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 of 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 four activities to provide a comprehensive overview of the planning and design of roads for traffic considerations. 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: Quick Fixes for High-Crash Highways**

Activity 1 provides students with an introduction to traffic management and road improvement planning. Students are given five unique scenarios in which road improvement or traffic management techniques are required and must make a decision on which improvements to make based on data and available funds. Students will gain an understanding of traffic problem identification, traffic data analysis, and road improvement opportunity costs.

**Volunteer Topics**

A traffic engineer could discuss real-world traffic management and road improvement scenarios that they have experienced. In addition, they could describe the process necessary to develop solutions for these scenarios. An urban planner could discuss how a well-developed city can avoid many traffic problems encountered in these scenarios.

**Activity 2: Quick Curves**

Activity 2 is a hands-on project showing the importance of curve design. Students will receive a brief demonstration on the impact of speed when navigating curves, then they will use their problem solving skills to design and build the curves. This will be taught with a Quercetti Roller Coaster Mini Rail track by negotiating a series of obstacles using properly designed curves. This activity allows students to validate the importance of calculated decisions when designing roadway curves.
Volunteer Topics

A traffic engineer could touch on curve design considerations not covered in this activity and emphasize the importance of speed on curve design. A physicist could discuss the physics behind curve design through the explanation of centrifugal forces acting on a moving body around a curve. To go into further detail, they could emphasize the importance of minimizing these effects, along with the dangers when they are not properly minimized.

Activity 3: Sharp Curve Ahead!

Activity 3 takes a mathematical approach to explaining curve design. Students will learn equations that are used by engineers to design curves and will explore the concepts that are used to formulate those equations. Students will be guided through an example problem, then perform their own calculations pertaining to road curvature.

Volunteer Topics

A traffic engineer could discuss how they apply these equations in design, while explaining some more advanced techniques that could be implemented. A mathematician or Surveyor could explain how geometry is used in curve design equations and assist students with performing the calculations.

Activity 4: Create a Plan!

Activity 4 allows for students to apply the knowledge they have gained in this module through computer aided design (CAD) software: MicroStation PowerDraft v8i. Students are provided a plan of obstacles that they must navigate by creating roads with known speed limits. These roads must pass through the given intersection points and must be designed properly through the application of engineering equations.

Volunteer Topics

A traffic engineer could explain design considerations not explored in this activity. A surveyor could explain the CAD design process as it applies to them, highlighting how they gather point data on construction sites and stake the construction plans in the field.
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
- National Association of Regional Councils www.narc.org

Throughout this module, students will investigate how traffic engineers design effective roadways, as well as evaluate and improve problematic roadways. In Activity 1, students are presented with a variety of roadway scenarios and must determine what improvements to make given a limited budget. In Activity 2, students will focus on curve design and construct a marble track to visualize the importance of speed when designing curves. Activity 3 will expand on Activity 2 by teaching students how to
calculate a minimum curve radius based on speed limits and the concept of superelevation. Activity 3 leads into Activity 4, where students will implement their knowledge of curve design by planning a series of roads using CAD software. Overall, this module will demonstrate the process of identifying and resolving roadway problems and will introduce the importance of curve design in roadway planning.
National Education Standards

National Science Education Standards: Physical Science

Grades 6-12

Science as Inquiry
- Identify questions that can be answered through scientific investigations.
- 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.

Abilities of Technological Design
- Identify appropriate problems for technological design.
- Design a product.
- Implement a proposed design.
- Evaluate completed technological designs or products.

National Educational Technology Standards for All Students

Basic Operations & Concepts

Technology Problem-Solving & Decision-Making Tools
- Students use technology resources for solving problems and making informed decisions.
- Students employ technology in the development of strategies for solving problems in the real world.
- Standards for Technological Literacy for the International Technology Education Association

Design
- Students will understand the role of trouble shooting, research and development, invention and innovation, and experimentation in problem solving.

The Designed World
- Students will be able to select and use construction technologies.

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: Quick Fixes for High-Crash Highways

Activity Summary

<table>
<thead>
<tr>
<th>Instructor Prep Time</th>
<th>20 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Time</td>
<td>50 minutes</td>
</tr>
<tr>
<td>Grade/Class</td>
<td>9 - 12</td>
</tr>
<tr>
<td>Suggested Activity Grouping</td>
<td>Five groups (three to five students per group)</td>
</tr>
<tr>
<td>Technology</td>
<td>Low Tech</td>
</tr>
</tbody>
</table>
| National Science Education Standards | Formulate and revise scientific explanations and models using logic and evidence  
|                      | Recognize and analyze alternative explanations and models  
|                      | Communicate and defend a scientific argument |

Introduction

In this activity, students step into the shoes of traffic engineers and local government officials to consider highway safety problems. Students should collaborate in groups of three to five to examine five accident locations at intersections and along roadways. Background data is provided to substantiate the problems at each location. The students must evaluate the situations to determine the critical issues and the most cost-effective ways to use their limited budget to reduce accidents at the locations.

Objective

Students will be able to:

- Gain knowledge of how safety problems are determined and documented.
- Demonstrate that anecdotal data is not competent in definitively establishing problems, while numerical data is most effective.
- Become familiar with options for highway improvements, as well as the opportunity cost.

Background

With every decision, there is an opportunity cost and benefit; therefore, students should be warned to weigh each scenario and improvement option carefully. The end goal is to optimize the resulting benefits with the funding available, so students may have to make compromises based on the improvements they can afford to make. All fields of engineering involve budgeting and dealing with tradeoffs, although for the traffic engineers, these decisions are greatly influenced by public opinion.
Activity Expansion Ideas

Hard Times
Activity 1 gives students latitude in choosing one or more of the improvement alternatives at each location due to their sufficient budget. However, in real life, governing bodies and engineers have a limited budget to fix a large number of problems. Safety is always considered to be one of the most important elements in managing traffic locations, although safety budgets do experience cuts.

To mimic the budget cuts that some engineers may have to face, the teacher may choose to reduce the budget available to students. This will cause students to make hard decisions regarding the improvements. In order to compensate for the loss in funds, students may choose to pick a less expensive alternative than desired or leave some high-crash locations without improvement. This alternative can either replace the activity or be done in addition to the original activity.

Role Play Town Meeting
This expansion allows students to realize the different interests present within a community and explore the decision making process. In this expansion, students play the roles of special interest groups. Divide students into groups of no more than six. Each person in the group must play a different role or represent a different interest. You may allow the students to create and develop their own roles or assign them from the list below:

- Politician/ city mayor
- Environmentalist
- Police officer
- Businessperson
- Traffic Engineer
- Concerned Citizen
- City Financial Representative
- Real Estate Developer
- City Utility Worker
- Public Works Administrator

After each student has a role, he or she should develop a short list of their positions on the given topics. Such as, describing what is important to them, what type of safety improvements they would advocate for, what types they would oppose, and their goals for the “town meeting.” They should debate each situation and present their point of view. The group can then decide on their choice for the safety solution. Sometimes having to defend a position that isn’t consistent with their own opinion has more of an impact on students than defending a position that mirrors their own.

Create Your Own Solutions
Students may propose and explain alternate solutions for the “Quick Fix” activity. This gives them the freedom to form their own ideas about how to fix each intersection. Other groups can then evaluate their solutions to decide if they are sufficient for solving the problem.
Locate Local High-Crash Locations
Students can try to identify real-life trouble spots in their town. Students can conduct research of a site by collecting traffic reports from police, local traffic engineers, or State Departments of Transportation. An alternative method of conducting research would be for students to observe traffic themselves and interview bystanders. After determining a solution to the problem, volunteers could help students ‘price’ their solutions. After gaining knowledge of the problems in their area, interested students could also choose to attend a city or county government meeting where highway improvements are being considered. Students may even choose to take part in local decision making by advocating changes at particularly dangerous locations.

How to Determine Safety
Activity 1 deals exclusively with safety problems inherent in highway design, ignoring the influence of the driver and vehicle. As an activity expansion, students may research the influence of driver age, type of vehicle, number of previous crashes, and number of previous traffic convictions on insurance rates. Since insurance rates are based on statistical models of demographics and driving records, rates generally reflect the probability of crashes and the cost of repairs resulting from these crashes. Thus, insurances rates can be a good measure of the safety of a particular car and driver. Students can visit the following websites to find information on how companies set their rates and why they give discounts for certain safety equipment (like antilock brakes.)

http://www.nsc.org National Safety Council
http://www.highwaysafety.org Insurance Institute for Highway Safety
http://www.saferoads.org Advocates for Highway Safety

Students may also wish to visit insurance company websites to determine the cost of insuring themselves when they reach licensing age.
Activity 1: Quick Fixes for High-Crash Highways

Questions

1) Was there ever a reason to do nothing? How would you justify this decision to the public?

Sometimes the cost to fix a problem is simply not worth the benefit, especially when the money spent on that fix could be used to make a more significant change elsewhere. It is often more difficult to justify doing nothing when there is a problem; however, it can be easier if you explain what other options could be implemented instead. In addition, there are some cases where horrible accidents occur under very specific conditions that are not likely to happen again.

2) What do you think was the key to choosing the most serious problems and the most effective solutions?

The students must use their best judgement when making decisions. They should note that often making the necessary improvements means forgoing other options.

3) What would you do differently if you were to do this activity again?

Answers will vary.

4) Were there issues deciding on the best path? Often traffic engineering decisions must be confirmed by a number of people who are often not engineers. Did you use effective communication to explain your point?

Answers will vary. Some groups will get into arguments about what is the correct choice, but arguing is not an effective way to solve an issue. Explain to them that if they regressed into arguing, it means they failed at effectively explaining their point and working with others. Although working in groups can be difficult, working well with others is a skill they will need beyond middle and high school.

Discussion

If we were in an ideal world, there would be enough money to improve all of the high-crash areas that can be definitively identified and funds would be invested based on the traffic engineer’s analysis. However, this is not the case. Often, state and local employees have to consider other important factors. Being a public servant, the traffic engineer sometimes has to adjust their response to meet public opinion. Local, state, and national politicians may have preferences that the traffic engineer must consider when making decisions. Traffic engineers try to keep this sort of influence to a minimum, to ensure public tax dollars are spent wisely.

Scenario Discussions

Scenario 1: Too Many Driveways

This type of commercial driveway problem (also called “access management”) is occurring with alarming frequency in most urban and suburban areas in the United States as a result of development. We can all think of an arterial roadway, one originally designed to take us quickly and efficiently from one activity center to another, which has become bogged down with local traffic traveling to retail stores, strip
malls, fast food restaurants, and other service-oriented businesses. One of the reasons this congestion occurs is due to each business having its own driveway. Every time drivers pass a driveway, they have to decide whether to slow down and pull in, slow down or change lanes to avoid the car turning into the driveway, slow down or change lanes to avoid the car exiting the driveway, or yield to vehicles coming from the opposite direction trying to make a left turn into a business. Thus, each driveway is a decision point. Research has shown that increasing these decision points by 50% increases crashes by 40%. Based on this data, it is easy to see how an arterial road that was like a freeway ten years ago can become today’s driveway nightmare.

Traffic engineers initially try to reduce the number of decision points by closing driveways and making left turns illegal (or closing median crossovers). However, business owners complain loudly about this, and they often have powerful political connections. The traffic engineer’s next best option is installing a traffic signal (if an engineering study says one is warranted); but, in order to avoid stop-and-go tie-ups, the traffic engineer avoids installing too many stoplights. Business owners often want traffic lights to make it easier for patrons to enter their establishments. Although, implementing a light in an unnecessary location adds to congestion and accidents.

In terms of the solutions offered to the students, building the service road (solution 4), will have the greatest impact on both safety and congestion. However, this will be VERY unpopular with business owners and many will fight to stop the project. Closing driveways and the crossover median (Solution 2 and Solution 3) are the next best choices, and, although they also provoke political opposition, they are workable solutions. Finally, lowering the speed limit is the worst choice. From the crash data tables, it can be seen that most crashes occurred at very low speeds anyway, since congested traffic can’t move at free flowing speeds.

Scenario 2: Where the City Meets the Suburbs

To add perspective, this scenario is typical of commuter roads that were originally constructed in rural areas that now accommodate residential traffic going to and from work, school, and business centers. Communities spring up as close to work centers as possible, causing demands on roadways that were not designed for this purpose. In addition, speed limits (and travel speeds) on country roads tend to be faster than in suburban centers, often creating safety problems.

On this roadway, traffic coming from heavily-populated residential areas is in conflict with fast-moving traffic heading from previously rural areas to the city. At this uncontrolled intersection, left turning vehicles often get rear ended by faster moving traffic or broad-sided from both directions by other vehicles.

The best answer, in terms of safety, for this scenario is to install a stoplight (Solution 1). This reduces the number of potential vehicle conflicts. However, it also increases congestion, since vehicles must stop at the new light and then move on to the nearby light at the next intersection, possibly stopping there as well. As it is not uncommon for safety solutions and improvements to have a deleterious effect on congestion, these two factors must be weighed against one another. Due to these factors, the second best solution is to lower the speed limit coming from the country to 35 mph (Solution 2). This, at least, should reduce the severity of the crashes. Enforcing the speed limit for vehicles coming from the city might have an impact on crash severity by keeping impact speeds down; however, no one has established that drivers are speeding in this area. If there is no speeding problem, spending money for
police enforcement will accomplish nothing. Finally, since this problem is not caused by the roadway being curved, straightening the road (Solution 4) is the worst selection.

Scenario 3: Interstate Backup

Even some interstate roads are “under-designed” for current conditions. Almost every big city has an interstate loop that was once the best way to get quickly from place to place but is now heavily congested with backups occurring on the exit ramps. At rush hour on this exit, over 600 vehicles need to turn left each hour. Many must wait a considerable amount of time to find an opening in traffic to make the turn, preventing cars from turning right and causing traffic to build-up. Some turn right and then make a U-turn at a gas station down the road, therefore circumventing the problem, and many drivers who want to turn right from this one-lane exit ramp are unwilling to wait their turn and instead use the shoulder as a right-hand turn lane. Police “hearsay” is presented as evidence of a crash problem involving the vehicles turning left. Citizen complaints appear to document a crash problem with people making U-turns at the gas station.

The best resolution to this problem is installing a traffic signal at the problem intersection (Solution 1). This would allow traffic exiting the interstate to make either a left or right turn with greater ease and would clear up congestion on the exit ramp during peak hours. This would also resolve the concerns presented by the police and local citizens, and have a positive impact on public relations in the area. However, this solution would increase congestion on the secondary road as cars may have to come to a complete stop. Expanding the off-ramp to two lanes (Solution 2) would allow traffic taking a right off of the exit ramp to do so more quickly, clearing some congestion from the off-ramp and negating the occasional problem of fender-benders and sideswipe crashes that result from cars driving on the shoulder. However, cars will still have difficulty turning left, leaving the safety concern presented by police. Also, a majority of congestion from the off-ramp will still be present and wouldn’t solve the U-turn issue at the gas station, upsetting the business owners.

Solution 3, installing high-visibility street lighting to make left-turning vehicles more visible, may reduce crashes at the intersection and resolve police concerns but will do nothing to solve the off-ramp congestion problem and the U-turn situation. Solution 4, closing the median at the gas station, is the worst option. There is no evidence to support that this will make the intersection safer; rather, it will move the U-turn situation to another business down the road, potentially making the off-ramp more congested. Solution 4 could also make it more difficult for customers to visit the gas station.

Scenario 4: Watch Out for Fog

Scenario 4 describes a disturbing fatal crash that affects us as citizens, parents, and animal lovers. However, this crash is a “fluke.” A number of extremely rare circumstances, such as fog and brake failure, drew several very poignant groups of riders (the children, the mother, and the horse) together tragically. It is unlikely that all these conditions will ever come together again at this location. In fact, there hasn’t been another crash here in the last eight years. A lot of money could be spent on fog warning systems and traffic lights on a very low volume road with almost no fog and no conflicting traffic and nothing would be gained for the effort. The best solution, then, is to do nothing (Solution 5) and concentrate our efforts in places where improvement can be achieved.

Another point in this crash involves a statement one often hears: “If it saves just one life, it’s worth it.” Traffic engineers and governing bodies try to maximize the impact their funds have. In doing so, they may pass over locations where the odds of being able to avoid a single fatality—like the terrible one
described here—are low in order to invest in a location with better odds of improving safety and reducing injury crashes.

Traffic Engineers increase their odds of being effective by asking the following questions:

1. Is there really a problem at this location?
2. Is this problem worse (more crashes or more serious crashes) than the other locations being evaluated?
3. Do we have real data to prove that the problem is worse, not just this year, but over several years?
4. Are there solutions at our disposal that can directly address these needs?
5. Will these solutions be able to not adversely affect safety at nearby locations or worsen congestion?

Scenario 5: Blind Curve in the City

Many towns that outgrew their central business districts (CBDs) have later restored them for retail and recreational use. Again, the roadways in and around the CBD were not built for the level of traffic that the newly restored downtown attracts. Due to this, the four-lane road around the CBD is very curved and has a traffic light located just around the curve. The curve preceding the light is so tight that when drivers are doing the speed limit, 35 mph, they don’t have enough time (or distance) to stop once they see the light, even if they apply their brakes immediately. This is what traffic engineers call a “sight stopping distance” problem, and it’s fairly common, since roads designed years ago didn’t take current speeds into account. The faster the speed, the more room you need to stop. The more the curve keeps you from seeing obstacles in your way, the less time you will have to stop if you need to.

The best solution to this problem is to make Hill Street one-way southbound (Solution 1). That way, cars won’t be able to travel northbound through the curve, rear-ending the vehicles that are stopped at the light. This also eliminates conflicts between northbound vehicles and turning southbound vehicles, since they are all traveling in one direction. However, this solution may affect traffic patterns to the popular downtown area. For the next best solution, it’s a toss-up as to whether Solution 4 (putting up a sign warning northbound drivers that there is a light ahead) or Solution 2 (eliminating left turns at the intersection of Hill Street and Center Street) is better. Solution 4 should reduce the rear-end crashes at the light, but many people don’t slow down for or even read warning signs. Solution 2 should reduce left-turn crashes, but not all drivers obey such signs. The worst choice is to close Center Street to truck traffic (Solution 3). Hill Street is already closed to truck traffic, and since a truck safety problem on Center Street has not been documented, making this change is unlikely to have any effect.
Activity 1: Quick Fixes for High-Crash Highways

Introduction
In this activity, you will consider highway safety problems from the point of view of traffic engineers and local government officials. Working in groups of three to five, you will examine five accident prone locations at intersections and along roadways. Data are provided to substantiate the problems associated with each location, you must choose which problems to address and how to use your limited budget to have the greatest impact on lessening crashes.

Objective
You will be able to:

- Familiarize yourself with the work of traffic engineers and the ways they document and isolate safety problems.
- Demonstrate that anecdotal data is least effective in definitively establishing problems, while actual numerical data is most effective.
- Familiarize yourself with the types of highway improvements commonly available to address safety problems and the cost of those improvements.

Background
Certain sections of roadway are more troublesome than others, and it is the job of traffic engineers to identify these locations. Often, numerous sections of road require improvement to reduce congestion or increase safety. Traffic engineers must develop solutions to correct these issues. However, there is often limited funding for roadway improvements, if any at all. A limited number of problems can be addressed in a given year, so funding must be spent where the best results will be produced.

In order to address these problems, we must first find out which areas are in need of the most improvement. Often traffic engineers must play detective in order to determine how many crashes is “too many,” and while some would say that any crash is “too many,” often times there is not enough money in the budget to make every necessary improvement. Traffic engineers are then left with the problem of where they can spend their limited resources. Should they implement changes to a road with a low amount of traffic, but with a high crash ratio, or should they instead change a road with more traffic and a lower crash ratio? As with many decisions in engineering, the answer is not straightforward. It’s the job as a traffic engineer to figure out where problems are most problematic.

One of the best ways to analyze a road is to compare it to other roads to see if it is significantly better or worse. A good way to compare roadways is to analyze two similar roads or intersections, then cross-reference the findings with historical data to determine if it has been significantly worse for an extended period of time. Thus, the traffic engineer looks at the accident trends—whether the number of crashes and crash rates are consistently going up or are consistently high—compared to similar locations.

So how do we choose which changes to make? The first and most important step is to look at the problem and ask, "Why is this an issue here?" You want to understand and analyze the root of the problem—not simply treat the symptom—often the root is much more difficult to understand. For example, imagine that cars regularly get hit turning left onto a road with a speed limit of 35 mph
because the drivers on that road often are driving significantly faster. While you could solve the issue by placing police officers at that location to monitor speed, the root of the issue may be that down the road the speed limit is 45 mph, and drivers don’t like to adjust their speed. By reducing the speed limit to 35 mph, the drivers would be traveling slower and would be less likely to get into an accident, without spending the money required to post an officer.

**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash posters</td>
<td>5</td>
</tr>
<tr>
<td>Ledger</td>
<td>1 per group</td>
</tr>
<tr>
<td>Results cards</td>
<td>1 set per poster</td>
</tr>
</tbody>
</table>

**Setup**

Set up the posters in different areas around the room. They should be far enough apart so that each group can see and discuss the problem without interfering with other groups’ work. Distribute ledgers to each group.

**Procedure**

1. Form five small groups with approximately 3 to 5 students in each group.
2. As a group of traffic engineers, your job is to decide how to improve traffic safety in your community. Groups will rotate between all five scenarios, reading about each problem area and reviewing possible solutions. Your goal is to reduce as many accidents as possible within your allotted budget.
   
   As you move from scenario to scenario, read and discuss all the information on the poster, but do not make any final decisions about spending your road improvement budget just yet.

3. After reviewing all five scenarios, meet with your group to discuss how to spend your budget. You may decide to invest all your money at one location, or you may decide to invest in multiple projects. You may also choose more than one solution for a scenario. Any unbudgeted and unused money will be re-appropriated by the local governing body for other purposes. Be wise in your spending and try to reduce as many accidents as possible by funding as many improvement projects as your budget allows.

4. Use the ledger to record your expenses for any road improvements. Your group’s beginning balance is $425,000, or as otherwise specified by your instructor.

5. Rotate to each of the five scenarios again in order to make your final decisions. After your group agrees on a solution for a scenario, record the decision in your ledger.

6. As a class, discuss what options were chosen by each group. Read the Results cards together to see how each groups design decisions affected traffic at the location.

7. Record your group's results on the Highway Improvement Tallies table in the *Research Notes* section.

8. Finally, answer the questions in the Research Notes section.
Scenario 1: Too Many Driveways

Since the 1950s, the central business district of a growing city has deteriorated, causing businesses to move north, outside of the city. In this area, there was vacant land that was less expensive and more plentiful. Since this area was still open country, no one worried much about where or how many driveways the businesses had. Expansion continued and property values increased until this was a very attractive location to own a business, the local owners began subdividing their property for more businesses. Eventually, the roadway was bordered by wall-to-wall businesses and too many driveways. Now the road is highly congested.

**Description**

- Heavily traveled four-lane, divided highway, with retail establishments, fast food and other restaurants, gas stations, motels, and various other businesses
- Length of segment: 1,500 feet
- Speed Limit: 45 mph
- Traffic Volume: 45,000 vehicles per day (very high)
- Each business has at least one driveway

![Figure 1-1: Too Many Driveways Site Depiction](image-url)
Crash Problem
This area has a crash rate that is three times higher than any other four-lane divided highway in the county. Crash statistics from the last five years have been recorded and compiled into Table 1-1 and Figure 1-2.

Table 1-1: Speed and Severity of Crashes in the last 5 years

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Property Damage Crashes</th>
<th>Minor Injury Crashes</th>
<th>Serious Injury Crashes</th>
<th>Fatal Crashes</th>
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<td>0 – 9</td>
<td>12</td>
<td>0</td>
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<tr>
<td>10 – 19</td>
<td>10</td>
<td>0</td>
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</tr>
<tr>
<td>20 – 29</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30 – 39</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40 – 49</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50 mph and faster</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 1-2: Configuration of Crashes in the last 5 years
**Improvement and Costs**
Review and discuss the following improvement options.

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Solution</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement 1</td>
<td>Lower speed limit to 25 mph</td>
<td>$1000</td>
</tr>
<tr>
<td>Improvement 2</td>
<td>Close off every other driveway, making the businesses share driveways</td>
<td>$2500</td>
</tr>
<tr>
<td>Improvement 3</td>
<td>Close the median so that vehicles cannot cross over</td>
<td>$75,000</td>
</tr>
<tr>
<td>Improvement 4</td>
<td>Build a service road behind the line of businesses, so that entrance to all the businesses would be on a service road rather than on the main road</td>
<td>$425,000</td>
</tr>
<tr>
<td>Improvement 5</td>
<td>Do nothing</td>
<td>$0</td>
</tr>
</tbody>
</table>
Scenario 2: Where the City Meets the Suburbs

This rural area has developed into a “bedroom community” for people who commute into the city for work. As people moved into the area, more businesses have sprung up, mainly to the east of the residential area, whereas the land on the west side has remained primarily rural. Now, the residents use the main road, not only to commute to work, but also to get to shopping and recreational areas.
Description
• A two-lane, north-south subdivision road runs into a busier, east-west primary road at a T-intersection.
• There is a traffic signal about 30 feet east of this intersection between the primary road and another busy, multiple-lane road.
• The subdivision road is straight, while the busier, primary road is gently curved.
• There is currently a yield sign on the subdivision road at the intersection with the busier primary road.
• In the westbound lane of the primary road, there is an exclusive right-turn lane, turning into the residential area.
• The speed limit on the primary road to the east of the residential feeder is 35 mph. To the west of the residential feeder, the speed limit is 55 mph.

Crash Problem
Residents turning left from the residential street toward the city are being struck by westbound traffic on the primary road, which is resulting in cross-traffic crashes. These “T-bone” or angle crashes can produce serious injuries, especially since vehicles speed up after they go through the traffic light anticipating the 55 mph speed limit. There are also conflicts between vehicles turning right from the subdivision road and those going westbound on the primary road. In addition, a number of the residents have complained about the westbound traffic sometimes using the exclusive right-turn lane to illegally go straight, causing near misses with other traffic.

Crash statistics from the past five years have been recorded and compiled in Table 1-2 and Figure 1-4.

<table>
<thead>
<tr>
<th>Crash Direction (turns from subdivision road)</th>
<th>Fatal Crashes</th>
<th>Injury Crashes</th>
<th>Property Damage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left turning vehicle and east bound traffic (angle)</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Left turning vehicle and west bound traffic (angle)</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Right turning vehicle with west bound traffic</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>5</td>
<td>11</td>
<td>16</td>
</tr>
</tbody>
</table>
Improvements and Costs
Review and discuss the following improvement options.

<table>
<thead>
<tr>
<th>Improvement Options and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
</tr>
<tr>
<td><strong>Improvement 1</strong></td>
</tr>
<tr>
<td><strong>Improvement 2</strong></td>
</tr>
<tr>
<td><strong>Improvement 3</strong></td>
</tr>
<tr>
<td><strong>Improvement 4</strong></td>
</tr>
<tr>
<td><strong>Improvement 5</strong></td>
</tr>
</tbody>
</table>
Scenario 3: Interstate Backup

About 12 years ago, a new interstate exit was built in a rural area about two miles away from a growing town. Since then, businesses from the town have spread toward the exit, and while the area is still mostly rural, traffic has increased significantly since this interstate is now the most convenient way to get from one end of the town to the other. Therefore, the two-lane rural road at the interchange is handling more traffic than was originally anticipated.

Figure 1-5: Interstate Backup Site Depiction

Description

- Intersection between an Interstate highway and a secondary road with a “diamond” interchange (see Figure 1-5).
- At the bottom of the off-ramp is an intersection without a signal, with one lane exiting from the interstate and intersecting with a two-lane secondary road.
- Most traffic would like to turn left (westward) at the bottom of the ramp.
- The off-ramp from the Interstate experiences backups during peak evening hours.
**Crash Problem**
An evening peak-hour traffic count revealed more than 638 left-turning vehicles per hour from the ramp to the secondary road. Some traffic made a right turn at the bottom of the ramp and then made a U-turn at a gas station about one-quarter mile down the road to go west and avoid the left turn. In addition, traffic generally gets backed up onto the Interstate, and some vehicles travel down the ramp’s shoulder to turn right at the intersection and make the U-turn at the gas station. These vehicles interfere with traffic legally turning right.

One local police officer reported that they “regularly” investigate crashes between vehicles turning left from the off-ramp and those going west on the secondary road. He also stated that the police occasionally investigate rear-end and sideswipe crashes between vehicles turning right from the ramp and those turning right from the shoulder. The owner of the gas station has complained that many people are making dangerous left turns onto her property, and citizens have made the same complaint.

**Improvements and Costs**
Review and discuss the following improvement options.

<table>
<thead>
<tr>
<th>Improvement Options and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
</tr>
<tr>
<td><strong>Improvement 1</strong></td>
</tr>
<tr>
<td><strong>Improvement 2</strong></td>
</tr>
<tr>
<td><strong>Improvement 3</strong></td>
</tr>
<tr>
<td><strong>Improvement 4</strong></td>
</tr>
<tr>
<td><strong>Improvement 5</strong></td>
</tr>
</tbody>
</table>
Scenario 4: Watch Out for Fog

In an upscale community just outside the city, two secondary roads meet at a T-intersection; a high-volume main road and a low-volume narrow road. The main road connects this area with schools and shopping and is highly traveled. The area is very hilly, and the intersection at which the two roads meet is at the bottom of a hill by a stream. Under certain conditions (about two days a year), the intersection becomes foggy.

**Description**

- The traffic volume on the major road is 12,500 vehicles per day. The volume on the narrow road is just 750 vehicles per day.
- The narrow road is basically flat with a number of very sharp s-curves.
- The T-intersection between the two-lane roads has a stop sign on the narrow road.
- The speed limit on the main road is 45 mph. However, since the T-intersection is in a valley, downhill traffic in both directions averages about 50 mph.
- The speed limit on the narrow road is not posted, but the default speed limit is 55 mph.

Figure 1-6: *Watch Out for Fog* Site Depiction
Crash Problem
There has been one crash at this intersection in the last eight years. A day-school minivan was traveling on the main road, returning from a field trip to a local farm. There were five students in the van, all five-and six-year-olds. Conditions at the intersection were foggy. An SUV towing a loaded horse trailer was stopped at the stop sign on the narrow road. The minivan was traveling at about 35 mph due to the fog ahead. The SUV pulled out into the intersection at about 5 mph. The minivan had plenty of time to stop, but its brakes failed, and it struck the horse trailer. The driver of the minivan and two of her passengers were killed. One of the passengers was paralyzed and two were uninjured. The SUV driver was also uninjured, but the horse was injured and had to be put down. Everyone in the crash was wearing their seat belt.

Improvements and Costs
Review and discuss the following improvement options.

<table>
<thead>
<tr>
<th>Improvement Options and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
</tr>
<tr>
<td>Improvement 1</td>
</tr>
<tr>
<td>Improvement 2</td>
</tr>
<tr>
<td>Improvement 3</td>
</tr>
<tr>
<td>Improvement 4</td>
</tr>
<tr>
<td>Improvement 5</td>
</tr>
</tbody>
</table>
Scenario 5: Blind Curve in the City

One of the main roads running through the central business district of a town has many cross streets and traffic lights. The city was originally built in 1906 on a flat hilltop, but it expanded to include the sloped area that surrounded it. Some of the original streets were built with sharp curves in order to go around the business district while remaining on the hilltop. Hill Street, a four-lane street, curves around the hilltop portion of the central business district and intersects with Center Street, a two-lane street.

Figure 1-7: Blind Curve in the City Site Depiction
Description
- Four-way intersection between Hill and Center Streets, with a traffic light, preceded by a sharp vertical curve.
- Heavily traveled business district.
- Distance from the beginning of the curve to the traffic light is 121 feet.
- Just past the traffic light (on the north side of the intersection), Hill Street drops off down a steep hill.
- Trucks are no longer permitted on Hill Street.
- Speed limit is 35 mph. Most drivers obey the speed limit at this intersection.

Crash Problem
Vehicles traveling northbound around the curve on Hill Street are having difficulty seeing the traffic light at the intersection because a building blocks the view of it, causing many cars to not see traffic backups when the light is red. Citizens are reporting that they often see cars slamming on their brakes to come to a stop when this situation occurs. Some who slam on their brakes do not stop in time, resulting in numerous documented rear-end collisions at the intersection.

Additionally, northbound vehicles turning left off of Hill Street onto Center Street are being hit by southbound vehicles at the intersection. Citizens are reporting that it is sometimes difficult to see approaching southbound vehicles from the left turn lane due to the sharp grade of the hill north of the intersection. Vehicles making left turns when Hill Street has a green light in both directions are being struck at an angle by southbound vehicles. Most of these crashes have been caused by southbound compact cars that cannot fully see the intersection while climbing the hill.

Collision data from the past three years has been compiled in Table 1-3. Table 1-4 lists required stopping distance data at various speeds.

<table>
<thead>
<tr>
<th></th>
<th>Rear-end Crashes</th>
<th>Angle Crashes with Left Turning Vehicles</th>
<th>Head-on Crashes</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southbound vehicles</td>
<td>1</td>
<td>14</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Northbound vehicles</td>
<td>15</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Westbound vehicles</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Eastbound vehicles</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16</td>
<td>16</td>
<td>0</td>
<td>32</td>
</tr>
</tbody>
</table>
Table 1-4: Total Stopping Distances Required at Various Speeds

<table>
<thead>
<tr>
<th>Speed</th>
<th>Cars</th>
<th>Pickup Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 mph</td>
<td>44 ft.</td>
<td>47 ft.</td>
</tr>
<tr>
<td>25 mph</td>
<td>85 ft.</td>
<td>95 ft.</td>
</tr>
<tr>
<td>35 mph</td>
<td>135 ft.</td>
<td>155 ft.</td>
</tr>
<tr>
<td>45 mph</td>
<td>195 ft.</td>
<td>228 ft.</td>
</tr>
<tr>
<td>55 mph</td>
<td>265 ft.</td>
<td>313 ft.</td>
</tr>
</tbody>
</table>

Improvements and Costs
Review and discuss the following improvement options.

<table>
<thead>
<tr>
<th>Improvement Options and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
</tr>
<tr>
<td><strong>Improvement 1</strong></td>
</tr>
<tr>
<td><strong>Improvement 2</strong></td>
</tr>
<tr>
<td><strong>Improvement 3</strong></td>
</tr>
<tr>
<td><strong>Improvement 4</strong></td>
</tr>
<tr>
<td><strong>Improvement 5</strong></td>
</tr>
</tbody>
</table>
Activity 1: Quick Fixes for High-Crash Highways

Ledger

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description of Expense</th>
<th>Expense</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Beginning Balance: $</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

Highway Improvement Tallies

<table>
<thead>
<tr>
<th>Problem</th>
<th># Crashes Reduced</th>
<th># Crashes Increased</th>
<th>Other Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Too Many Driveways</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Where the City Meets the Suburbs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Interstate Backup</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Watch Out for Fog</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Blind Curve in the City</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions

1) Was there ever a reason to do nothing? How would you justify this decision to the public?

2) What do you think was the key to choosing the most serious problems and the most effective solutions?

3) What would you do differently if you were to do this activity again?

4) Were there issues deciding on the best path? Often traffic engineering decisions must be confirmed by a number of people who are often not engineers. Did you use effective communication to explain your point?
Activity 2: Quick Curves

<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>
</tbody>
</table>
| National Science Education Standards | Science as inquiry  
|                   | Identify problems for technological design  
|                   | Design a product  
|                   | Implement proposed design  
|                   | Evaluate product |

Introduction

This activity will demonstrate the importance of curve design speed and provide space for innovation and independent decision-making. Students will be able to test their own roadway designs, using the Quercetti Roller Coaster Mini Rail tracks (Figure 2-1) to validate the importance of calculated decisions that engineers make when designing roadway curves.

The activity will begin with a demonstration regarding the importance of speed when navigating a curve. After the demonstration, students will be broken into groups and will be tasked with using the supplied pieces of track to create a path through an obstacle course (Figure 2-4). Obstacle courses are recommended to be constructed in advance by the instructor.

Objective

Students will be able to:

- Understand the process behind curve designs.
- Explore the relationship between speed and curve safety.
- Demonstrate the impact of curve design on roadways.

Background

Curves on the road need to be designed in order to accommodate the speed of the road. As the speed of the road increases, the radius of the curve needs to increase in order for the road to be traveled safely. Often if a curve cannot be increased in size, the road will have a reduced speed limit around the curve to allow for safe travel. In this activity, students will explore the relationship between speed and curve safety.
Before class begins, an instructor or volunteer should construct a demonstration curve (Figure 2-2) and create an obstacle course (Figure 2-3) for students to navigate (Figure 2-4). The goal of the demonstration curve is to show the students how the track pieces connect and how too sharp a curve at too high of speeds cause the marble to jump out of the track. Begin with the ramp at a height that causes the marble to fly off the track (three M6 pillars tall), and then shorten the ramp until the ball safely makes it around the track (one or two M6 pillars tall). Duct tape may be needed to hold the base of the track in place.

The demonstration track requires:

- (3) M6 pillars
- (2) L1 Connectors
- (2) Base pieces
- (5) Joints
- (2) Junctions
- (2) Track Supports
- (3) Track Connectors
- (3) Straight Tracks
- (1) Curved Track
- Duct Tape
Figure 2-3: Sample Obstacle Course

Figure 2-4: Sample Track Configuration
Activity Expansion Ideas

As referenced in the *Research Manual*, superelevation is present on roadways and even NASCAR raceways (or speedways). This could be used as an opportunity for students to research the application and necessity of large superelevations on raceways. This information could be relayed through either oral or written reports. Some of the example topics that could be addressed are the definition of superelevation, the use of superelevation on raceways, the necessity of superelevation on raceways, and the location of the largest superelevation applied to a raceway.

The track kit comes with a light plastic marble. A solid steel ball bearing could be substituted and the tracks could be retested using a different mass. A class discussion could center around how objects of different mass require different speeds when navigating curves.
Activity 2: Quick Curves

Questions

1) **What effect did the speed of the marble have on its ability to safely travel along the curve?**

   As the speed increases, the marble becomes more likely to fall out of the track around the curve. If the sidewall was not on the track, the marble would fall out easier than it does with the sidewall present.

2) **On the curved piece of track, there are sidewalls to help keep the marble in the track. What options have you seen on a road curve to keep cars on the road?**

   While students may answer guard rails, a better answer would be superelevation. (Students may be unfamiliar with this term, but should hopefully be familiar with the idea.) If required, explain that guard rails can help stop vehicles from going off the road, but a better solution is to angle the road so that the cars don’t crash into the barrier in order to stay on the road.

3) **Why do you think that some roads have a reduced speed limit around curves?**

   As we have seen, the speed of the marble around the track has a significant effect on whether the marble will remain on the track. As the speed of a vehicle increases, the radius of a curve must increase significantly to remain safe for travel. The radius is not always able to be increased, resulting in the need to reduce the speed limit to match the curve’s radius.

Discussion

Some possible discussion topics include why roads cannot always follow a straight, flat path. For example, if there was a road in a mountainous region, the road would have to be adjusted to the elevation changes, since it would be cost prohibitive to add and remove enough fill to flatten the entire road. In general, the less material that needs to be added or removed and the less obstacles to overcome, the cheaper the road will be to build.
Activity 2: Quick Curves

Introduction
The radius of a road curve is an important design consideration because if the radius is too small, cars will have to slow down to safely travel around it. If the curve is too large, it will be difficult, costly, or even impossible to build. In order to create proper road curves, designers need to know certain parameters, one of which is the speed that a car will travel on the road. As the speed of a vehicle increases, the size of the curve must increase in order for the road to remain safely maneuverable; otherwise, the curve must have a reduced speed limit. This activity will explore the effects that speed has on a curve design.

You and your classmates will use Quercelli Roller Coaster Mini Rail tracks to navigate obstacle courses created by your instructor. The success of your track depends on curve designs that can effectively keep the marble on the track.

Objective
You will be able to:

- Understand the process behind curve designs.
- Explore the relationship between speed and curve safety.
- Demonstrate the impact of curve design on roadways.

Background
Curves on the road need to be designed in order to accommodate the speed of the road. As the speed of the road increases, the radius of the curve needs to increase in order to be traveled safely. Often if a curve cannot be increased in size, the road will have a reduced speed limit around the curve to allow for safe travel.

When traveling along curves in a road, it can sometimes feel like the car is being pulled off the road. This is because as you travel, your body wants to continue moving in a straight line, while the car is forcing your body to move sideways with the curve. This effect is known as a centrifugal force and is more apparent when traveling at higher speeds. When designing roads, there are certain factors that engineers take into account to ensure that cars stay on the road despite this effect; such as the design speed, curve radius, and superelevation. Superelevation is when a roadway is sloped through a curve, similar to the slopes of a NASCAR track, although we don’t use quite as steep of curves in highway design.

Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quercelli Roller Coaster Mini Rail Kit</td>
<td>1</td>
</tr>
<tr>
<td>Ball bearings</td>
<td>2</td>
</tr>
<tr>
<td>Obstacles</td>
<td>As Needed</td>
</tr>
<tr>
<td>Duct Tape</td>
<td>As Needed</td>
</tr>
</tbody>
</table>
The contents of the *Quercelli Roller Coaster Mini Rail Kit* will be evenly divided between obstacle courses:

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>M6 pillar (tall)</td>
<td>1</td>
</tr>
<tr>
<td>M2 pillar (mid-size)</td>
<td>3</td>
</tr>
<tr>
<td>M3 pillar (short)</td>
<td>9</td>
</tr>
<tr>
<td>L3 connector (tall)</td>
<td>1</td>
</tr>
<tr>
<td>L1 connector (short)</td>
<td>13</td>
</tr>
<tr>
<td>Joints</td>
<td>24</td>
</tr>
<tr>
<td>Track supports</td>
<td>9</td>
</tr>
<tr>
<td>Junctions</td>
<td>9</td>
</tr>
<tr>
<td>Track connectors</td>
<td>36</td>
</tr>
<tr>
<td>Base pieces</td>
<td>6</td>
</tr>
<tr>
<td>Marbles (2 sizes)</td>
<td>8</td>
</tr>
<tr>
<td>Curved tracks</td>
<td>12</td>
</tr>
<tr>
<td>Straight tracks</td>
<td>20</td>
</tr>
<tr>
<td>Instruction manual (with examples)</td>
<td>1</td>
</tr>
<tr>
<td>Obstacles</td>
<td>As needed</td>
</tr>
<tr>
<td>Duct Tape</td>
<td>As needed</td>
</tr>
</tbody>
</table>

**Setup**

Your instructor will first perform a demonstration on the effects of speed when navigating a curve. After this demonstration, the class will be broken into groups and the contents of the *Quercelli Roller Coaster Mini Rail Kit* will be evenly distributed. Obstacle courses will be presented by your instructor for your groups to maneuver.

**Procedure**

Use your imagination to develop a track through your obstacle course. In order for your track to be successful, the marble must be able to navigate the entire course without falling off the track. If you are having trouble accomplishing this, try to reduce the speed of the marble by changing column heights. You may find it useful to brainstorm and sketch your ideas on a sheet of paper prior to attempting the course. Try to minimize the amount of material that you use, if possible. Just like real-world road curves, tracks using minimal materials are the most efficient, and, therefore, the most desired. Once you have constructed a successful track for your obstacle course, show your instructor. If time allows, you may attempt to navigate additional obstacle courses.
Activity 2: Curve Ahead!

Questions

1) What effect did the speed of the marble have on its ability to safely travel along the curve?

2) On the curved piece of track, there are sidewalls to help keep the marble in the track. What options have you seen on a road curve to keep cars on the road?

3) Why do you think that some roads have a reduced speed limit around curves?

Discussion Notes
Activity 3: Sharp Curve Ahead!

Activity Summary

<table>
<thead>
<tr>
<th>Instructor Prep Time</th>
<th>20 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Time</td>
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<td>Grade/Class</td>
<td>9 - 12</td>
</tr>
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<td>Suggested Activity Grouping</td>
<td>Individual</td>
</tr>
<tr>
<td>Technology</td>
<td>Low Tech</td>
</tr>
</tbody>
</table>
| National Science Education Standards | Formulate and revise scientific explanations and models using logic and evidence  
Recognize and analyze alternative explanations and models  
Communicate and defend a scientific argument |

Introduction

This activity will teach students the basics of horizontal curve design by examining terminology and definitions. By exploring the factors involved in curve design, students will understand how the dimensions of a curve affect traffic safety. Students will gain exposure to the equations that are pertinent to the design of a road by reading the background information and working through an example problem. At the end of this activity, students will practice the concepts they've learned by answering the questions in the Research Notes section.

Note: This activity relies on advanced math skills and, as such, is recommended for more advanced students.

Objective

In this activity, students will:

- Learn the design requirements of road curves.
- Understand how roadway plans are created.

Background

Engineers consider factors such as speed, angle of intersection, and degree of curvature when designing curves, as well as state and federal design criteria. While the previous activity explored the effects of speed on curve design, this activity will expand upon this in a more technical manner and introduce the ideas of degree of curvature and angle of intersection.
Activity Expansion Ideas

In this activity, students learn about horizontal curves on a roadway and how they are designed. If time permits, students could research a modified, simple horizontal curve: spiral curves. To provide a bit of an introduction, spiral curves were originally implemented on railroads to smooth the transition from the tangent rail to the curve and to minimize the wear and tear on the tracks. Drivers naturally execute a spiral transition with their vehicles through the process of gradually turning their steering wheel in and out of a curve. When students conduct their research, a few topics that could be explored are the history of spiral curves, the application of spiral curves, and the calculations associated with spiral curves.
Activity 3: Sharp Curve Ahead!

Questions

1) A proposed road is being designed with an intersection angle of 50 degrees and a degree of curvature of 10 degrees. What would the radius of this curve be? Round your answer up to nearest whole number.

\[
D = 10^\circ \\
\Delta = 50^\circ \\
r = \? \\
\]

\[
r = \frac{36000}{2\pi D} = \frac{36000}{2\pi(10)} = 573 \text{ ft}
\]

2) A road has an intersection angle of 30 degrees and a degree of curvature of 8 degrees. What is the length of this curve? Round your answer up to nearest whole number.

\[
D = 8^\circ \\
\Delta = 30^\circ \\
L = \? \\
\]

\[
r = \frac{36000}{2\pi D} = \frac{36000}{2\pi(8)} = 716.2 \text{ ft}
\]

\[
L = \frac{r\Delta \pi}{180} = \frac{(716.2)(30)\pi}{180} = 375 \text{ ft}
\]

3) Given a road with a minimum degree of curvature of 8 degrees, a design speed of 45 mph, and no superelevation, what would be the minimum design radius? Refer to Table 3-1 for friction factor. Round your answer up to nearest whole number.

\[
D = 8^\circ \\
v = 45 \text{ mph} \\
e = 0 \\
r = ? \\
\]

There is enough information presented in this problem to solve for minimum radius using both the minimum radius formula and the degree of curvature formula. If we solve both equations, we find that different answers are achieved. The larger of the two values must be taken as the minimum radius, so therefore \( r = 900 \text{ ft} \) is the correct answer.

\[
r = \frac{v^2}{15(0.001e + f_s)} = \frac{45^2}{15(0.01(0) + (0.15))} = 900 \text{ ft}
\]
\[ r = \frac{36000}{2\pi D} = \frac{36000}{2\pi(8)} = 716 \text{ ft} \]

4) Which of the following options would cause a turn to become “smoother”?
   a. Increasing the Radius of Curve
   b. Increasing the Degree of Curvature

5) What effect does the design speed have on the sharpness of a curve?

As the design speed of a road increases, the required radius increases at an exponential rate. This effect is somewhat compounded by the change in friction factor as the design speed increases.

Discussion

Discuss the geometry that goes into the degree of curvature and arc length equations. Explain where the values in the equations come from. A surveyor could discuss stationing more in depth, especially its use in highway plans and how those plans are staked out on a job site.
Activity 3: Sharp Curve Ahead!

Introduction
This activity will explore the basics of horizontal curve design by examining terminology and definitions associated with road design. By exploring the factors involved in curve design, you will learn how the dimensions of a curve affect traffic safety. You will gain exposure to the equations that are pertinent to the design of a road by reading the background information and working through an example problem. At the end of this activity, you will apply the concepts you’ve learned by answering the questions in the Research Notes section.

When designing curves, engineers consider factors such as speed, angle of intersection, and degree of curvature, as well as state and federal design criteria. While the previous activity explored the effects of speed on curve design, this activity will expand upon that gained knowledge through an introduction of degree of curvature and angle of intersection.

Objective
In this activity, you will:

- Learn the design requirements of road curves.
- Understand how roadway plans are created.

Background
A driver is speeding along a roadway when a curve appears ahead. As the car proceeds around the curve, the driver feels a force pulling him or her toward the outside of the curve. This means that the driver is traveling around the turn faster than the design speed. Typically, these curves are designed to be large enough so drivers won’t feel this force pulling on them. Often if there are constraints that require the curve to be small, the speed limit around the curve will be reduced to compensate for the reduced radius. In addition, superelevation, which is the cross-slope (transverse incline) of a roadway around a curve, can be added to a road to help offset curve size limitations. Superelevation allows vehicles to hold increased traction around a curve at higher speeds, thus the curve radius can be reduced.

This activity will examine the process for designing road curves and the equations used to calculate them. A road will be examined in order to define and understand the terms used by engineers.

Imagine if every time a road needed to switch directions, drivers had stop at an intersection, such as depicted in Figure 3-1. The drivers would need to stop or significantly slow down each time and make a sharp turn. Obviously, this isn’t very practical. Instead, road designers use gentle curves on the road, but how is the size of the curve determined?
There are a few pieces of data required to create a proper curve: the Point of Curve (also known as the Point of Curvature), Point of Intersection, and Point of Tangent. The Point of Curve (PC) and the Point of Tangent (PT) can be thought of as the beginning and ending of the curve, respectively, while the Point of Intersection (PI) is where the roads would intersect if they continued straight with the absence of a curve (See Figure 3-2).

The design radius of a curve must be calculated. As the radius increases, the sharpness of the curve decreases and the turn becomes smoother. Think about how this applies to a roller coaster. As the turns become tighter, you begin to feel more force acting on your body. Now, compare this to a more gentle curve, where you may not feel much force or possibly any at all. From this comparison, you can begin to understand why the radius of a curve is so important (See Figure 3-3).
In order to determine the length of the curve, we need to know the **central angle**. The central angle, known as the Intersection Angle ($\Delta$), is the angle between the PC and PT (see Figure 3-4). Note that the terms from the previous figures have been rewritten as abbreviations in Figure 3-4.
Now that we have defined all of the necessary terms for designing a curve, we will explore the formulas for the operation. To begin, we will determine the minimum curve radius based on the design speed, friction factor, and superelevation.

As you may know from practical experience, how sharp a curve feels has a significant amount to do with how fast you are traveling. Roads with higher speeds require smoother, longer curves to provide safe driving conditions, whereas lower speed roads can be managed with tighter curves. When an engineer designs a road, one tool they use is the minimum radius formula. Take note that this formula calculates the \textit{minimum} radius, meaning any radius larger than the calculated radius will be appropriate.

### Minimum Radius Formula

$$r = \frac{v^2}{15(0.01e + f_s)}$$

Where:
- $r$ = radius (ft)
- $v$ = velocity (mph)
- $e$ = superelevation (%)
- $f_s$ = friction factor (as given in Table 3-1)

### Table 3-1: Friction Factors at varying speeds

<table>
<thead>
<tr>
<th>$v$ (mph)</th>
<th>$f_s$</th>
<th>$v$ (mph)</th>
<th>$f_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.32</td>
<td>50</td>
<td>0.14</td>
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<tr>
<td>20</td>
<td>0.27</td>
<td>55</td>
<td>0.13</td>
</tr>
<tr>
<td>25</td>
<td>0.23</td>
<td>60</td>
<td>0.12</td>
</tr>
<tr>
<td>30</td>
<td>0.2</td>
<td>65</td>
<td>0.11</td>
</tr>
<tr>
<td>35</td>
<td>0.18</td>
<td>70</td>
<td>0.1</td>
</tr>
<tr>
<td>40</td>
<td>0.16</td>
<td>75</td>
<td>0.09</td>
</tr>
<tr>
<td>45</td>
<td>0.15</td>
<td>80</td>
<td>0.08</td>
</tr>
</tbody>
</table>

The minimum radius formula demonstrates the effect that speed and road conditions have on the required radius of the road. As the design speed of a road increases, the required radius of curvature exponentially increases. Although, increasing the radius of the curvature isn’t always an option due to factors such as terrain limitations and existing infrastructure. If the curve cannot be the correct size for the design speed due to geometric issues, the road may require a reduced speed. An important issue to keep in mind when designing roadways is that drivers may not obey the reduced speed signs, therefore creating curves with reduced speed limits should be avoided when possible.

In addition to the minimum radius formula, we have formulas to determine the degree of curvature (D) and the total length of a curve (L). The degree of curvature is the angle that the radius would create for an arc length of 100 feet. Degree of curvature is used to help define the location of stations along a roadway that would otherwise be difficult to describe. Stations are a way of tracking the distance along a roadway in increments of 100 feet and are used to call out locations of improvements to be made along a roadway. For example, a traffic engineer could indicate on roadway plans that a traffic light is to
be placed at Station 4+00 (which means 400 feet from the beginning of the project, Station 0+00). Stationing is also clearly marked by surveyors when surveying a construction project.

### Degree of Curvature Formula

\[
D = \frac{36000}{2\pi r} \\
\text{or} \\
\frac{r}{2\pi} = \frac{36000}{D}
\]

Where:
- \( r \) = radius (ft)
- \( D \) = degree of curvature (°)

The full length of a curve is found by using the arc length formula shown below and is based on the radius and the intersection angle. This allows us to know exactly how long our road will be which is helpful for material estimation calculations.

### Arc Length Formula

\[
L = \frac{r\Delta\pi}{180}
\]

Where:
- \( L \) = arc length / length of curve (ft)
- \( r \) = radius (ft)
- \( \Delta \) = intersection angle (°)

These formulas are critical tools for the road designer to be able to derive important information about horizontal curves.

### Materials

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

The example problem will guide you through the use of these equations and assist you with the questions in your Research Notes:

Example Problem:

Imagine a roadway curve with a design speed of 55 mph and no superelevation (e). Find the minimum radius, corresponding degree of curvature, and arc length for this curve. The curve has an intersection angle of 40°.

First, we must find the friction factor. Using Table 3-1 with a velocity of 55 mph, we find that the friction factor is 0.13.

Using the minimum radius formula, we apply the velocity, superelevation, and friction factor to find the minimum radius.

\[
r = \frac{v^2}{15(0.01e + f_s)} = \frac{(55)^2}{15(0.01(0) + (0.13))} = 1551 \text{ ft}
\]

This calculated minimum radius can then be used to determine the degree of curvature (D).

\[
D = \frac{36000}{2\pi r} = \frac{36000}{2\pi(1551)} = 3.69^\circ
\]

The calculated minimum radius can then be used with the intersection angle to determine the arc length, which is the distance the car would travel along the curve.

\[
L = \frac{r\Delta \pi}{180} = \frac{1551 \cdot 40 \cdot \pi}{180} = 1083 \text{ ft}
\]
Activity 3: Sharp Curve Ahead!

Questions

1) A proposed road is being designed with an intersection angle of 50 degrees and a degree of curvature of 10 degrees. What would the radius of this curve be? Round your answer up to nearest whole number.

\[ D = 10 \]
\[ \Delta = 50^\circ \]
\[ r = ? \]

2) A road has an intersection angle of 30 degrees and a degree of curvature of 8 degrees. What is the length of this curve? Round your answer up to nearest whole number.

\[ D = 8 \]
\[ \Delta = 30^\circ \]
\[ L = ? \]

3) Given a road with a minimum degree of curvature of 8 degrees, a design speed of 45 mph, and no superelevation, what would be the minimum design radius? Refer to Table 3-1 for friction factor. Round your answer up to nearest whole number.

\[ D = 8^\circ \]
\[ v = 45 \text{ mph} \]
\[ e = 0 \]
\[ r = ? \]
4) Which of the following options would cause a turn to become “smoother”?
   a. Increasing the Radius of Curve
   b. Increasing the Degree of Curvature

5) What effect does the design speed have on the sharpness of a curve?

Discussion Notes
Activity 4: Create a Plan!

<table>
<thead>
<tr>
<th>Activity Summary</th>
</tr>
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<tbody>
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<td>Instructor Prep Time</td>
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<tr>
<td>Class Time</td>
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<tr>
<td>Grade/Class</td>
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<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 explore the road design process by experimenting with Computer Aided Design (CAD) Software. Students will apply the road curvature skills they learned in Activity 3 by designing a series of roads on a plan created in the CAD software *MicroStation PowerDraft v8i*. Students will calculate minimum curve radii and will consider this when navigating their roads around obstacles. This module will give students an understanding of the reason roads are designed and planned the way they are, as well as provide an introduction to CAD programs.

**Note:** This activity relies on advanced computer skills and is recommended for more advanced students.

*MicroStation PowerDraft v8i* is available for this activity from Bentley. Download instructions are provided in Appendix B.

Instructors and students with little or no experience with *MicroStation PowerDraft v8i* would benefit from the video tutorials offered by MDOT for the Bridge Builder Competition, found in the link below:

http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-394779--,00.html

Objective

In this activity, students will:

- Understand the basics of how roadway plans are created.
- Calculate minimum road curve radii.
- Plan and construct new roads using Computer Aided Design (CAD) software.

Background

If you are unfamiliar with CAD software, it may be beneficial for you to familiarize yourself with it by completing the tutorials in the above link. It may also be beneficial for you to attempt the practice drawings in this activity by following the steps provided in the procedure section of the *Research Manual*. 
This activity provides students with exposure to CAD software which is common in most engineering programs and careers today. If students choose to continue on to pursue an engineering degree in the future, having prior experience in this software will certainly prove beneficial to them.

**Activity Expansion Ideas**

**Multi-view Projection**

During this activity, students will gain exposure to designing roadways using *MicroStation PowerDraft*. There are numerous other applications for this software including, but not limited to, bridge design, multi-view projection, and cross-section views. For an activity expansion, students are challenged to learn how to draw multi-view projection of objects on paper, then advance their *MicroStation PowerDraft* skills by drawing these in CAD. The multi-view projection is applicable to civil engineering because 3-D structures – bridges, culverts, etc. – must be drawn to show all dimensions clearly.

**Tutorial Exploration**

Students could also explore how *MicroStation PowerDraft v8i* software is used for other civil engineering applications, have them follow along with some of the free tutorials offered in the link provided below:

https://www.youtube.com/playlist?list=PL62856D3954D0AFB2
Activity 4: Create a Plan!

<table>
<thead>
<tr>
<th>Road Color</th>
<th>Speed Limit (all roads)</th>
<th>Minimum Radius (with 0% superelevation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>35 mph</td>
<td>454</td>
</tr>
<tr>
<td>Pink</td>
<td>40 mph</td>
<td>667</td>
</tr>
<tr>
<td>Yellow</td>
<td>35 mph</td>
<td>454</td>
</tr>
<tr>
<td>Red</td>
<td>50 mph</td>
<td>1191</td>
</tr>
<tr>
<td>Green</td>
<td>35 mph</td>
<td>454</td>
</tr>
</tbody>
</table>

Questions

1) Were there multiple solutions to complete the final plan? Do you think you designed the most effective solution? Why or why not?

   Answers will vary here. Generally, there are multiple solutions to the plan that students can design. More effective solutions will have smoother, less abrupt curves with as many straight sections as possible.

2) What types of obstacles and limitations would you expect to be present in real-world scenarios that were not represented in these plans?

   Answers will vary here. Topographic features, property lines, proximity to buildings or landmarks, overhead power lines, etc.

3) What observations can you make about the size of the minimum radius as the speed limit of the road increased?

   The size of the minimum radius grows exponentially larger when higher speed limits are used.

Discussion

Students’ answers to Question 1 could be discussed once students answer questions individually. Help students understand that straighter, less curved roads are more desired, when possible, to reduce complex design and construction.

Students’ answers to Question 2 could also be discussed. Explain other factors going into the road design that students did not consider. Discuss some solutions to these problems as well. For example, undesired topographic features can be resolved by cutting or filling (removing or adding) earth at the site.
Activity 4: Create a Plan!

Introduction

In this activity, you will explore road design by experimenting with Computer Aided Design (CAD) Software. You will apply the road curvature principles that you learned in Activity 3 by designing a series of roads on a plan created in the CAD software MicroStation PowerDraft v8i. You will calculate minimum road curve radiiuses, and will consider them when navigating your roads around obstacles. This module will give you an understanding of how road plans are developed as well as provide you with basic CAD experience.

Objective

In this activity, you will:

- Understand the basics of how roadway plans are developed.
- Calculate minimum road curve radii.
- Plan and construct new roads using Computer Aided Design (CAD) software.

Background

Computer Aided Design (CAD) software is an essential tool used by traffic engineers in roadway planning and design. This powerful software can be used to streamline difficult tasks and provide accurate and detailed plans and figures. For example, a land surveyor can go to a proposed road construction site and collect three-dimensional point data of important features in the area, which can then be directly imported and processed with CAD software to make a topographic map. This topographic map can be overlaid with a satellite image, which can be read and used by a traffic engineer to make an informed roadway design directly overtop this topographic map. The resulting design can then be converted into various critical points and returned to the surveyor, who will mark these points with stakes on the construction site. Contractors can then match the construction design plans prepared by the traffic engineer to these survey stakes in the field to accurately construct the design. A visual guide of this process is presented in Figure 4-1.

Figure 4-1: (Left) Surveyor collecting point data, (Middle) Construction plans designed in CAD software by a traffic engineer over a topographic map, (Right) Surveyor placing stakes at a construction site to lay out construction plans.
In this activity, you will step into the role of a traffic engineer in this design process. Several new roads are to be constructed on a plot of land surrounding a few small towns and a river. A survey has been conducted for this site to identify key obstacles to avoid while designing the roads. Results of this survey have been plotted using MicroStation PowerDraft v8i and provided to you, the engineer. Using this survey and your knowledge of curve design, create roadway plans by designing roads around these obstacles based on the desired speed limits.

**Materials**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
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<tr>
<td>Computer with MicroStation PowerDraft v8i</td>
<td>1 per student or group</td>
</tr>
<tr>
<td>Data File: Activity 4 – Create a Plan!.dgn</td>
<td>1 per student or group</td>
</tr>
<tr>
<td>Calculator</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

**Setup**

On your computer, open MicroStation PowerDraft v8i. Upon opening this program, you will be prompted to open a file. Navigate to the folder containing the file entitled ‘Activity 4 – Create a Plan!.dgn’ and open this file. This file is available in the Traffic Engineering & Safety Module section of the TRAC webpage.

**Procedure**

This file contains several practice drawings as well as a full-size plan template. Start by completing a few of the provided practice drawings, such as the one in Figure 4-2, by following the instructions provided in this procedure section. These practice drawings will allow you to learn the technique of creating roads and road curves before starting on the full-size plan. On these practice drawings, road speed limits and minimum radii are provided, as shown in Table 4-1; these practice drawings incorporate 5% superelevation into the minimum radius calculations. On the full-size plan, road speed limits are given to you, but the minimum radii must be calculated. Remember that these are minimum radii; any radii larger than these will meet the requirements of the specifications.

The outer white rectangle is the extent of the plan, and the white shapes within represent obstacles, such as houses or trees, that the road must not pass through. The colored markers at the edges of the plan indicate start and end points for a road which must be drawn and connected by you. Solid color markers within the plan represent areas where the road must pass through. Crossing markers within the plan represent intersections that a road must pass through and the roads may only intersect through these points.

**Table 4-1: Practice Drawing Speed Limits and Minimum Radii**

<table>
<thead>
<tr>
<th>Simple Map #</th>
<th>Speed Limit (all roads)</th>
<th>Minimum Radius (with 5% superelevation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30 mph</td>
<td>240ft</td>
</tr>
<tr>
<td>2</td>
<td>40 mph</td>
<td>508ft</td>
</tr>
<tr>
<td>3</td>
<td>25 mph</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>25 mph</td>
<td>149ft</td>
</tr>
<tr>
<td>5</td>
<td>25 mph</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4-2: Sample Practice Drawing

Once you feel comfortable with the practice drawings, move on to the full-size plan. The full-size plan is presented in Figure 4-3. The blue lines represent a river passing through the plan that must be crossed at marked points. On this full-size plan, only road speed limits are given to you, and the minimum radii must be calculated. Assume that no superelevation will be used on these curves for simplicity, and use the minimum radius formula from the last activity to compute minimum curve radiiues. Record your calculations in the Research Notes section. Once you have completed the full-size plan, show the completed plan to your instructor for confirmation of completion, and then answer the questions provided in the Research Notes section.
While following the instructions for creating roads and curves, refer to Figure 4-4 as a visual reference. The minimum radius formula from Activity 3 has been repeated below, use it to calculate the minimum road radii on the full-sized plan.

**Minimum Radius Formula**

\[
r = \frac{v^2}{15(0.01e + f_s)}
\]

Where:
- \( r \) = radius (ft)
- \( v \) = velocity (mph)
- \( e \) = superelevation (%)
- \( f_s \) = friction factor (as given below)

### Friction Factors at varying speeds

<table>
<thead>
<tr>
<th>v (mph)</th>
<th>( f_s )</th>
<th>v (mph)</th>
<th>( f_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.32</td>
<td>50</td>
<td>0.14</td>
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<td>20</td>
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<td>25</td>
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<tr>
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<td>0.16</td>
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</tr>
<tr>
<td>45</td>
<td>0.15</td>
<td>80</td>
<td>0.08</td>
</tr>
</tbody>
</table>

1. Select the ‘Place SmartLine’ tool (as shown in Figure 4-5). This will be used to create straight sections of road.
2. Sketch the rough path you would like your road to follow using these straight lines. Think about where you would like your curves to fall while creating these lines.
   - a. This tool will draw connecting lines until it is commanded to stop, which can be done by right-clicking on your mouse.
   - b. Do not worry about making a line that extends farther than you would like. This will be corrected in step 4.
   - c. Use different colored lines that match the start and end points of the road path. Different colored lines may be selected from the top toolbar as shown in Figure 4-6.
   - d. Draw your road on the plan using dashed lines. Select line type 2 from the top toolbar as shown in Figure 4-6.
   - e. If you make a mistake press ‘Ctrl + Z’ to undo your last action or delete the road using the ‘Delete Element’ tool (as shown in Figure 4-5).
3. After you have constructed your straight sections of road, select the ‘Construct Circular Fillet’ tool (as shown in Figure 4-5) and use it to create road curvature. A dialog box will appear; enter in the minimum road radius given or calculated and set truncate to both, as shown in Figure 4-7.
4. Click on the first road you would like to create a curve through, and then click on the second road. If
the radius is small enough to fit a curve properly, the program will automatically set the Point of
Curvature and the Point of Tangent, and the curve will be created.
   a. Excess straight line segments will be trimmed away automatically (truncated).
   b. If the radius is too large to fit in the space, nothing will happen after selecting both lines,
      and the road must be redesigned to fit a curve.

Figure 4-4: (Left) Sample Practice Drawing, (Middle) Practice Drawing with SmartLines Drawn, (Right) Completed
Practice Drawing with truncated curves

Figure 4-5: (Left) Smartline Tool, (Middle) Circular Fillet Tool, (Right) Delete Element Tool
Figure 4-6: (Left) Line Color (road dependent), (Right) Line Shape

Figure 4-7: ‘Construct Circular Fillet’ Dialog Box
Activity 4: Create a Plan!

Data Sheet

<table>
<thead>
<tr>
<th>Road Color</th>
<th>Speed Limit (all roads)</th>
<th>Minimum Radius (with 0% superelevation)</th>
</tr>
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<tbody>
<tr>
<td>Orange</td>
<td>35 mph</td>
<td></td>
</tr>
<tr>
<td>Pink</td>
<td>40 mph</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>35 mph</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>50 mph</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>35 mph</td>
<td></td>
</tr>
</tbody>
</table>

Questions

1) Were there multiple solutions to complete the final plan? Do you think you designed the most effective solution? Why or why not?

2) What types of obstacles and limitations would you expect to be present in real-world scenarios that were not represented in these plans?

3) What observations can you make about the size of the minimum radius as the speed limit of the road increased?
Discussion Notes
Appendix A: Document Links

NCHRP 20-52


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

TRAC/Michigan Education Standards

Link: http://www.michigan.gov/mdot/0,4616,7-151-9623_38029_38059_41397-184233--,00.html

The Michigan Education Standards are outlined in terms of how TRAC meets the benchmark goals. This page includes the standards for 6th, 7th, and 8th grades as well as high school standards. Both the TRAC modules and bridge building competition are listed.
Appendix B: MicroStation PowerDraft Download Instructions

TRAC & Rides Program

Getting started with Bentley’s STUDENTserver:

Faculty and students must first create accounts, using the following School Code to set up an individual account:

ceUlppmq/CV1ia8npF48K6sfC6t3hqv0JPihQw5FgQ/XzFpJ0krLJIA==

Visit STUDENTserver at http://apps.bentley.com/StudentServer and click JOIN NOW

Create your account:
1. Add your School Code to that field, as requested in the registration form.
2. Add your personal information in the other form fields.
3. Submit the form, and an Email will be sent to you from Bentley for further verification. (If you do not see email within a few minutes check you spam/junk folder)

Verify your account:
- Click the link in the account verification Email to activate your STUDENTserver account.
- Once you verify your new account, you can log in and access all that STUDENTserver has to offer.

Benefits include:
- More than 50 software applications
  (those with ** after the product name are excluded; products are Country-specific where indicated)
- On-Demand training
- Training Transcripts, to send to potential employers
Appendix B: MicroStation PowerDraft Download Instructions

Welcome to STUDENTserver

Step 1
Download Software
Once you have joined the STUDENTserver, fill out the business-to-business downloading and installation one or more of the many Bentley software products relevant to your studies. Be sure to check for the site activation code required to register the software as part of the installation process.

Step 2
Take Online Training
To learn how to use Bentley software, be sure to check out the online training. You will find a suite of tools to help you to use your new software in advanced subjects taught by experts in the field. To get started, a list of recommended introductory courses are available on the eLearning page.

Step 3
Review Transcript
Bentley records each student’s completion of on-demand training in their personal Bentley Professional Training transcripts. It is available for review at any time and can be forwarded by Bentley to potential employers for both internships and full employment. It may take up to 24 hours for a completed course to appear in your transcript.

Step 4
Visit Be Communities
Through the Be Communities, Bentley provides access to a wealth of information including discussion forums, webinars, blogs, and all Bentley products as well as designing engineering discipline specific communities where students and faculty can network with working professionals and Bentley colleagues.

News Feeds
- Teaching BPM: why, what and how?
- Quick Start for Roadway Designers & for Surveyors, using OpenRoads Technology
- Quick Start for Mapping Designers using MicroStation available
- And the Order for Infrastructure goes to...
- Architecture students: Quick Start for using AECOffice: Building Designer available
Appendix C: Glossary of Terms

Central Angle: Angle that is formed by two radii, in this case it is the two radii formed by drawing from the PC and PT to the center of the circle.

Centrifugal Force: An apparent force that acts outward on a body moving around a center (or a curve), as a result of the body’s inertia.

Contractor: A general contractor is responsible for executing a construction project. Responsibilities include constructing the project as designed, overseeing the construction site day-to-day, managing subcontractors and vendors, and communicating information to all involved parties throughout the project.

Degree of Curvature (D): Angle that the radius would create for an arc length of 100 feet long.

Horizontal Curve: Transition between two tangent sections of roadway in the form of a curve.

Point of Curve (PC): Location of the curve’s starting point.

Point of Intersection (PI): Location where the two roads would intersect if there was not a curve.

Point of Tangent (PT): Location of the curve’s end point.

Superelevation: Vertical distance between the heights of the inner and outer edges of highway pavement, also referred to as cross-slope.

Surveyor: A person who gathers three-dimensional point data in order to create topographic maps. They also take construction plans and place stakes in the field to represent them for contractor use. Usually hired by the contractor or the owner to perform these tasks.

Topographic Map: A map that displays elevation changes and the arrangement of the physical features of an area. Typically, elevation changes are displayed through contour lines.
This manual was updated and revised in 2017 by of the Center for Technology and Training (CTT) at Michigan Technological University for the Michigan Department of Transportation (MDOT).