did not consider the speed limit of a roadway, the capacity of a roadway, construction activity, or accidents that would slow travel time.

2) What are the limitations of this code? What might we want to change to increase efficiency for solving more complex mazes?

Answers will likely vary here. Generally, this code works by analyzing each and every possible route combination between the start and finish of the maze. As the number of route options goes up, so do the amount of links that can be taken. This will add to computational time to analyze each and every possible path. Map applications have a narrow window for the route options they look at, attempting to route drivers on main roadways whenever possible.

3) How is your decision process different from the code’s process when selecting a route in your area?

Answers will vary here. Generally, they should state that based on their past experience, they know the shortest route and when the shortest route might change due to factors such as time of day or construction. This code is different in that it analyzes every possible route option and does not consider any other factor but distance in determining the quickest route.

Discussion

Be sure to emphasize the influence of these map applications on our travel habits. Remind them of a time when GPS and map applications did not exist and routes had to be thought through carefully. Drivers once analyzed paper maps or asked directions; map applications have replaced this process.
Activity 5: Shortest Path

Introduction
As you finish packing the car for a road trip, you pull out your phone and plug your destination into a map application, and your phone displays a route. While this seems like a simple process, there is a significant amount of work going on behind the scenes. This activity will familiarize you with the process these programs use to calculate the shortest path to your destination.

Objective
In this activity, you will:
- Learn how a map application determines the shortest possible route.
- Gain experience with spreadsheets and programming logic.

Background
When you use a map application, the application calculates the quickest route from your location to your destination, and, while it appears simple, the process requires a great deal of mathematical computations. In order to calculate the quickest route, a number of factors need to be considered, such as how long a certain path will be, what the average speed on that road is, and if there are any temporary problems with the road (such as traffic jams or construction) that would delay the trip. Since the program running the map application has access to all of this information, it is able to provide you a route in a few seconds. In this activity, we will focus on only one piece of information to determine the quickest route: distance.

We will use the Excel Solver function to determine the quickest route through a short maze.

Materials

<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 5 – Shortest Path.xls</td>
<td></td>
</tr>
</tbody>
</table>

Note: Due to the inclusion of the Solver function, this activity may not be transportable to other spreadsheets.

Setup
Open Microsoft Excel, select File/Open, and navigate to the file entitled Activity 5 – Shortest Path.xls, which is located where your instructor specifies. This file is available for download in the Traffic Technology Module section of the TRAC webpage. In this file, there are two worksheets (tabs located at the bottom of the screen); one is labeled Guided Example and the other is labeled Individual Assignment.
Procedure

Guided Example

The objective of this example is to get from the start to the end of the maze in Figure 5-1 by taking the shortest route possible. This will be determined by using the Solver function in Microsoft Excel. The numbers on each branch represent the distance from one node to another. In this Excel file, there is a Guided Example worksheet for you to use to follow along with this example.

In this worksheet, there are two incomplete tables. These tables will assist us in calculating the shortest path, and will be broken down and discussed step-by-step.

Figure 5-1: Maze – Guided Example

1. First, we must define where we are going to, going from, and how long it will take. This “link” information has been defined for us in the highlighted section of Figure 5-2. When we write these links, we want to make sure that we are always progressing towards the end of the maze, not going in a circle or backwards. For example, in Figure 5-2, we could travel from Start to B and from B to C, but we would not travel from C to Start, we would travel from C to End.
Figure 5-2: Link Start and End Points, and distances between them

2. The Yes/No column indicated in Figure 5-3 is the section where we will decide whether or not to take the specific link. In this case, a value of 1 means Yes, a value of 0 means No. Currently, there are no values in this column because we will be using the Solver function in Excel to complete this column in a later step.

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>A</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>B</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>C</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>B</td>
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<td>A</td>
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<tr>
<td>B</td>
<td>A</td>
<td>3</td>
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</tr>
<tr>
<td>B</td>
<td>C</td>
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<tr>
<td>B</td>
<td>E</td>
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<tr>
<td>C</td>
<td>B</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>End</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>End</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>End</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-3: Y/N Column (will be completed by the Solver Function)

3. The cell indicated in Figure 5-4 is the total distance we will take on our shortest route. In this cell, we will write the formula `=SUMPRODUCT(Distance,Y/N)` which will multiply the distance of each route by either 1 or 0—depending on if we take that link—and then sum the product together to find the total length of the shortest path. For this example, the following formula should be written in the total distance cell:

`=SUMPRODUCT(C2:C13,D2:D13)"
Research Manual Activity 5: Shortest Path

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>A</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>B</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>C</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>D</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>E</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>B</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>End</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>End</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>End</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-4: Total Distance Cell; enter equation here

4. Now we will look at the other table, which will allow us to determine where we are going to and where we are coming from. In the Starting/Ending Location column indicated in Figure 5-5, a value of 1 represents where we are coming from, a value of -1 represents where we want to be, and a value of 0 represents a node we could travel through.

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Net Flow</th>
<th>Starting/Ending Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>End</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

Figure 5-5: Starting/Ending Location

5. The Net Flow column indicated in Figure 5-6 will also be using the Solver function. This column will tell the Solver function that we need to go from Start to End, and prevent the Solver function from selecting two unlinked nodes to travel between. In these cells, we use the formula “=SUMIF(From,Node,Y/N)-SUMIF(To,Node,Y/N)” where Node represents the node cell to the left of the Net Flow cell. For this example, this translates to the following formula which should be entered into the first cell of the column:

=SUMIF(A$2:A$13,F2,D$2:D$13)-SUMIF(B$2:B$13,F2,D$2:D$13)

Then, apply the formula to the rest of the cells by using copy & paste. The necessary values will be changed automatically. See Figure 5-7 for help with this step.
Note: You may have noticed the “$” signs that appear in this equation. When you place this symbol in front of either the row or column reference, it locks the location, so that when the formula is applied to different location, the references remain in the same cell. For example; $A12 fixes column A, A$12 fixes row 12, and $A$12 fixes both column A and row 12.

![Figure 5-6: Net Flow Formula Setup](image)

![Figure 5-7: Step 5 Equation Setup](image)

6. Now, we will use the Solver function to find the shortest path. To use the Solver function, click on the **Data** tab and, under the **Analysis** tab, select the **Solver** button (see Figure 5-8).

**Note:** If the Solver function is not appearing as shown in Figure 5-8, you will need to add it to Excel. Follow the steps in the following link to add it in:

Figure 5-8: Location of the Solver Function

7. In the dialog box that appears, we want to input the information as it appears in Figure 5-9, following the steps listed below.
   a. In the Set Objective section, select the Total cell, indicated in Figure 5-4.
   b. In the To section, select Min.
   c. In the By Changing Variable Cells section, select the entire Y/N column, indicated in Figure 5-3.
   d. In the Subject to the Constraints section, click Add. A dialog box will appear as shown in Figure 5-10.
      i. In the Cell Reference section, select the Net Flow column, indicated in Figure 5-6.
      ii. In the center drop down menu, select the ‘=’ symbol
      iii. In the Constraint section, select the Starting/Ending Location column indicated in Figure 5-5.
      iv. Press OK to add the Constraints
   e. In the Select a Solving Method section, set the solving method to Simplex LP.
   f. Click Solve.
   g. After this process is complete you will see “Solver found a solution”. Click OK.
8. After you click Solve, the Total cell should display the final answer of 10, following the path “Start-B-E-End” (see Figure 5-11 and 5-12). The values of 1 and 0 in the Y/N column describe the links that are taken on the shortest route. For example, since Start to B has a value of 1, the shortest path takes that link, and since Start to A has a value of 0, the shortest path does not take that link.
Figure 5-11: Guided Example Solved Data

Figure 5-12: Guided Example Solved Maze
Individual Assignment

Now that you have worked through the guided example, try the more advanced maze, presented in Figure 5-13 below. Tables that correspond with this figure are presented in the Individual Assignment tab of the Excel file. Refer to the guided example for assistance with this activity. Record the shortest route of this maze, as well as the shortest distance, in the space provided in the Research Notes section.

Figure 5-13: Maze – Individual Assignment
Activity 5: Shortest Path

Data Sheet

<table>
<thead>
<tr>
<th>Shortest Route (Example: Start-A-B-End)</th>
<th>Shortest Route Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions

1) What additional factors for determining the shortest route to a destination were not taken into account for this activity?

2) What are the limitations of this code? What might we want to change to increase efficiency for solving more complex mazes?

3) How is your decision process different from the code’s process when selecting a route in your area?

Discussion Notes
Activity 6: Traffic Light

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

**Introduction**

In this activity, students will discover how magnetic sensors are used at traffic lights to help detect vehicles and collect traffic data. Students will observe changes in a magnetic field from data collected during the activity.

**Objective**

In this activity, students will:

- Learn about the use of magnetic sensors in traffic detection.
- Gain understanding in the process of recognizing a vehicle and communicating information to the traffic signals.

**Background**

The system simulated in this activity is known as an Intelligent Traffic System (ITS). An ITS is used to sense the presence or absence of vehicles in order to collect data for traffic signals. These systems reduce the amount of time that vehicles wait at a red light. In this activity, the focus will be on magnetic field disturbances detected by wireless sensors.

**Activity Expansion Ideas**

In this activity, steel washers are used to provide an effect on the magnetic field measured by the magnetic sensor. Students could experiment with other materials and or objects and see what kinds of impact these have on the sensor readings.

This activity is formed around the concept of magnetic fields and, more specifically, the Earth’s magnetic field. Encourage students to research magnetic fields; for example, what a magnetic field is, how magnetic fields are created, and what the Earth’s magnetic field looks like. Additionally, challenge
students to research the types of intelligent traffic systems used in their local area. After completing the research, students could turn in a written report or deliver a brief oral report on their findings.
Activity 6: Traffic Light

Questions

1) What effect did the vehicle loaded with 8 washers have on the magnetic field?

The vehicle loaded with 8 washers should cause the magnetic field readings to drop to a lower value during the time in which the vehicle is located under the sensor.

2) When loaded with 4 washers, how was the magnetic distortion different than with 8 washers?

When 4 washers are located in the vehicle the effect on the magnetic field will be similar to that observed with 8 washers but the degree to which the magnetic field readings change will not be as great.

3) Could the magnetic field sensor register the vehicle without any steel washers? Does a magnet stick to the vehicle? Describe why the vehicle itself behaves as it does with the magnetic field sensor.

Most die-cast vehicles are made of a zinc alloy and contain no iron, therefore a magnet will not stick to the die-cast vehicle and it does not have a strong effect on the magnetic field measured by the sensor. Students may notice some affect but it is difficult to distinguish from the noise in the measurements.

Discussion

This activity focuses on Magneto-resistive sensors that collect data on disturbances in the Earth’s magnetic field as vehicles pass near the sensor. There are other Intelligent Transportation Systems that could be discussed, along with their advantages and disadvantages in certain regions. For example, image processing systems should be avoided in areas with inclement winter weather or areas that commonly experience thick fog. Although, image processing may be advantageous for areas where people speed or run red lights frequently. What systems are used in the local area? Discuss why the systems in the local area are used and why others may not be.
Activity 6: Traffic Light

Introduction
As a red light changes to green, you may ask yourself how the system works and how it knows that your vehicle is there. There are various systems that are used to measure a vehicle’s presence on the roadway. In this activity, we will take a closer look at a system that observes changes in the Earth’s magnetic field.

Objective
In this demonstration, you will observe the following:

- How magnetic sensors detect traffic.
- The process of recognizing vehicles and communicating data to the traffic signal computer.

Background
The system simulated in this activity is known as an Intelligent Traffic System (ITS). An ITS is used to sense the presence or absence of vehicles in order to collect data for traffic signals. These systems reduce the amount of time that vehicles wait at a red light.

ITSs have changed overtime and detect traffic in different ways. Older systems used the weight of vehicles to trigger a response from the system, whereas systems now react to the motion of vehicles through various mediums. Modern systems involve electromagnetic induction, image processing, or magnetic field distortion to trigger a response from the system. In this activity, we will focus on the magnetic field distortion detected by wireless sensors, more commonly known as pucks. Agencies are using pucks more frequently due to their minimally invasive nature; specifically in areas with high water tables or damaged pavement. Pucks are installed below the surface of the roadway.

The magneto-resistive sensing device built into the puck collects data based on the x-, y-, and z-axis components of the Earth’s magnetic Field. When a vehicle is within range of the sensor, changes in the x-, y-, z-axis components of the Earth’s magnetic field are collected. This variation in the magnetic field allows for the system to collect data on the presence of a vehicle. If desired, the sensors can detect speed and measure the length of vehicles with the installation of an additional sensor in the roadway. The sensor continually collects data on the background magnetic field to establish base-line information. All of the data collected by the sensor or sensors is transmitted to a computer system containing analysis software similar to that discussed in Activity 4; which calculates and sets the appropriate signal changes.

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die-cast truck</td>
<td>1</td>
</tr>
<tr>
<td>Steel washers</td>
<td>8</td>
</tr>
<tr>
<td>Cardboard (approx. 4-inches x 24-inches)</td>
<td>1</td>
</tr>
<tr>
<td>Chemistry stand</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-----</td>
</tr>
<tr>
<td>Clamp</td>
<td>1</td>
</tr>
<tr>
<td>Vernier magnetic field sensor</td>
<td>1</td>
</tr>
<tr>
<td>Vernier LabQuest 2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Setup**

1. Assemble the chemistry stand and attach the clamp roughly 4 inches above the surface of the table, or high enough for the truck to be able to pass under the clamp.
2. Attach the Magnetic Field Sensor to the clamp parallel to the table.
3. Turn on the LabQuest 2
4. Connect the Magnetic Field Sensor to the analog CH 1 port (located on the left side of the LabQuest 2). Once connected, the LabQuest 2 should recognize the sensor is attached.
5. Place the magnet on the table directly below the sensor (Figure 6-1). Move the magnet around until you find the location that provides the highest reading on the LabQuest 2.

![Figure 6-1: Magnetic Field Sensor Setup](image)

6. Place a strip of cardboard that is roughly 24 inches long and 4 inches wide over the magnet to act as the roadway (Figure 6-2). The length of the cardboard should be perpendicular to the magnetic field sensor and the middle should be under the sensor. Tape the ends of the cardboard to the table top.
7. After placing the cardboard, check to make sure that the vehicle still passes under the magnetic field sensor. If not, adjust the clamp and sensor (Figure 6.2).
8. Secure steel washers to the vehicle. Typically, there is not a strong enough magnetic material within a die-cast vehicle to distort the magnetic field.
Procedure

In the demonstration, you will be able to observe the change in the magnetic field as a vehicle passes between a sensor and a magnet. The setup of the demonstration is equivalent to the sensing system used in a typical intersection. We use a magnet under the cardboard strip in order to strengthen the readings of the sensor. The sensors used in the roadways are able to capture the Earth’s magnetic field so the additional magnet is not necessary in a real intersection.

1. Position the vehicle on either end of the cardboard, pointing toward the magnetic sensor.
2. Select the play button in the lower left had corner of the LabQuest 2.
3. Push the vehicle along the strip of card board, passing under the sensor.
4. Repeat Steps 1-2 to thoroughly demonstrate the magnetic field disturbances created by the passing vehicle.
5. Repeat Steps 1-2 with 4 washers in the back of the truck
6. Repeat Steps 1-2 with no washers in the back of the truck.
Activity 6: Traffic Light

Questions

1) What effect did the vehicle loaded with 8 washers have on the magnetic field?

2) When loaded with 4 washers, how was the magnetic distortion different than with 8 washers?

3) Could the magnetic field sensor register the vehicle without any steel washers? Does a magnet stick to the vehicle? Describe why the vehicle itself behaves as it does with the magnetic field sensor.

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.

Vernier LabQuest 2 Manual
Link: http://www2.vernier.com/manuals/labquest2_user_manual.pdf
The LabQuest 2 is used in Activity 2. For additional help with setup, please refer to the LabQuest 2 manual.

Vernier Photogate Manual
Link: http://www2.vernier.com/manuals/LabQuest_Introduction_to_the_Vernier_Photogate.pdf
The Vernier Photogate is used in Activity 2. For additional help with setup, please refer to the Photogate manual.
Appendix B: Glossary of Terms

**Algorithm**: A logical process to be followed in a series of calculations, written for computer programs, often displayed in the form of a flowchart.

**Boolean Logic**: Form of algebra in which all values are reduced to either TRUE or FALSE; important in computer science and programming initiatives.

**Electromagnetic Induction**: Process where a conductor placed in a changing magnetic field causes the production of a voltage across the conductor.

**Friction Forces**: Forces that resist motion, generated when two surfaces are in contact and slide against each other.

**Grade**: The angle of a slope as measured from the horizontal. Used for describing hills, roads, or railways.

**Gravitational Acceleration**: Acceleration of an object due to the effects of gravity.

**Kinetic Energy (KE)**: Energy of motion. Forms of KE include: vibrational, rotational, and translational motion.

**Law of Conservation of Energy**: The total energy of an isolated system is constant; energy is transferred from one form to another (conserved), but never destroyed.

**Magnetic Field**: Region near a magnet, electric current, or moving charged particle where a magnetic force acts on another magnet, electric current, or moving charged particle; magnetic intensity.

**Magneto-resistance**: Tendency of a material to change the value of its electrical resistance in an externally-applied magnetic field.

**Velocity (v)**: Physical vector quantity that is defined as the speed and direction of an object in motion. (distance / time)

**Work**: Work is performed when an applied force moves an object, and is calculated as the applied force multiplied by the amount of movement of an object. The resulting units are equal to that of the units of energy. (force * distance)
This manual was updated and revised in 2016 by the Center for Technology and Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).