MODULE 1: CRASH PREVENTION

LESSON 2: STOPPING DISTANCE AND CRASH AVOIDANCE

GRADE LEVEL: 6 - 8

This lesson introduces students to the physical concepts of surface friction and the distance vehicles need to come to a complete stop under a variety of roadway situations. Students will discuss and calculate vehicle stopping distances for different pavement conditions, and study how Intelligent Transportation System (ITS) sensors and communication networks can help avoid collisions.

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Lesson 2: Stopping Distance and Crash Avoidance

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Grade Level: 6 - 8	**Lesson in this Module:** 2 of 4
Time Required: 120 minutes	**Lesson Dependency:** None
Keywords: transportation engineering; intelligent transportation systems; stopping distance; crash avoidance; friction	

Related Curriculum

Subject Areas	Science; technology; engineering; mathematics
Curricular Units	Intelligent transportation systems
Activities	Friction demonstration; thought experiments; stopping distance calculations; cooperative learning

Educational Standards

This lesson plan and its associated activities are correlated to the national standards in the each of the core discipline areas of STEM: Next Generation Science Standards, American Association for the Advancement of Science Standards, Standards for Technological Literacy, International Society for Technology in Education Standards, Common Core Mathematics Standards, and the National Council of Teachers of Mathematics Standards.

Materials List

Stopwatch, stopping distance calculation worksheet, wooden ramp, small squares of various materials (thin sheet of rubber, sandpaper, wax paper, etc), small wooden block, toy truck

Pre-Requisite Knowledge

Lesson 1 of this Module.

Learning Objectives

- Students will understand that various vehicles and road conditions have different stopping properties.
- Students will use mathematical formulas to calculate stopping distances.
- Students will identify specific connected vehicle technologies that exist to prevent crashes at intersections.

Introduction/Motivation

All students know that it is more difficult to walk on a slippery or icy sidewalk than on a dry one. This lesson introduces students to the physical concepts of surface friction and the distance vehicles need to come to a complete stop under a variety of roadway situations. Students will discuss and calculate vehicle stopping distances for different pavement conditions, and study how Intelligent Transportation System (ITS) sensors and communication networks can help avoid collisions.

Lesson Background & Concepts for Teachers

Activity 1 – Demonstrating the Physics of Friction

The first activity deals with the concept of the coefficient of friction. Coefficient of friction is a property of how an object interacts with a surface. For example, a block that is sliding down a ramp has a friction force that resists, or slows down, its ability to slide. Different surfaces have different levels of friction. A surface's smoothness can be quantified and compared using coefficient of friction measured values.

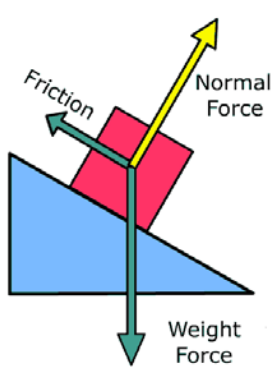


Figure 1: Basic Friction Concept (http://www.stmary.ws/highschool/physics/home/notes/dynamics/friction/introFriction.htm)

The force of friction is directly related to how much force is pushing the two objects together. This can be demonstrated by showing or explaining the different effort it takes to push objects of different weights on a sandpaper track. The lighter object will be easier to push because it has a lower friction force resisting the movement.

Another factor in how far an object slides down a ramp is the material properties of the sliding surface. For example, when sliding a block of ice on an icy surface, the smooth surfaces provide very little resistance between the two blocks due to a low coefficient of friction (average = 0.03). On the other hand, when sliding a block of rubber on a slab of concrete, the resistance is much greater; the coefficient of friction value is 0.80.

Activity 2 – Vehicle Stopping Distances

Transportation engineers consider surface friction when they determine how long it takes a vehicle to stop. This plays into a variety of different applications such as how long to make an exit ramp, how to design a tight curve, and how much time to display a yellow light at a traffic signal that is about to turn red. This activity will focus on the last example: determining how long it takes a vehicle to stop at an intersection.

In general, we use the following equation to determine the amount of distance a vehicle will travel while attempting to stop:

$$d_{stopping} = \frac{v_{initial}^2 - v_{final}^2}{2\mu g}$$

where

$d_{stopping}$ = the distance a vehicle travels (meters)

$v_{initial}^2$ = the initial velocity of the vehicle (m/s)

v_{final}^2 = the final velocity of the vehicle (m/s)

μ = the surface coefficient of friction (unitless)

g = the gravitational acceleration (9.8 m/s^2)

Since we are looking to determine how long it takes a vehicle to stop, we will assume that v_{final} is zero. That leaves the following equation:

$$d_{stopping} = \frac{v_{initial}^2}{2\mu g}$$

where all terms are previously defined.

The coefficient of friction varies depending on the road's surface condition.

Thought experiment: Will a vehicle take longer to stop on dry pavement, or on pavement covered by snow or ice? How will that affect the object's coefficient of friction?

Table 1: Coefficient of Friction (Principles of Highway Engineering and Traffic Analysis by Mannering and Washburn)

Pavement Condition	Approximate Coefficient of Friction
Good pavement, dry	1.0 to 0.95
Good pavement, wet	0.90
Poor pavement, dry	0.80
Poor pavement, wet	0.60
Packed snow or ice	0.25

Since we know that higher coefficients of friction result in more resistance to push an object, the same is true for stopping. On dry pavement in good condition ($\mu = 0.95$), a vehicle is most likely to stop within a shorter distance than on a road covered in ice ($\mu = 0.25$).

As engineers, we design traffic signals to ensure that everyone gets a fair chance to go through the intersection at an appropriate time. If you're approaching a green traffic light that suddenly turns yellow, the amount of time a light is yellow depends partially on the amount of time it takes for a vehicle to stop given a certain starting speed.

Let's do an example.

A vehicle is driving 45 mph (20 m/s) as it approaches a green light. If the light suddenly turned yellow, how far would the vehicle travel before it came to a complete stop? Assume a dry road with fairly good pavement condition ($\mu = 0.95$).

Taking the original equation and substituting in the known values,

$$d = \frac{v_{initial}^2}{2\mu g}$$

$$d = \frac{20^2}{2 * 0.95 * 9.81}$$

$$d = 21.46\ meters\ (approximately\ 70\ feet)$$

Under these conditions, this is the distance it takes for the vehicle to stop once the driver has applied the brakes. Now think back to the first lesson in this module. Assuming a perception reaction time of approximately 1.5 seconds, what is the total distance it would take for this vehicle to stop?

$$D = d_{PR} + d_{stopping}$$

where

$D =$ the full perception-reaction stopping distance (meters)

$d_{PR} =$ the distance a vehicle travels while a driver perceives and reacts to a stimulus (meters)

$d_{stopping} =$ the distance it takes a vehicle to stop after applying the brakes (meters)

Knowing that the distance a vehicle travels while a driver perceives and reacts to a stimulus is equal to the speed times the time it takes to react, we get the following equation.

$$D = v_{initial} * t_{PR} + d_{stopping}$$

where

$t_{PR} =$ the time it takes for a driver to react (seconds)

The full perception-reaction stopping distance is calculated to be:

$$D = 20 * 1.5 + 21.46$$

$$D = 30 + 21.46$$

$$D = 51.46\ meters\ (approximately\ 168.5\ feet)$$

Use attached worksheet to provide students with practice calculating stopping distances.

Activity 3 – Using Technology to Prevent Crashes

The ability for a vehicle to stop quickly is important for preventing crashes. Let's continue using the traffic signal example for the remaining discussion in this lesson.

If a traffic engineer designed the traffic signal to allow vehicles just enough time to stop in dry conditions, what would happen if the road were wet?

Answer: The vehicle would need 51.36 meters to stop, so it still might be able to stop.

What if the road was icy?

Answer: The vehicle would require 131.5 meters to stop so it would definitely not be able to stop in time.

Have the students brainstorm ways to ensure that other vehicles aren't permitted to enter the intersection while this vehicle is making its way through. Potential answers that align with existing or futuristic capabilities include:

- Using environmental sensors to determine the road's surface condition and adjusting the yellow light and red light times accordingly (longer for wet weather and more for icy or snowy weather)
- Extend the yellow or red light time on the cross-street to ensure that no one else is given the opportunity to enter the intersection until the intersection is clear.
- Use advanced vehicle technologies to improve driver reaction time (by improving reaction time, total stopping distances are reduced)
- Use connected vehicle technology to send alerts to other vehicles when their anti-lock braking system is engaged. This system would be able to warn other drivers that an oncoming vehicle is having trouble stopping.
- Use connected vehicle technologies so the vehicle anticipates the yellow light before it happens, slowing appropriate based on pavement conditions and its knowledge of the signal timing by communicating with the intersection (Vehicle-to-Infrastructure).

Conclude this discussion by showing the YouTube video that explains connected vehicle intersection technology.

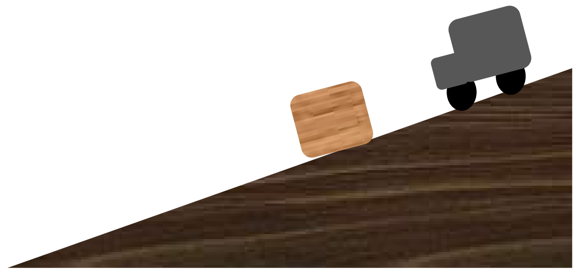
Vocabulary/Definitions

Vocabulary Word	Definition
Friction	The resistance that one surface or object encounters when moving over another surface or object; usually represented as a coefficient between 0 and 1.0
Perception-Reaction Time	The time it takes for someone to see or perceive a problem and react to it (includes cognitive processing time and physical time to move to react)
Stopping Distance	The distance a vehicle travels once a driver begins stopping a vehicle (this does not include the distance a vehicle travels while a driver is perceiving and reacting to a problem)
Total Stopping Distance	The sum of the distance traveled during the perception-reaction time plus the time it takes to stop the vehicle from an initial speed
Connected Vehicles	A system of communications between vehicles and transportation infrastructure that allows vehicles to make their presence known and improve transportation safety and mobility
Intersection Collision Avoidance	A series of technology solutions to reduce the number of crashes that happen at intersections

Associated Activities

Introduction Activity 1 (Optional) – Demonstration of basic physics concepts using physical demonstrations and thought experiments. Depending on the students' background knowledge, consider performing the following demo.

- In order to introduce the concept of friction, the teacher will lead a demonstration on friction. First ask a student who has on rubber soled shoes, like sneakers, to slide across the classroom floor. Next ask a student to slide across the floor with only socks on their feet. Ask students why the socked footed student was able to slide further?



- Next, demonstrate the interaction between vehicles and pavement using a toy dump truck and a few blocks of wood. Demo set up: Obtain a toy dump truck. Create an inclined plane, 3-4 feet long. Obtain several blocks of wood and put a different material (sandpaper, plastic, rubber, etc.) on the bottom of each block. The wood blocks represent different surface conditions of the pavement.
- First, let the dump truck roll down the inclined plane alone with no braking system. Students can time the dump truck to see how long it takes for it to reach the bottom. Next, take turns attaching the dump truck to the back of each of the wooden blocks using duct tape. Have students predict what they think the effect of each wooden block will be on the "roll time". Let the dump truck/wood block travel down the inclined plane. Have students time each roll.
- You can also try this demo set-up without the inclined plane by pushing the dump truck down the school hallway with the same initial force and seeing how long it takes it to stop.

Activity 2 – Introduction to stopping distance calculations

- Lecture on stopping distance equations with examples
- Worksheet provided for students to practice calculations
- Thought experiment: Why do larger or heavier vehicles take longer to stop? How does momentum play a part in stopping distances?
  Momentum is calculated by multiplying the vehicle's mass times its velocity. If a vehicle is larger and heavier, that means that it has a larger mass than smaller vehicles. A vehicle with a higher mass has more momentum when traveling at the same speed as a smaller vehicle; this increases the amount of effort it takes to stop a heavier vehicle.

Activity 3 – Discussion about using technology to prevent crashes

- Discussion prompt: Imagine you are a truck driver approaching an intersection at a high rate of speed, the light changes to yellow and you are not sure if you are able to stop in time. Have students work together to research methods of preventing other vehicles from entering the intersection.
    - *Back-loop detectors to prevent the light from changing before the truck passes through the intersection*
    - *Environmental sensors to determine whether the road is wet or icy in order to adjust signal timing plans*
    - *The yellow light could be extended for the truck or the green light would not be given to conflicting traffic movements.*
    - *Technologies to improve reaction time*
    - *Anti-lock brake alert sent through connected vehicle technology*
- Have students present their findings to the class.

Lesson Closure

- How could in-vehicle or connected vehicle technology change the way you drive in the future?
    - What impacts do human decisions have on crashes?
    - How can intersection crashes be reduced using connected vehicle technologies?
    - How would the ability to understand road conditions improve traffic safety using the connected vehicle technology?

Attachments

- Stopping Distance Calculation Worksheet

Extensions/Multimedia

- YouTube video on stopping distance calculations: http://www.pbslearningmedia.org/resource/ket09.sci.lsci.regulation.stop/vehicle-stopping-distance/
- Websites for more information on intersection collision avoidance
    - This is a short video that talks about DSRC for intersection collision avoidance (0:29): https://www.youtube.com/watch?v=QkXvg4kL5rk
      DSRC is Dedicated Short Range Communications (0:48): https://www.youtube.com/watch?v=hMc1XiWdEUY
    - This video demonstrates Collision Avoidance Technology in a Volvo car (1:02) https://www.youtube.com/watch?v=Ld36WEhSrPE

- This video is a more in-depth demonstration of Volvo's technology (1:47) http://bcove.me/pyv1qi7q

- This video demonstrates Chrysler's Forward Collision Warning System. This shows what the system display looks like inside the vehicle (1:18): https://www.youtube.com/watch?v=EmFi7S-yJCg

- YouTube video on connected vehicle intersection safety: https://www.youtube.com/watch?v=kOlL1fWBYAI
- Utilize Edmodo (www.edmodo.com) to provide further questioning and discussion between students and teacher. Edmodo is safe social learning website made specifically for teachers and students. It is a way to collaborate on assignments, homework, projects, and after-school STEM programs and is used as a communication tool to provide additional questioning and feedback from teachers and students.