National University Rail Center - NURail
US DOT OST-R Tier 1 University Transportation Center

NURail Project ID: NURail2014-UIUC-E09

Guidebook for Railway-themed K-12 STEM Outreach Activities

By

C. Tyler Dick, Ph.D., P.E.
Lecturer and Principal Research Engineer
Rail Transportation and Engineering Center (RailTEC)
University of Illinois at Urbana-Champaign
ctdick@illinois.edu

Lee Evans
Graduate Research Assistant
Rail Transportation and Engineering Center (RailTEC)
University of Illinois at Urbana-Champaign
leonele2@illinois.edu

23-12-2020

Grant Number: DTRT13-G-UTC52 (Grant 2)

Introduction

Welcome to the *Guidebook for Railway-themed K-12 STEM Outreach Activities*! Inside, you will find descriptions of educational activities designed to introduce students to the railroad transportation mode through the lens of STEM (Science, Technology, Engineering, and Mathematics) concepts.

Railroads have been a critical part of the global economy since the 1830s. Today, railroads haul more ton-miles of intercity freight (one ton of freight moved one mile) than any other mode of transportation in the United States. While the railroad industry is the leader in long-haul freight transportation, recruiting students to leadership roles in the industry is challenging. With many railroad employees approaching retirement age, the need to raise student awareness of railway industry career opportunities has never been greater.

The activities in this guidebook cover a wide variety of railroad topics. The activities are intended to be hands-on to provide students with knowledge through experiential learning that also increases their awareness of railway transportation technology. Although the following chapters provide a step-by-step guide to each activity, we encourage you to experiment with modifications to each activity and to create your own activities on other facets of the railroad industry and STEM topics.

We hope you find the activities in this guidebook to be informative and entertaining!

Acknowledgements

This guidebook was made possible by the financial support of the following organizations:

- National University Rail Center (NURail), a U.S. DOT OST Tier 1 University Transportation Center
- National Railroad Construction and Maintenance Association

NURail Center

NRC NATIONAL RAILROAD CONSTRUCTION & MAINTENANCE ASSOCIATION

The authors would also like to acknowledge the following individuals and organizations for their contributions to this guidebook:

- Christopher Barkan, Rail Transportation and Engineering Center (RailTEC), University of Illinois at Urbana-Champaign
- Pasi Lautala and Dave Nelson, Rail Transportation Program, Michigan Technological University
- Bryan Schlake, Rail Transportation Engineering Program, Penn State Altoona
- Dimitris Rizos, Advanced Railroad Technology Group, University of South Carolina
- Members of American Railway Engineering and Maintenance-of-Way Association (AREMA) Committee 24 - Education and Training
- LB Frye, and faculty, staff and students with RailTEC, University of Illinois at Urbana-Champaign
- Members of the AREMA Student Chapter at the University of Illinois at Urbana-Champaign
- Students and staff at the Next Generation School, Champaign, Illinois

Table of Contents

Railcar Puzzle and Commodity Matching Game

This puzzle matching game introduces different types of freight railcars and the commodities they carry.

Number of Participants: 1-2 **Recommended Age:** 3+

Setup Time: 3 minutes **Activity Time:** 1-5 minutes

STEM Concepts:

- *Technology: railcars incorporate various design features according to commodity properties*
- *Engineering: railway operators must match the number and type of railcars to their traffic*
- *Mathematics: geometric properties such as shape, length, height and volume are key differences between different types of railcars*

Key Learning Points

1. **There are many different types of railcars designed to fit the needs and characteristics of different types of commodities shipped by rail.**
2. **While some types of railcars are general purpose and can carry a range of freight, other railcars are designed specifically for transporting one type of commodity (examples include "autoracks" for transporting motor vehicles or coil cars for carrying rolls of steel).**

Background

Railroad locomotives and freight cars (or "rolling stock") come in all shapes and sizes. Why is that?

- Some types of freight require protection from the weather, while others do not.
- Some commodities are solid, while others are liquid or gas.
- Some shipments are granular or will flow, while others are solid and fixed in shape.
- Some types of freight require special handling to be sure they will arrive safely.
- Shippers may want to load or unload a railcar from the side, end, top and/or bottom.

To meet the distinct needs of each commodity or type of freight shipped by rail, the railroads and railcar manufacturers have develop different types of railcars to efficiently transport different materials. Each type of railcar possesses a unique combination of features, including:

- Length, height, volume and overall shape (rectangular, cylindrical, ellipsoidal)
- Fully enclosed with a roof or open to the weather
- Doors on the sides or ends for loading and unloading
- Hatches in the roof for loading and/or outlets in the floor for unloading
- Special fittings for loading or unloading liquids or pressurized gasses

This activity aims to familiarize participants with different types of freight cars and the commodities that they are designed to carry.

While technically not a railcar, nearly all freight trains in the United States are powered by one or more **diesel-electric locomotives**. The diesel-electric locomotive uses an internal combustion engine powered by diesel fuel and an alternator to generate electricity. The electricity is used by electric motors mounted on each axle that provide the power to turn the locomotive wheels and move the train. Typically two crew members control the train from the locomotive cab. Connections between locomotives allow the crew in the cab of one locomotive to control other locomotives it is coupled to. Radio signals can also allow the crew at the front of the train to also control locomotives located at the rear or middle of the train. The locomotive also provides braking force to stop the train when needed, and carries lights, a horn and a bell to help warn pedestrians and motorists at highway-rail grade crossings.

Figure 1: Typical diesel-electric freight locomotive. Used to provide propulsion for the train.

Boxcars were once the most common type of freight car and are used to carry materials and packaged goods that require protection from the weather but cannot by shipped loose in bulk.

Figure 2: Box car. Transports rolls of paper, building materials, auto parts, packaged freight and other goods that are sensitive to the weather.

Much of the freight that was once shipped in boxcars is now shipped in **shipping containers** and **highway trailers** that can move on both truck and rail in "intermodal service". Containers can also transport freight overseas via ship. Containers and trailers transport consumer goods such as appliances, bicycles or packages from online retailers. Specialized intermodal railcars are used to transport the containers and trailers between terminals where cranes and other specialized equipment lift them on and off the train.

Figure 3: Intermodal well car and two containers "double-stacked" on top of each other.

Figure 4: Intermodal spine car carrying highway trailer.

Railways often transport commodities that are shipped loose or in bulk. These materials may be granular or liquids or gasses that flow and conform to the shape of the railcar. Railcars designed for these products include open and covered **hoppers**, **tank cars** and **gondola cars**. Railcars used to transport bulk commodities may have an open top, roof hatches or a top fitting for loading materials, and may also have bottom outlets or fittings for unloading.

Figure 5: Open top hopper. Used to haul loose commodities that can withstand water such as gravel or coal.

Figure 6: Covered hopper. Used to haul loose commodities that cannot withstand water such as grain, salt, fertilizer, sand, or plastic pellets.

Figure 7: Tank car. Used to haul liquid commodities or pressurized gases such as propane, chemicals, crude oil, ammonia, ethanol, gasoline or corn syrup.

Figure 8: Gondola car. Used to transport commodities that are not sensitive to water such as rail, scrap steel, or pipes.

Certain shipments are discrete objects such as automobiles, steel shapes, machinery and other equipment. Specialized railcars are correctly sized for these shipments and have different features to protect the freight and secure it in place when moving from origin to destination.

Figure 9: Autorack car. Transports finished motor vehicles from assembly plant to distributor.

Figure 10: Coil car. Transports steel coils from steel mills to various manufacturers.

Even **flat cars,** with a long level platform for shipping large loads that do not require any protection from the weather, come in different varieties. In addition to containers and highway trailers, flat cars are used to transport a wide range of other large loads that do not need to be transported inside a railcar.

Figure 11: Flat car. Transports commodities that do not fit in other car types or do not need protection from the weather such as machinery, pipes, and poles (as pictured). Flat cars can come in many configurations with special equipment for the specific commodity being carried (for example, the car pictured has stakes to help hold the poles on the car).

Figure 12: Centerbeam flat car. Transports lumber products.

Figure 13: Bulkhead flat car. Flat car except equipped with vertical bulkheads to prevent shipments from sliding off the end of the car. Transports commodities such as pipes or beams.

In addition to freight cars, railroads have various other pieces of equipment that move in trains or individually on the rails under their own power. This equipment may be used to ensure safe train operations, move railcars at industrial facilities, or help maintain and repair the track.

Figure 14: Caboose / shoving platform. A place for the conductor and other crew members to ride, now only used in local freight service as a platform on which crews can stand rather than riding on the side of a freight car.

Figure 15: Railcar mover. Although not found in trains, railway shippers, such as this grain elevator, may use a railcar mover instead of a locomotive to shift individual railcars for loading or unloading at a rail-served industrial facility. Railcar movers also have rubber tires that allow them to also use roadways to move around a facility.

<u>Materials List and Setup</u>

Materials:

This activity can be conducted and constructed with a variety of different materials. Options include:

- Railcar and commodity matching game with one set of labelled railcar pictures and another set of images depicting different commodities that match a specific railcar. The railcar pictures and commodities can be printed on cardstock and laminated for re-use. Participants must match the commodity "cards" to the correct railcar picture taped to a table.
- Model railway cars with labels can also be used for the matching game in place of the railcar pictures. Commodity images on laminated cards could be matched to the correct railcar, or samples of different commodities in small clear plastic containers could be used for matching.
- A "railcar puzzle" (Figures 16 and 17) featuring a wooden game board with removable railcar cutouts. The puzzle was constructed from two layers of plywood, with the bottom layer serving as a base. Before being affixed to the bottom layer, a jig saw was used to cut out several "puzzle pieces" shaped like a locomotive and different types of railcars in the overall pattern of a train. The removable cutout puzzle pieces are decorated with an image depicting the outside of the railcar, while an image of the commodity corresponding to that railcar is inserted into the cutout where the railcar fits. A cutaway view showing the diesel engine, cab, and other internal components can be used for the locomotive.

Regardless of the materials used, a set of railcar types and commodities can be selected from the figures presented on the previous pages to show the range of railcars and types of freight shipped by rail.

Side views of cars and locomotives for use in construction of a puzzle or matching game can be found on the internet: http://paintshop.railfan.net/home.html

Figure 16: Puzzle showing locomotive puzzle piece and cutaway view in puzzle board cutout.

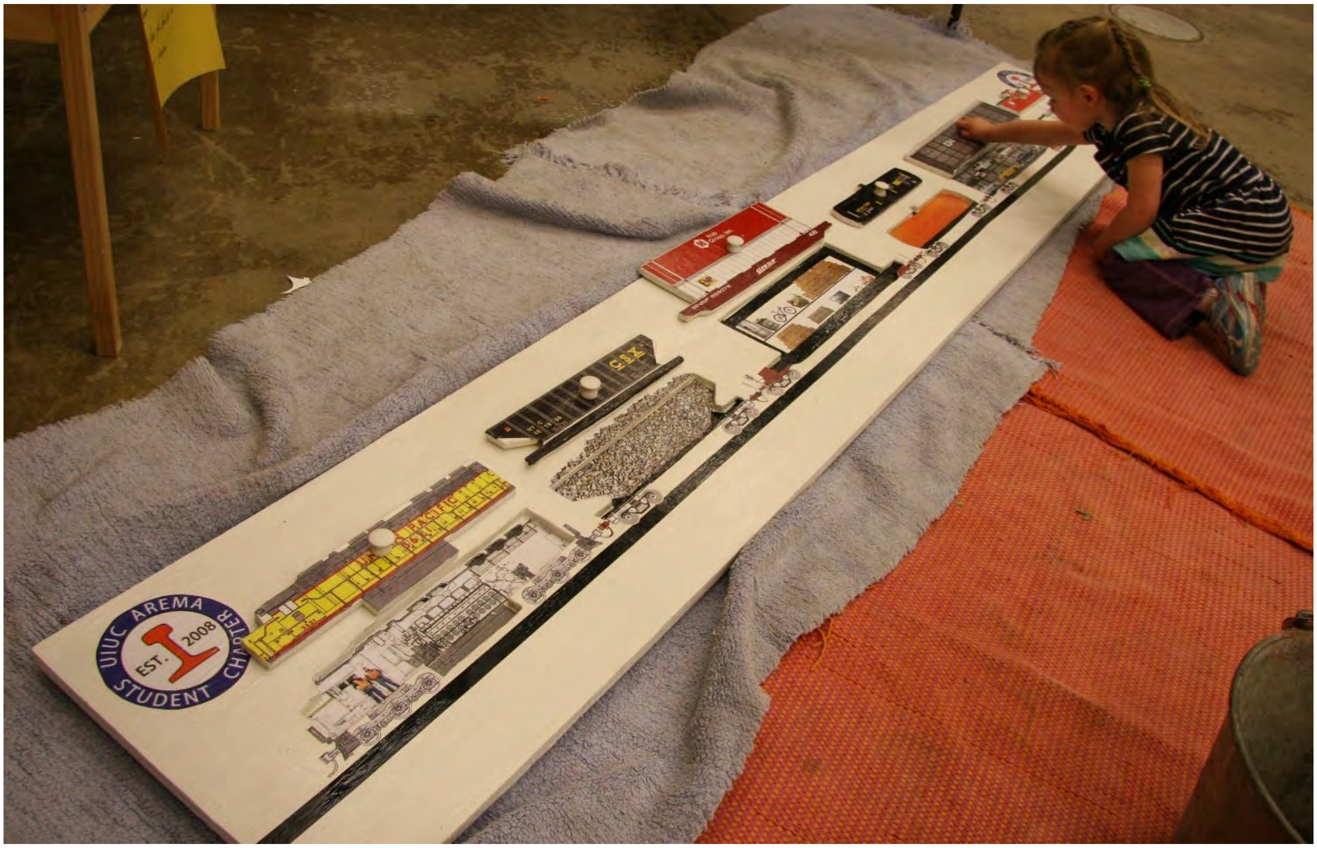


Figure 17: Wooden railcar puzzle constructed with wooden car cutouts forming a train composed of a locomotive, open hopper, double-stack container well car, tank car, autorack and caboose.

<u>Script</u>

This activity can be conducted as an interactive activity with an activity leader, or it can be setup as a display. The puzzle option works well as a display since the shape of the puzzle pieces guides participants to the correct answers without any supervision or guidance. When conducted with an activity leader, participants engage in a matching game between the types of railcars and commodities.

- Begin by asking the participants what trains carry. Naturally, there are a wide range of correct responses.
- After some discussion, explain that such a wide variety of commodities require a wide variety of railcars to carry them. Provide the participant with the commodity cards if being used.
- Introduce the railcar types and have the participant try to match the commodities with the appropriate railcar type by matching the commodity card to the correct railcar picture or model, or placing the correct railcar puzzle piece in its matching commodity cutout opening.

If using railcar and commodity pictures and there is more time for each participant, or the activity is being used a demonstration for a group, the matching game could also be played like “Memory”. Place all of the railcar and commodity picture cards face down and have the participants take turns flipping over two cards at a time until they successfully match railcars and commodities.

Questions to Stimulate Student Thought

1. What are some reasons that freight is hauled in different car types?
2. How many different freight car types can you name?
3. What are some other commodities transported by railroads and what kind of railcar is required to transport them?
4. Why might railcars of the same type have different lengths, sizes and shapes? *(See the Railcar Size and Weight activity description for additional ideas on this topic)*

Adjusting for Time and Participant Age

1. This activity can be lengthened or shortened by increasing or decreasing the number of railcar types in the puzzle or matching game.
2. For older participants, ask them if they can think of some kinds of freight that may be moved in each car type (see question 3 under *Questions to Stimulate Student Thought*).
3. This activity can serve as a good lead-in for the Railcar Size and Weight activity that conducts a more detailed exploration of the relationship between railcar size, weight and shipment density.

Railcar Size and Weight for Different Freight Shipment Density

Railroads carry many different commodities with different densities. This activity demonstrates why railcars of different sizes are optimized for the commodity they carry.

Number of Participants: 1-2 **Recommended Age:** 10+

Setup Time: 10 minutes **Activity Time:** 15-20 minutes

STEM Concepts:

- *Science: density, or mass per unit volume, is an important property of materials shipped by rail*
- *Technology: to increase efficiency, railcars are optimized to carry freight of a specific density*
- *Engineering: size and weight carrying capacity are important aspects of railcar design*
- *Mathematics: calculating gross, net and tare weight are important for loading railcars*

<u>**Key Learning Points**</u>

1. **Railcars are designed for freight shipments with different density. This affects railcar size.**
2. **All railcars are loaded to the same gross rail load when they are optimized for their lading.**
3. **The less an empty railcar weighs, the more tons of freight it can carry.**
4. **Over-loaded railcars will damage the track structure while under-loaded railcars are an inefficient use of railcar capacity.**

<u>Background</u>

Railcars (or freight cars, also known simply as "cars") are the vehicles that form trains and are loaded with freight to be transported by the railroad. There are many types of railcars that are designed to carry specific types of freight. For example, liquids or pressurized gases that flow and take the shape of their container are transported in tank cars that are accordingly designed as long cylinders. However, in looking at different tank cars, one may notice that certain tank cars may be longer than others or may have cylinders of different diameters (Figure 1). Why do railroads need tank cars of different sizes? This activity explores how and why railroads need to match the size and shape of a railcar to the density of the specific freight commodity it is intended to transport.

Figure 1: Tank cars with different length and diameter cylindrical tank bodies

Every railcar has a maximum capacity for hauling freight. This capacity constrains the weight and volume of freight that can be transported by a railcar.

The maximum weight of freight that can be transported by a railcar is limited by the ability of the railcar wheels and track structure to support heavy loads. The total weight of a loaded railcar is known as the gross rail load (GRL). Depending on the track and bridges a railcar will move over, and the wheels and design features of a particular railcars, the maximum GRL is usually either 220,000 pounds, 263,000 pounds, 286,000 pounds, or 315,000 pounds. Most common railcars that can travel over much of the North American freight rail network have a maximum GRL of 286,000 pounds.

The gross rail load for a given railcar is the sum of two parts (Figure 2):

- The tare weight or "light weight" of the railcar when it is empty
- The weight of the freight load or "lading" the railcar is carrying

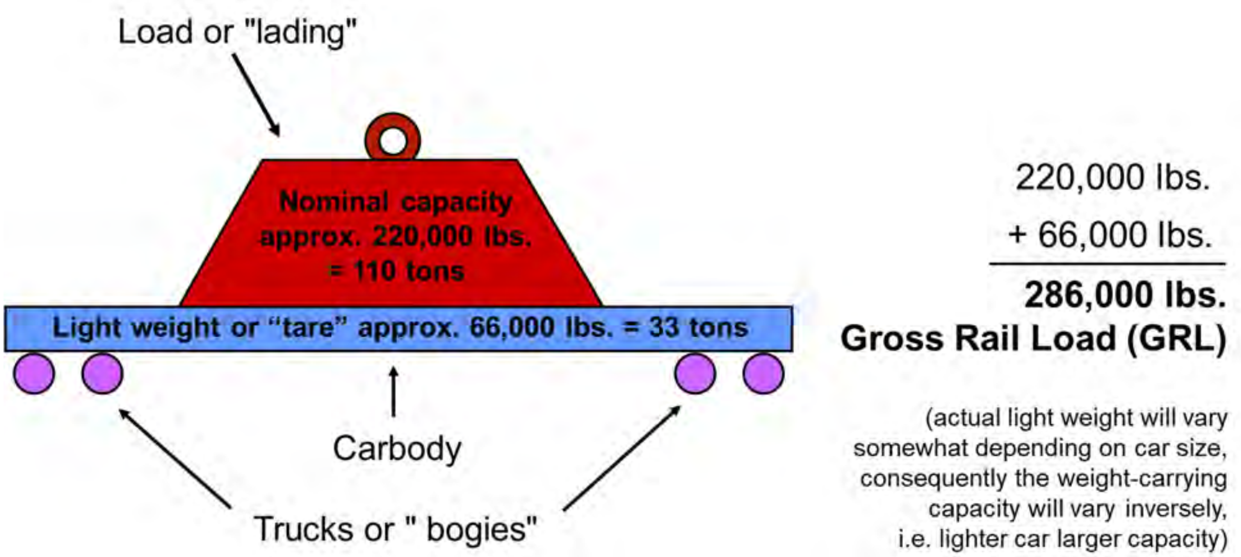


Figure 2: Gross Rail Load (GRL) is composed of empty railcar weight and lading weight

As shown in Figure 2, a typical railcar with the GRL of 286,000 pounds might have an empty weight of 66,000 pounds, allowing it to carry 220,000 pounds or 110 tons of freight. If a railcar is designed to weigh less when empty, by using aluminum or other composite materials for example, the railcar will be able to transport additional freight for the same 286,000 pound GRL. Thus railroads can be more efficient when railcars are designed to be as light as possible while still meeting requirements for overall strength, durability and safety.

The maximum volume of freight a railcar can transport is limited by its overall physical size (length, width and height) or "volumetric capacity". A typical railcar with a 286,000-pound GRL can transport 110 tons of freight, but the volume occupied by that 110 tons of freight can be quite different depending on the specific material of commodity being shipped. The volume occupied by a given mass of material is related to its density:

Density = Mass / Volume

Because 110 tons of material will occupy a different volume depending on the density of the material, railroads require railcars of different sizes to optimally transport materials of different density. For example, a dense material such as sand requires a smaller railcar (Figure 3) compared to less dense material such as plastic pellets that requires a larger railcar (Figure 4) for the same weight of freight to be transported.

Figure 3: A short covered hopper designed for a high-density material (such as sand).

Figure 4: A long covered hopper designed for a low-density material (such as plastic pellets). Notice how this car is nearly twice as long as the car shown in Figure 3.

A railcar that is optimized for the density of the lading it is carrying will run out of volume exactly at its maximum weight. When there is a mismatch between the size of the railcar and product density, one of two conditions is encountered:

- A railcar that runs out of volume before reaching the maximum GRL is carrying a commodity with a density below optimum. With a lower-density material, the available volume is not enough to reach the weight-carrying capacity of the railcar, and the railcar will overflow before reaching its weight limit. This condition, known as "cubing out", is inefficient because it "wastes" the weight-carrying capacity of the railcar.
- A railcar that reaches its maximum GRL before the entire volume of the car is filled with lading is carrying a commodity with a density above optimum. With a higher-density material, the volume occupied by the maximum weight of lading will be less than the overall volume of the railcar. This condition, known as "maxing out", is inefficient because it "wastes" the cubic or volumetric capacity of the railcar.

This activity will experiment with different ladings and sizes of railcars to illustrate the difference between an optimized and unoptimized railcar.

<u>Materials List and Setup</u>

Materials:

- Two open-top model railcars of different size (volume)
    - An O scale or G scale ore hopper and coal hopper work well (Figure 5)
- Two granular materials with densities roughly proportional to the railcar volumes, such as:
    - Metal ball bearings or "bee-bees"
    - Unpopped popcorn seeds
- Digital kitchen scale
- Optional: other materials of different density (plastic pellets, popped popcorn, dried seeds etc.)

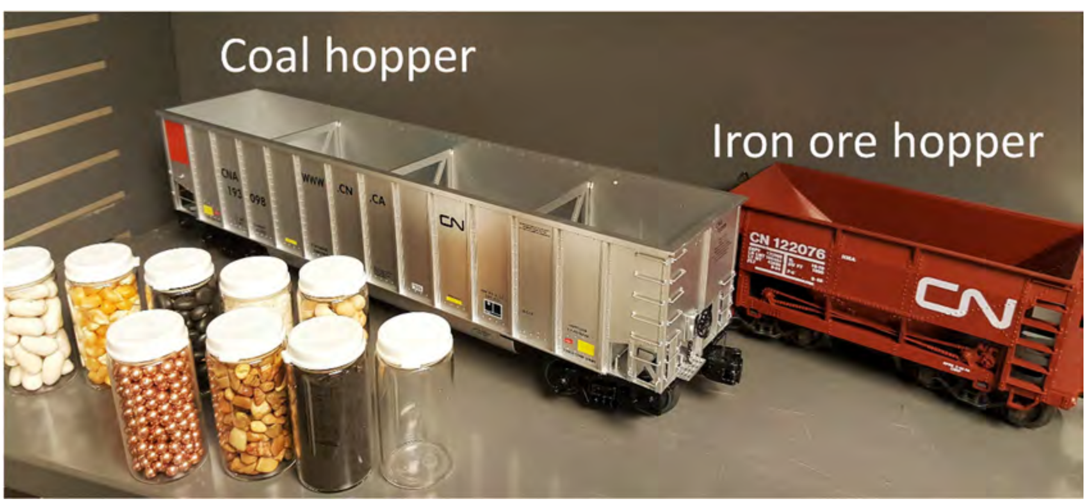


Figure 5: Model railcars and materials used for railcar size and weight exercise

<u>Script</u>

1. Ask the students to explain density or remind them of the concept. Ask them which of the provided materials are least dense, most dense, and how they know which is which (Figure 6).
2. Weigh the empty ore car (or other short car) and empty coal car (or other long car). Record the empty weights on the sample worksheet. This represents the tare (or empty) weight of the cars.
3. Have the participants fill the ore (short) car with metal ball bearings. Weigh the loaded car. This weight will set the maximum allowable gross rail load for both cars.
4. Have the students try filling the coal (long) car with ball bearings and weighing the car. They will find that the car is heavier than the maximum allowable gross rail load! This is known as “maxing out”, and because the overloaded car could damage track and bridges, it could not be shipped on most Class I railroads.
5. Have the students slowly remove ball bearings from the car until its weight matches the maximum allowable gross rail load. Have the students estimate how much of the railcar volume is still filled with material at the maximum gross rail load. Empty the coal (long) hopper.
6. Fill the coal (long) hopper with popcorn seeds. If the material densities are approximately proportionate to the volume of the two railcars, they should find that the weight of the coal hopper loaded with popcorn seeds is close to the gross rail load! The coal car is well optimized for the less-dense popcorn seed lading.
7. Have the participants fill the ore (short) hopper with popcorn seeds. The car will run out of volume long before it reaches the gross rail load. This is referred to as “cubing out.” The short ore hopper is optimized for the metal ball bearings but not the popcorn seeds.

Figure 6: Students comparing the density of the two materials before loading and weighing railcars .

Why are railcars different shapes and sizes?

1) Fill out the table below with the empty weight of each car and the gross weight of each car when loaded with each material.

Material	Short Car	Long Car	Notes
None			Empty Weight

2) Which material is the most dense? Least dense?

3) How did you decide which material was the most dense and least dense?

4) What is the most that these railcars can weigh (maximum allowable gross rail load of freight plus empty railcar)?

5) Which material will you transport in each car to be most efficient?

Questions to Stimulate Student Thought

1. Why would a railroad want to avoid loading a railcar above the maximum gross rail load?
2. Why would a railroad want to avoid loading a railcar with a commodity that has a density below the optimum such that it weighs far less than the maximum gross railcar load?
3. Why would a railroad want to avoid loading a railcar with a commodity that has a density above the optimum such that it only fills a portion of the volume of the railcar?
4. What are some ways that railroads and railcar manufacturers can decrease the empty or light weight of a railcar?

Adjusting for Time and Participant Age

1. To increase the complexity of the activity, try adding additional commodities such as dried seeds and beans, plastic beads, marbles, popped popcorn, etc. to find the perfect combination of materials to fill each railcar at the gross railcar load
2. Estimate the cross-sectional area of one of the model railcars and then ask the students to calculate the length for a railcar optimally designed to carry a commodity with a specific density. The density of a material can be estimated by dividing the weight of the material in the car when full by the volume of the car (estimated cross-sectional area times length). The students could even use cardboard and tape to build their own railcar model and test their calculations.
3. For younger students, one or both materials could be substituted with candy or healthy granola or cereal snack items to enhance student engagement.

Wheel-Rail Dynamics: How Railcars Travel Around Curves

The wheels are one of the most important parts of a railcar. This activity examines how the shape of railroad wheels is designed to minimize wear and steer the railcar on straight and curved track.

Number of Participants: 2+ **Recommended Age:** 6+

Setup Time: 45 minutes **Activity Time:** 10-15 minutes

STEM Concepts:

- *Science: A stable equilibrium is self-correcting while an unstable equilibrium is hard to maintain.*
- *Technology: Negotiating a curve with a fixed-axle railroad wheelset is a technical challenge.*
- *Engineering: The taper of a conical railroad wheel is designed for steering and stability at speed.*
- *Mathematics: The circumference or distance around a curve is related to its diameter or radius.*

Key Learning Points

1. **Railroad wheelsets use a fixed axle and are designed to steer around a curve. This is done by using a conical section for the wheel.**
2. **Use of a conical wheel section results in the wheelset hunting (a side to side motion) as it travels down straight track. This phenomenon is called Klingel motion.**
3. **A wheelset with conical wheels results in a stable equilibrium that helps keep the wheels on the track. However, other potential wheel designs could result in an unstable equilibrium that will pull the wheels off the track.**

Background

Unlike highway vehicles, railway locomotives do not have a steering wheel that allows the train crew to actively control the direction of the train. Instead, the track serves as a fixed guideway that dictates the path a train will follow. The flanged railroad wheel is a critical part of a railroad locomotive or railcar. Not only do railroad wheels support the weight of the railcar and allow it to roll and along the track, they also help steer the railcar through the various geometric features of the track. It is commonly thought that the flange on the railroad wheel always contacts the rail on curves and forces the train to follow a curved path. However, such an arrangement would generate a large amount of friction and noise on curves and increase wear on both the wheels and the rails.

Instead of relying on the flange, the shape of the wheel tread (the portion that rolls on the top of the rail) is carefully designed to allow railcars to negotiate curved and straight sections of track. Railroad wheelsets use a fixed axle to prevent the wheels from rotating at different rates or directions and subsequently causing a derailment on straight (tangent) track. On curves, the wheelset must be able to adjust its position so each wheel progresses through the curve at the same speed. A conical tapered wheel design allows the wheelset to shift in curves such that the difference in rolling radius between the two wheels can “match” the difference in length between the inside and outside rails on a curve. This activity examines different wheel designs and demonstrates the benefits of the conical design.

This activity is composed three parts:

- Background activity on rolling radius and curvature
- Main wheel-rail dynamics activity
- Behavior of additional wheelset shapes (see Adjusting for Time and Participant Age)

<u>Materials List and Setup</u>

Materials:

The background activity requires two "wheel set models" (one cylindrical and one conical) that can be constructed from several different materials:

- Two sheets of paper and tape
  - One sheet rolled and taped to form a cylinder
  - One sheet rolled and taped to form a cone
- Drinking glasses or cups
  - One with straight sides so the top and bottom have equal radius
  - One with tapered sides such that the top is larger than the bottom
- Circular cardboard cutout wheels pressed on to a pencil axle
  - One axle with two wheels of equal radius
  - One axle with two wheels of different size radius
- Tinker toys with wooden wheels and axles
  - One wheelset with two wheels of equal radius
  - One axle with two wheels of different radius

The main wheel-rail dynamics activity can be constructed in several ways:

- PVC pipe and/or wooden dowels and popsicle stick track with plastic cups as wheelsets
- G scale model railroad track with machined wheelsets (see worksheet for possible shapes)
- O scale model railroad track with icing tip wheelsets held together with modeling clay (see worksheet for possible shapes to make with pairs of icing tips)

For main the wheel-rail dynamics activity setup using PVC pipe and plastic cups described in detail on the following pages, the following materials are required:

- 8-12 feet of ½" diameter PVC pipe and/or wooden dowels to serve as rails
- Popsicle sticks (to serve as crossties)
- Glue to fasten pipe/dowel rails to popsicle stick crossties (a hot glue gun works well)
- 4 x Tapered plastic cups (taped end-to-end in normal and inverted configurations)
- Cardboard paper towel roll (optional)

The extended activity with additional wheelset shapes is best conducted with the G scale model railroad track and machined metal wheelsets or the O scale model railroad track and icing tip wheelsets.

<u>Script for Background Activity:</u>

1. Gather the required materials and assemble two railroad wheelset models, one cylindrical and one tapered.

2. Place the two wheelsets on a table or level surface and ask the students what is different about the two wheelsets. They should be able to identify that one is "cylindrical" or has wheels of equal size, while the other is "tapered/conical" or has wheels of different sizes.

3. Ask the students to predict what will happen when each of the two wheelsets is rolled forward across the table.

4. Roll the cylindrical or equal-sized wheelset forward. It should travel in a straight line.

5. Roll the tapered/conical or unequal-sized wheelset forward. It should travel in a curved path, turning in the direction of the smaller wheel or small end of the taper/cone (Figure 1).

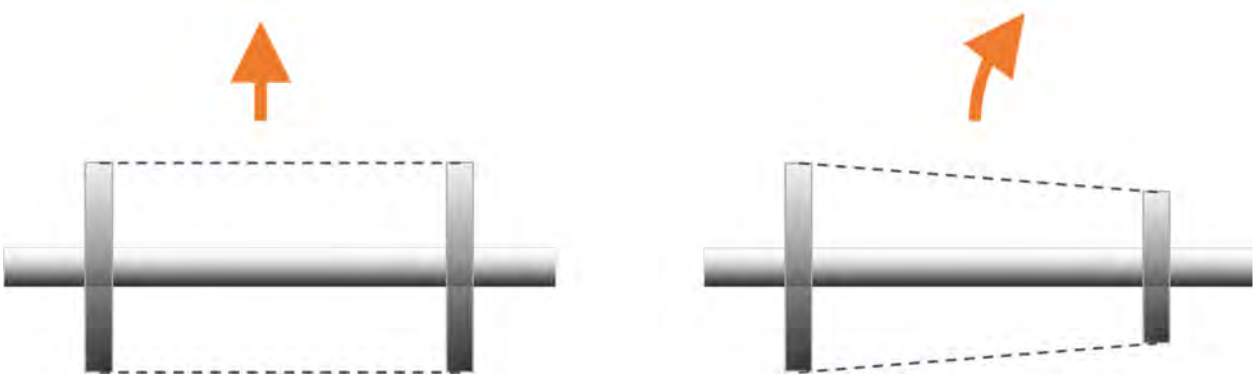


Figure 1: Straight direction of travel for cylinder or wheelset with equal-size wheels and curved direction of travel for taper/cone or wheelset with unequal-size wheels.

6. Ask the students to explain why the tapered/conical or unequal-sized wheelset travels in a curved path.
    a. With or without prompting, they may recognize that the wheels or ends of the taper/cone have different radius or diameter.
    b. Because of the difference in diameter, the circumference or distance around the wheels or opposite ends of the taper/cone will also be different. The circumference corresponds to the distance the wheel/end will travel forward when rotated once.
    c. Since the wheelset model has a fixed axle, for each rotation, the larger wheel/end must travel a longer distance than the smaller wheel/end while still moving together. This difference in rolling distance creates a curved path.

7. Ask the students to imagine or draw a circle of railroad track with a pair of rails.

8. Ask the students if each rail, referred to as the inner rail and the outer rail, comprising the circle of track is of equal length.
    a. They should come to the conclusion that the outer rail makes a larger circle than the inner rail, and hence the outer rail must be longer than the inner rail.
9. Explain to the students that because the outer rail is longer than the inner rail, if a railroad wheelset were to roll around the circle, the outer wheel must travel a longer distance then the inner wheel (Figure 2).

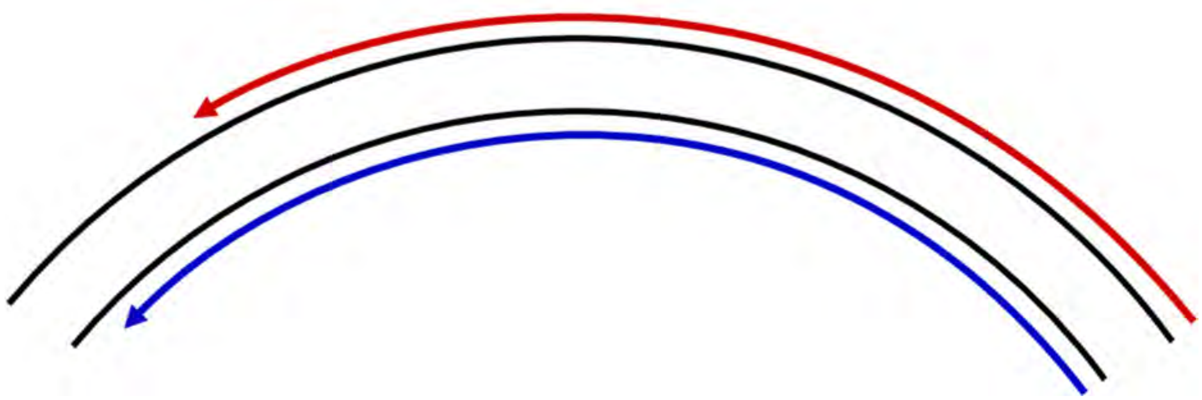


Figure 2: Difference in length between the inner and outer rail of curved track.

10. Ask the students how this relates to the first experiment with the cylindrical/equal-sized wheelset and tapered/conical/unequal-sized wheelset.
    a. They may suggest that a tapered/conical/unequal-sized wheelset would be able to roll around the circle of track.

11. Ask the students how such a tapered/conical wheelset would roll on straight track or a track with a different curvature.
    a. With or without prompting, the students should conclude that a different shape might be needed for different curves and straight sections of track.
    b. For example, a larger difference in wheel size is needed to travel around a sharper curve while a smaller difference in wheel sizes is required to travel in a broader gentle curve.

12. Explain that if the two wheels could change their diameters, the wheelset could adapt to travel on different curves in either the left or right-hand direction or, when the wheels are equal in size, travel straight.

13. Using the tapered wheelset model, explain how if a single railroad wheel were made to be tapered/conical, its diameter will change depending on where it sits on top of the rail (Figure 3).

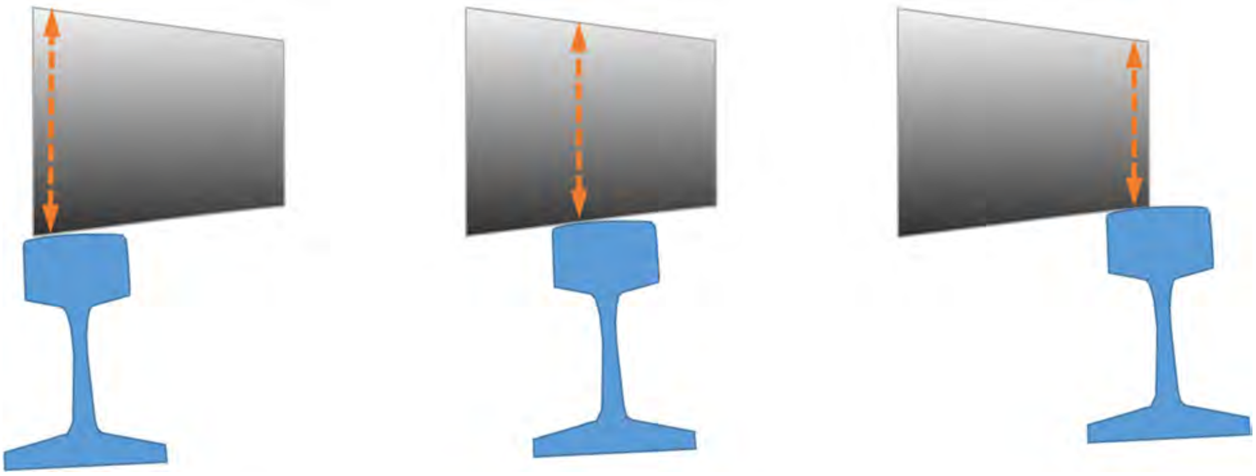


Figure 3: A tapered conical wheel can change its rolling diameter depending on where it contacts the top of the rolling it is rolling on.

14. Explain that this is why railroads use tapered conical wheels, but the questions remains of how to place the wheels on the axle: with the tapers facing in or out (Figure 4)? This leads to the demonstration in the main wheel-rail dynamics activity.

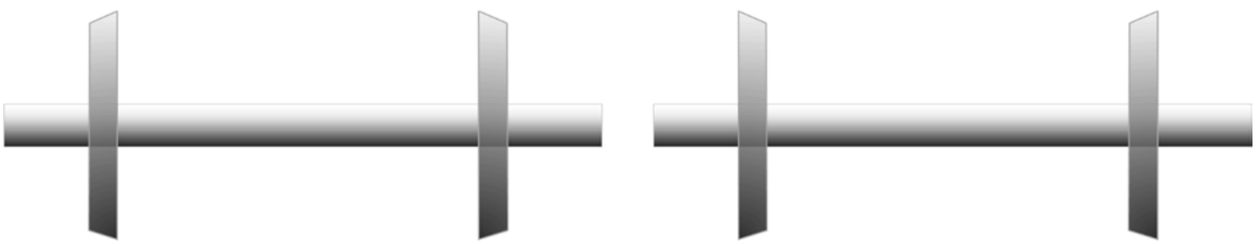


Figure 4: Two possible arrangements for a railroad wheelset with tapered wheels: tapers facing out (left) or tapers facing in (right).

<u>Script for Main Wheel-Rail Dynamics Activity:</u>

15. Before starting the main activity, assemble a track section that includes both a section of tangent (straight) track and a curve.
    a. If using PVC pipe and/or wooden dowels, the wooden dowels work well for straight sections of track but PVC is needed for curves. You may need to heat and bend the PVC pipe to create a curve. Glue the PVC pipe to the popsicle sticks as shown (Figure 5).
    b. If using G scale or O scale model railroad track, you should purchase several tangent sections and several curve sections.

16. Elevate the straight/tangent end of the track section to make the wheelsets roll down the track at a steady speed but not too fast (or wheelsets will become unstable and derail).

Figure 5: PVC pipe and popsicle stick track setup.

17. For setups using only the cups with PVC pipe and popsicle stick track, the demonstration will consist of the two wheelset configurations shown in Figure 6 below. A third shape that can be tested is a simple cylinder which can be represented to by an empty paper towel roll. These three shapes correspond to the first three shapes on the worksheet. Ask the students to predict which wheelset(s) will derail on both the tangent and curved track.

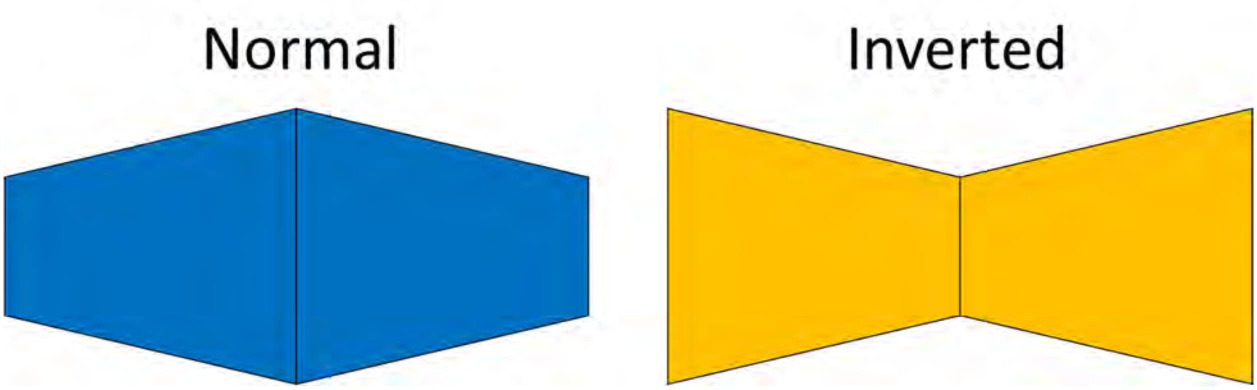


Figure 6: Wheelset configurations

18. Test each wheelset (Figure 7). The normal one should be able to make it to the end of the track and through any curves, while the inverted one will likely derail before reaching the end of the tangent track. A simple cylinder may make it down the tangent track but will roll right off the curve since it has no mechanism to steer around the curve and keep it on the track.

Figure 7: Testing a wheelset with normal conicity.

19. Explain that the normal configuration shown in Figure 6 can shift to match the radius of the "wheel" to the length of the "rail" that it is riding on in a curve. However, this leads to a back-and-forth motion while it travels down straight tangent track. This sinuous motion, called Klingel motion (Figure 8), is the result of the wheelset constantly trying to correct itself to the middle of the track, overcorrecting, and trying to re-correct again. This is a *stable equilibrium* because the wheelset will try to bring itself back to the middle of the track (the equilibrium state).

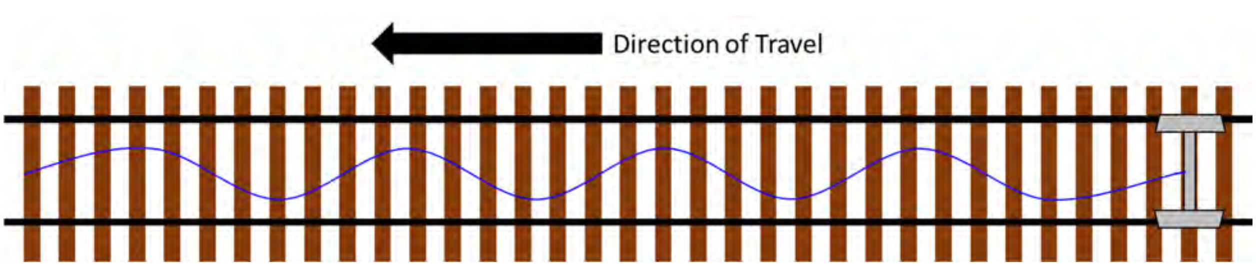


Figure 8: The (exaggerated) path of a railroad wheelset due to Klingel motion.

20. Explain that the inverted wheelset does not work because it is in an *unstable equilibrium*. If it was perfectly and symmetrically placed relative to the middle (centerline) of the track so that each wheel had the exact same rolling radius, the wheelset would be able to follow straight portion of the track. However, this is nearly impossible, meaning that the wheelset will pull itself off the track. If the wheelset did manage to reach a curve, it would immediately derail because the wheelset would shift in the wrong direction (smaller wheel radius would be matched with a longer rail and vice versa).

21. Allow the students to try rolling any of the wheelsets down the track themselves to get a better understanding of why the normal wheelset follows the track!

Questions to Stimulate Student Thought

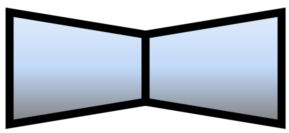
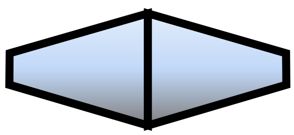
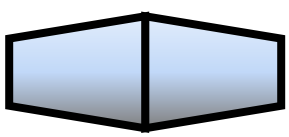
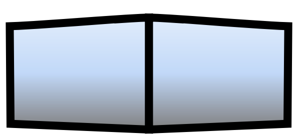
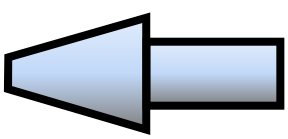
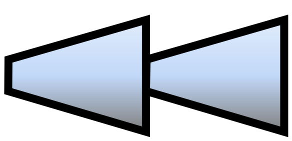
1. How does the railroad wheelset steer itself around the curve?
2. What do you think happens as the wheelset wears?
3. Even though the wheelset steers itself around curves, do you still think it needs a device to keep itself on the rail?

Adjusting for Time and Participant Age

1. This activity can be expanded by including other wheelset configurations as shown on the attached worksheet. These wheelsets can be machined (for use with G scale model railroad track) or, for use with O scale model railroad track, made using icing tips held together with modeling clay and an axle material of your choice (such as wooden dowel rod). As with the other wheelset types, ask students to predict which wheelsets pictured on the worksheet will follow the tangent and curved track sections.
    a. Wheelsets three, four and five on the worksheet are in the “normal” configuration but have different amounts of taper.
        i. Wheelset three with the largest taper can achieve a large amount of rolling radius difference and is thus less stable than the others on straight tangent track but has good performance on curved track.
        ii. Wheelset five with the slightest taper can only achieve a small amount of rolling radius difference and is thus more stable than the others on straight tangent track but has difficulty on curved track.
    b. Wheelsets six and seven represent different conditions that arise when railroad wheels wear at different rates. See if you can predict which ones will work well!

2. An additional task for the students could be to construct the track before testing the wheelsets. This expansion would allow for the students to learn about rail and crossties. See our *Railroad Track Construction* Activity for more information on track components and the track structure.

Performance of Railway Wheelset Shapes

	Tangent (Straight) Track	Curved Track
		
		
		
		
		
		
		

Train Rolling Resistance

Trains rely on the low friction between a steel wheel and steel rail to provide efficient transportation. This activity examines the forces resisting the movement of a train and compares them to that of a truck.

Number of Participants: 1-4 **Recommended Age:** 8+

Setup Time: 15 minutes **Activity Time:** 15-30 minutes

STEM Concepts:

- *Science: rolling resistance is a function of material properties and weight*
- *Technology: railroads can efficiently haul large amounts of freight over long distances partly due to low rolling resistance per ton of freight transported*
- *Engineering: railroad transportation engineers must estimate the rolling resistance and corresponding pulling force required to move a train at a constant speed in order to determine the maximum size and weight of train that can be moved by a particular locomotive*
- *Mathematics: rolling resistance force per ton is the force required to move the vehicle divided by the weight of the vehicle; graphs can reveal trends and relationships in observed data*

Key Learning Points

1. **Trains must overcome resistance to begin moving.**
2. **Drawbar pull is the force being exerted by the locomotive(s) on the train and train resistance is the total resistance of all the cars and locomotives in the train.**
3. **As train weight increases, its total resistance force also increases.**
4. **Rubber tires have more resistance than steel wheels, partially explaining why trains provide more efficient long-distance freight transportation than trucks.**

Background

Newton's first law of motion states that an object will remain at rest or in uniform motion unless acted upon by an external force. In a railroad setting, the locomotives on a train provide that "external force" that propels the train into motion. However, the train is also subject to external forces such as friction on the train wheels and axles, wind resistance, and gravity (if the train is on a slope), all of which resist the movement of the train. Of those factors, friction on the train wheels, axles and bearings has been the subject of much investigation. Lower friction means that a vehicle will have less rolling resistance to motion and consume less fuel and energy when transporting freight or passengers. Reduced energy and fuel consumption improves transportation efficiency by saving money and, by producing fewer greenhouse gas and other emissions, is better for the environment.

The steel railroad wheel on a steel railroad rail provides a stiff, low-friction interface between trains and the track structure. In comparison, rubber truck tires and asphalt pavements deform to produce a higher friction interface. Because of this difference, railroads have a lower rolling resistance per unit weight (ton) compared to highway trucks, buses and automobiles, as demonstrated by this activity.

<u>Materials List and Setup</u>

Materials:

This activity will require two model railcars capable of being loaded with additional weight, such as a flatcar, gondola or open hopper. One of the railcars should be kept in its standard configuration with metal railroad wheels while the other railcar is modified to be equipped with rubber tires in place of its metal wheels. Axles with the appropriate rubber-tire wheel spacing can be assembled from radio-control (RC) car parts appropriate for the particular railcar models, axle lengths and wheel sizes. Alternatively, to avoid modifying the railcars, one of the two railcars can be pulled on a rubber foam pad to represent the deformation of roadway pavement under highway trucks. Stiffer pads tend to yield better results.

- Two G scale gondola cars (one will suffice if using the rubber foam pad)
- Rubber-tire wheelsets for one railcar (or rubber foam pad)
- G scale track sections (a total of 2 to 4 feet of track length)
- Spring scale (500g/5 N range)
- Digital kitchen scale to weigh the railcars and verify weights
- Weights to load the railcars

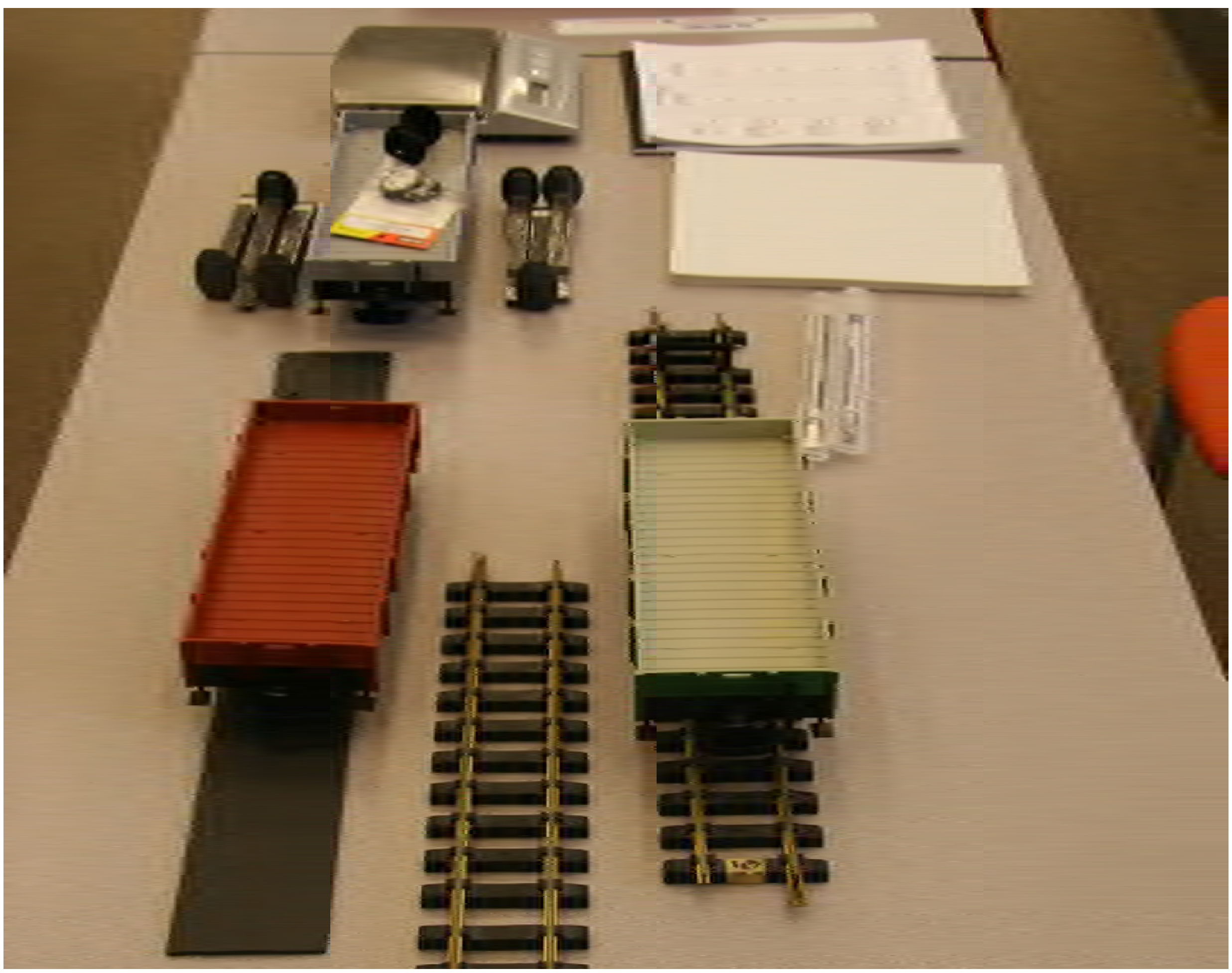


Figure 1: Some of the materials required for this activity.

<u>Script</u>

1. Set up one of the two freight cars with rubber tires instead of metal wheels if not using a rubber foam pad (Figure 2). This car will represent a rubber-tired truck driving on an asphalt road.

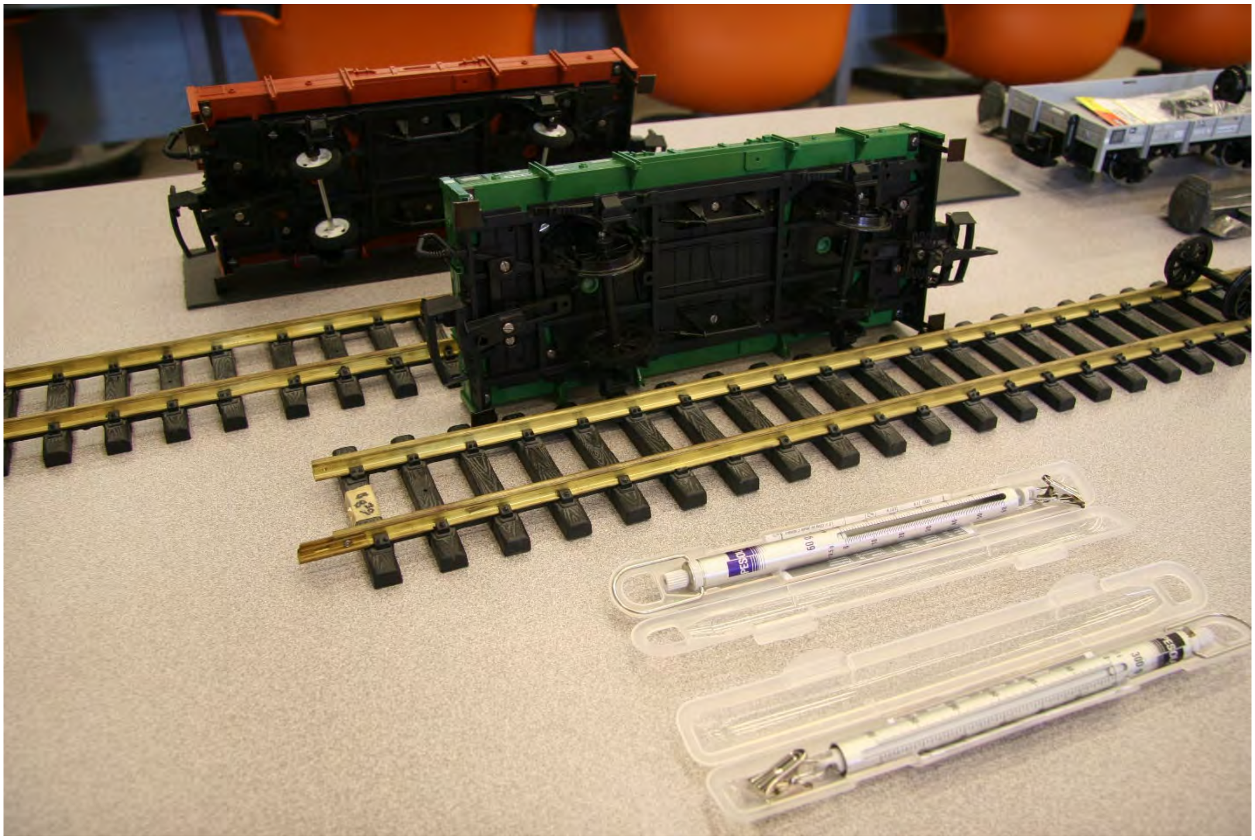


Figure 2: Railcars with metal wheels (front) and rubber tires (back).

2. Using a digital kitchen scale, measure the empty weight of each railcar and record it on the activity worksheet.

3. Place the rubber-tired car on the table surface or rubber foam pad (the “road”) and clip the spring scale to one end of the car. Use the spring scale to pull the car across the table or along the “road” at a <u>constant speed</u> and measure the force required. The participant may need to use both hands to support the spring scale and ensure it is measuring in a direct line of force parallel to the track centerline and tops of the rails (Figure 3). It may take a slightly larger force to start the car moving than required to move it at a constant speed. It may take a few tries to determine the proper pulling force to keep the car moving smoothly at a constant speed. Record the constant speed force on the worksheet as the “roadway” rolling resistance force.

4. Repeat Step 3 by loading the car with one or two weights. We tested the cars empty, loaded with one railroad spike, and loaded with two railroad spikes (each spike is about 12 oz.). Be sure to record both the total weight of the car (empty weight plus load) and the pulling (rolling resistance force) read from the spring scale on the worksheet for each combination!

Figure 3: Testing a car with metal wheels on a section of G-scale track.

5. Place the metal-wheeled railcar on the G scale track section and repeat Steps 3 and 4 to determine the "railroad" rolling resistance force with the same three weight conditions (empty, one weight, and two weights). Record both the total weight of the railcar (empty weight plus load as appropriate) and the pulling (rolling resistance force) read from the spring scale on the worksheet for each combination.

6. Plot the observed values of weight and rolling resistance force for each railcar on the same set of axes (weight on the horizontal axis and rolling resistance on the vertical axis). The resulting data points and trend lines will show the relationship between total railcar weight, rolling resistance force, and the effect of wheel material (or highway and rail transportation mode) on the rolling resistance relationship.

The experimental results should show that the "railroad" condition with metal wheels on track have less friction than the "highway" condition with rubber-tire wheels or a car on the foam rubber pad. This same relationship is observed in full-scale real-world transportation systems. Trucks must overcome more friction than trains and therefore burn more fuel by ton-mile. On average, a truck requires three times more fuel to haul a ton of freight one mile compared to a train. Stated differently, for the same amount of fuel, a train can transport a ton of freight approximately three times farther than a truck!

<u>Questions to Stimulate Student Thought</u>

1. Which transportation mode (truck or railroad) has lower resistance per ton? How do you know?
2. Which transportation mode would be better for moving a large amount of freight over long distances? Why?
3. Which is more expensive to construct, road or railroad? How does this relate to resistance per ton? (Does higher expense mean lower resistance per ton?)

<u>Adjusting for Time and Participant Age</u>

1. For older participants, try performing three measurements of each distinct railcar loading condition and then taking the average of those values for your final observed value. Explain that this averaging process more closely reflects the scientific process than only testing once.
2. For younger participants, or to shorten the activity, use Excel or other spreadsheet programs to plot the observed values quickly and show that the "railroad" railcar with metal wheels has a lower resistance than the "highway" car, and the overall trend as the total weight increases.
3. For a more comprehensive experiment that investigates other factors affecting train and railcar resistance to motion, experiment with one or both of the following:
   a. Elevate one end of the track section to create an incline or track "gradient". Test different amounts of incline and plot its relationship to the amount of force required to move the railcar at constant speed. This force relationship, known as "grade resistance" is explained by the classic physics and trigonometry of a block on an inclined plane.
   b. Instead of a straight track section, measure the force required to move the railcar at constant speed around a curved section of track. If possible, investigate track sections with a different curve radii to compare sharp and broad curves. The resisting force, known as "curve resistance" should be larger for sharper curves (of a smaller radius).

Train Resistance

Empty Cars:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

One Weight:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

Two Weights:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

Additional Weight Point:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

Additional Weight Point:

	Rubber Tires (or Foam Pad)	Metal Wheels on Track
Car Weight		
Force Measurement 1		
Force Measurement 2		
Force Measurement 3		
Average Force		

Locomotive and Train Simulators

This activity allows participants a chance to experience the challenge of operating a train through a computer simulation.

Number of Participants: 1 **Recommended Age:** 3+

Setup Time: 20 minutes **Activity Time:** 5-20 minutes

STEM Concepts:

- *Science: long train braking distances arise from the physics of high inertia and momentum*
- *Technology: modern locomotives are highly engineered with advanced technology on board*
- *Engineering: long train braking distances are reflected in design of track and signal systems*
- *Mathematics: calculating the braking distance of a train is critical to safe operation*

Key Learning Points

1. **Trains usually require a long distance to stop, typically farther than the locomotive engineer can see ahead. Thus, stay off the tracks since trains will not be able to stop for an obstruction.**
2. **Trains do not accelerate as quickly as automobiles.**
3. **The slow acceleration and deceleration characteristics of trains are directly related to its relatively large mass. Because trains are heavy, they have substantial amounts of inertia and thus it takes a lot of accelerating force or braking effort to start and stop.**

Figure 1: Student operates a virtual locomotive in Run8 Train Simulator with a RailDriver controller

Background

Becoming a locomotive engineer has been the dream of many children since the inception of the railroad. While many never get a chance to operate a locomotive in real life, locomotive simulators can provide a similar experience. It takes skill and practice for a locomotive engineer to learn how to properly handle a train up a steep mountain pass without stalling, or to know when to begin braking a higher-speed passenger train to make an exact stop at the platform of an upcoming passenger station. Train crews must spend time running a simulator and making multiple trips over a particular route with an instructor before they are allowed to operate a train over that same route on their own. If they need to operate a train over a different route, they must go through the same training process again with an instructor experienced on the unique requirements of that route.

A locomotive simulator also provides an avenue for educating students on how the physics of mass, acceleration, force, power and momentum pose a challenge for the train crew. When operating a heavy train at high speeds, the train crew does not have the ability to stop quickly. In most cases, the distance required for the train to stop exceeds how far the train crew can see along the track ahead. By the time the train crews sees an obstruction on the track ahead, it is too late to stop the train before reaching it. Besides having implications for the engineering of the railway signal system that controls the movement of trains, demonstrating the time and distance required to stop a train can reinforce the message of railway safety. Because a train cannot stop quickly, trespassing on the railroad or not obeying signs and signals at highway-rail grade crossings will often have fatal consequences.

Several locomotive simulator software programs (more commonly known as train simulators) are available for purchase and are a popular activity for students at rail-focused camps and outreach events.

Materials List and Setup

- Simulator of your choice
  - Microsoft Train Simulator
  - Train Sim World
  - Train Simulator
  - Trainz
  - Run8 Train Simulator
- RailDriver Desktop Train Cab Controller (optional, but highly recommended)

Each of the simulators listed above has its advantages and disadvantages, briefly summarized below.

Microsoft Train Simulator (MSTS) is well known but relatively old (released in 2001), so the graphics are somewhat dated compared to other locomotive simulation software. It is still possible to find MSTS in CD-ROM format through various outlets on the internet and it has the advantage of often being relatively inexpensive. However, MSTS is not supported on operating systems newer than Windows XP.

Train Sim World (TSW) is the latest train simulator on the market. TSW is produced by Dovetail Games and features the ability for the user to get out of the locomotive and walk around. Nearly every switch and button is functional in the world of the computer model. Because this is a relatively new product, the content selection is somewhat small and more expensive than other options listed here.

Train Simulator (formerly known as **Railworks**) produced by Dovetail Games has been updated regularly since 2009. It has a large content base available, although some of the add-ons are relatively expensive. The RailDriver controller is compatible with Train Simulator.

Figure 2: Screenshot from Train Simulator inside a GE ES44AC

Trainz was released in 2001 but new versions have been frequently rereleased since then with updated graphics and additional modeled routes and railway equipment. Trainz is a solid middle-ground option that is not too expensive but lacks some finer simulation details of other options on this list.

Figure 3: Screenshot from Trainz

Run8 Train Simulator is the most technically advanced simulator on this list. The price is comparable to Train Simulator or TSW. However, the geographic route content included with the base game is less than most of the other options on this list. Additionally, the simulator can be too accurate in the sense that it can require some advanced knowledge of locomotive operation and proper train handling to use without triggering an emergency brake application that consumes considerable time to recover from.

Figure 4: Students learn about operating a locomotive in Run8 Train Simulator

The train simulator programs described here can all be operated using a standard computer keyboard and mouse interface. However, it can often be difficult to recall which key commands correspond to the various controls in the locomotive cab, particularly for a facilitator that does not use the train simulation software on a regular basis.

Using the **RailDriver Desktop Train Cab Controller** from P.I. Engineering to interface with a selected train simulator software can provide a more realistic locomotive simulator experience. The RailDriver controller provides throttle, brake and direction controls, plus switches for the locomotive horn, bell and headlights, all with a look, feel and action matching that of an actual locomotive cab. The RailDriver controller connects to Windows computers running a locomotive simulator via USB. By manipulating the RailDriver cab controls in a realistic way and observing the corresponding response of the locomotive simulator software, students can get a better feel for the true experience of a locomotive engineer handling a freight train, as opposed to feeling like they are just controlling a computer mouse and keyboard.

<u>Script</u>

If you are unfamiliar with the controls in a typical locomotive cab, most train simulators have a tutorial that will walk you through the basics of running a locomotive in the context of that particular simulator. However, most diesel-electric locomotive models have the same basic controls. A short list of the most important ones and their functions is provided below.

- Reverser – selects the direction in which the locomotive will move. This can be removed from the control stand on a real locomotive to prevent unauthorized use
- Throttle – changes the amount of power the locomotive is generating and delivering to the wheels to move the train forward (or backward). Usually has nine positions (idle plus eight "notches" each corresponding to a different power output). Higher notched produce more power and allow the train to pull a heavier load or achieve a faster speed.
- Automatic (train) brake – applies/releases the air brakes on the entire train (including locomotives)
- Independent brake – applies/releases the brakes on the locomotives only
- Horn – sounds the locomotive's horn
- Headlight switch – selects headlight brightness and direction

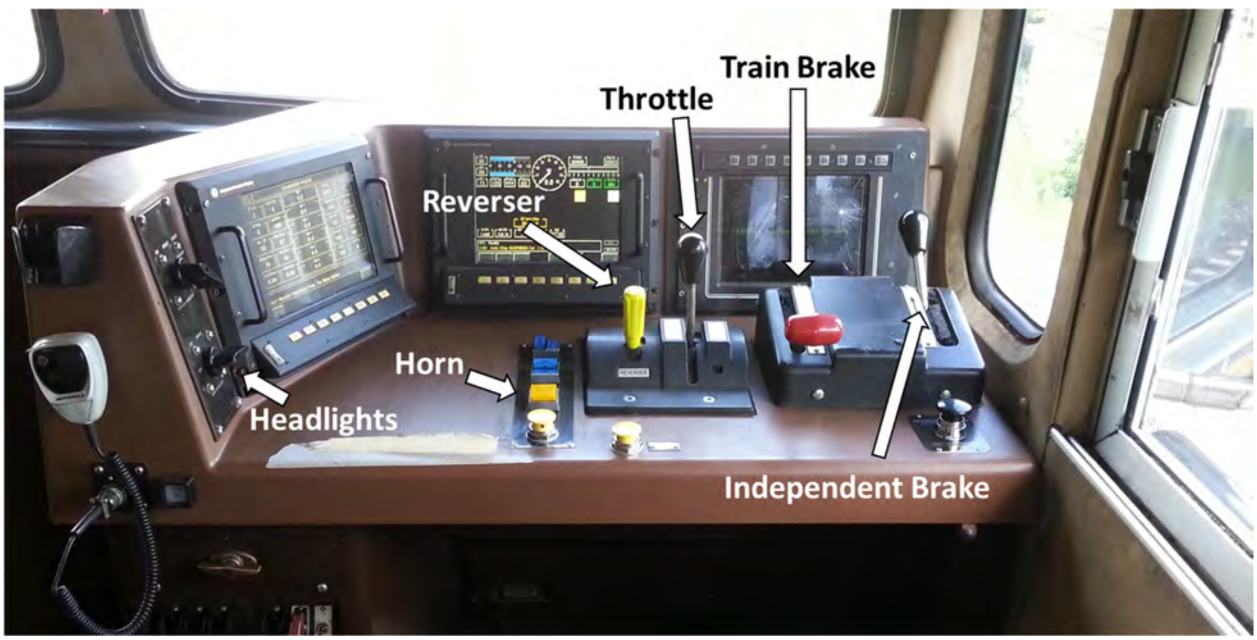


Figure 5: The control stand of a GE AC4400 freight locomotive. This control stand is similar to many other modern freight and passenger locomotives.

When conducting this activity, we recommend operating the train over a commuter line with frequent station stops or some other route that will require frequent starting and stopping. This keeps participants engaged with accelerating and braking the train by manipulating the throttle and brake controls. The stops also provide convenient places to swap participants. You will likely need to instruct each participant on the purpose and function of each of the locomotive cab controls, help them with starting/stopping the train, and with complying with posted speed limits.

Questions to Stimulate Student Thought

1. Why does it take so long for a train to stop?
2. How many of the controls in the cab can you name?

Adjusting for Time and Participant Age

1. The activity can be shortened or lengthened by allowing students to operate the simulator for longer or shorter periods of time as needed.
2. Younger students will likely need more direction while operating the simulator.
3. Older students could be introduced to signaling concepts with the simulator.

Railroad Simulation Software Package Websites

Train Sim World: https://live.dovetailgames.com/live/train-sim-world

Train Simulator (Railworks): https://live.dovetailgames.com/live/train-simulator

Trainz: https://www.trainzportal.com/

Run8: http://www.run8studios.com/

RailDriver Control Stand: http://raildriver.com/products/raildriver.php

Microsoft Train Simulator: No official website

Railroad Track Construction

This activity allows participants to build their own section of railroad track from the subgrade to the rails.

Number of Participants: 2 or more **Recommended Age:** 3+

Setup Time: 30 minutes **Activity Time:** 15 minutes

STEM Concepts:
- *Science: pressure is the amount of force applied over a given area*
- *Technology: track is a structure designed to support the weight of railway rolling stock*
- *Engineering: track components reduce pressure by distributing forces over a greater area*
- *Mathematics: use averages of multiple trials to obtain a representative measured value*

Key Learning Points

1. **Understand the basic components of railroad track (rail, ties, ballast) and their purpose.**
2. **Track components take very high forces and gradually spread them out over a large area.**
3. **Track ballast is effective at resisting lateral and longitudinal forces.**

Background

Railroad track is designed to support the weight of heavy locomotives and railcars moving at speed. The components of the track structure must be able to resist large forces created by trains in both the vertical and lateral directions:
- Rails guide the train wheels and transfer their weight across multiple crossties (also simply called “ties”).
- Crossties support the rails, hold them the proper distance apart, and distribute the weight of the train over a larger area, reducing pressure on the ground below.
- Ballast, the crushed rock gravel that is underneath and between the crossties, supports the crossties, and provides resistance to the forces created by the train. Ballast also facilitates drainage of water away from the track structure.

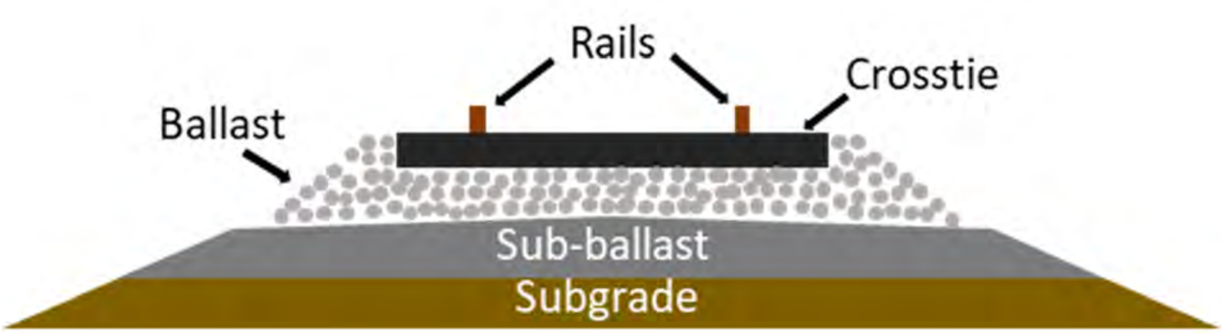


Figure 1: Typical railroad track cross-section showing the main components of the track structure.

This activity demonstrates the effectiveness of ballast at restraining the track and helps the participants understand the different components of track and their purposes.

<u>Materials List and Setup</u>

Materials to construct one 18-inch track section:

- Cookie sheet, approx. 18 inches in one dimension (with sides to keep materials from spilling)
- Approximately ten balsa wood “crossties”, each 3.5” x 0.5” x 0.5”
  - A 36” length of ½” square balsa wood strip commonly sold in craft stores can be cut into the ten crossties required for this length of track
- Two metal rails removed from G-scale model railroad track sections
  - The rails from one straight track section 18” to 24” in length work well
- 40 “Map-Style” push pins with 1/8” round head (approximately 1/2" to 3/5” overall length)
- Sand
- Aquarium gravel
- Spring scales (2.5 N/250g and 5N/500g capacity, we bought from https://sciencekitstore.com/)
- Sieve (to separate gravel and sand for storage after completion of the activity)
- Small hand saw (to cut ties to length from the balsa wood strip)
- G scale wheelset or railcar (optional)

Figure 2: Some of the materials required for this activity.

Script

In this activity, the participants will construct a short section of railroad track. The track will be built as skeleton track (no ballast) and will be gradually built up from individual track components. We recommend building the track on a cookie sheet with sides to prevent the sand and aquarium gravel from spilling. The lateral and longitudinal resistance of the track will be measured using a spring scale at various times during the activity.

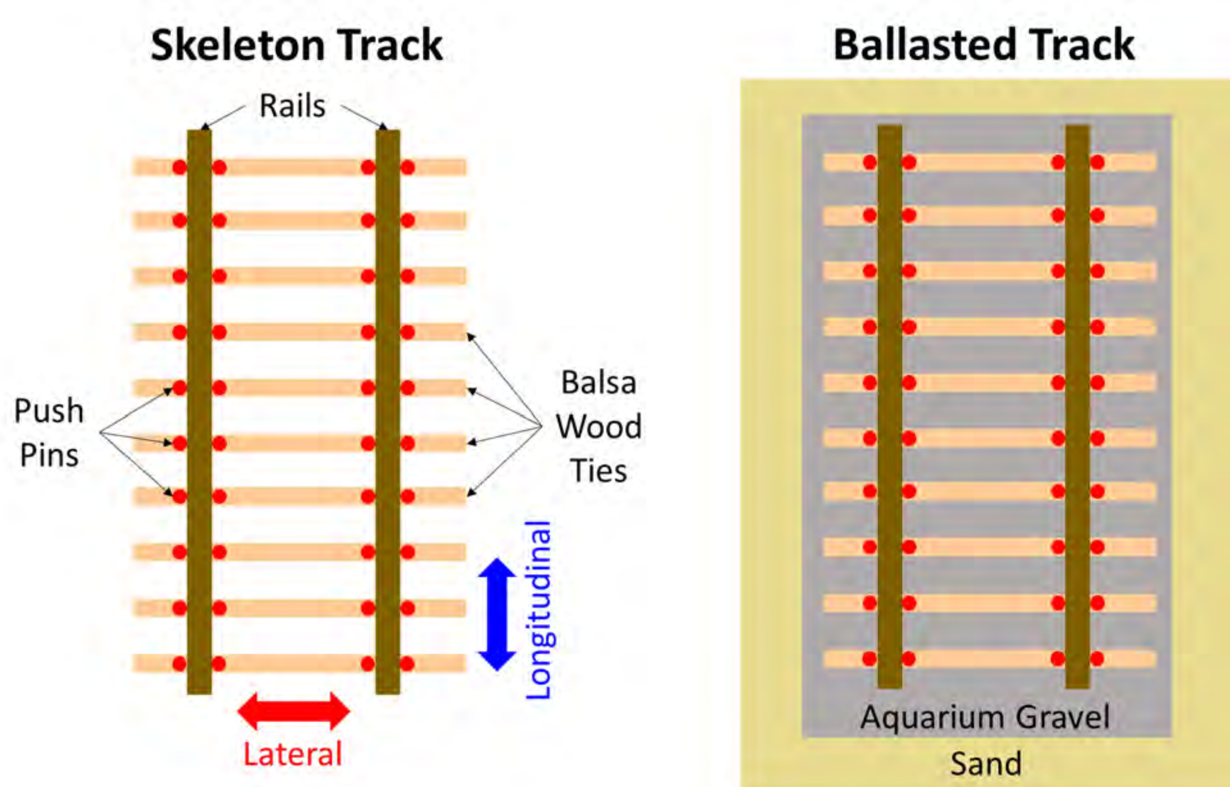


Figure 3: Schematic of skeleton track and ballasted track.

1. Construct the skeleton track by spacing out the balsa wood ties and laying the rails on top of them. For best results, construct at least 12" to 18" of track with approximately 1.5" of spacing between each crosstie. (If the ½" square balsa wood strip has yet to be cut into ties, you may either have the students perform this task or prepare the ties yourself prior to starting the activity. Each tie should each be around 3.5" long, although this dimension does not need to be precise as long as it is reasonably to scale.

2. Use push pins to secure one of the rails to the ties, approximately ¾" to 7/8" from the ends of the ties. Then position the second rail such that the distance between the rails is approximately 1 ¾" and secure with push pins. A distance of 1.75 inches between the rails is the proper "track gage" for G scale track, allowing the track to be tested with a G scale wheelset or railcar, if available. Each rail should be held to each crosstie by two push pins, one on each side of the rail, for a total of four push pins per crosstie as shown in Figure 3 above.

3. Once the skeleton track is assembled, use a spring scale to measure the lateral resistance of the track (perpendicular to the rails). Clip the spring scale to one of the rails and gently pull on the skeleton track perpendicular to the rails until the track starts to move. Also test the longitudinal resistance of the track by pulling on it parallel to the rails. From the spring scale reading in Newtons or grams, record the force resisted by the in each direction on the activity worksheet (found in the appendix). We recommend making three measurements and taking the average of the three. Without ballast, it will not require much force to move the track. This is not ideal for real track since movement of the track could cause a derailment!

Figure 4: Students test the lateral resistance of skeleton track. The sand subgrade for step 4 is ready on the left.

4. Once the values for the resistance of the skeleton track have been recorded, set the skeleton track to the side. Using the cookie sheet as a base, pour a level sand layer to serve as the subgrade that will support the ballast and track. The sand layer can fill the cookie sheet, or if the cookie sheet is considerably larger than the track section, the sand layer should extend longitudinally and laterally at least an inch or two around all sides of the track. Use a ruler or straightedge to smooth the top of the sand layer.

5. Set the skeleton track on top of the sand and measure the resistance in the lateral and longitudinal directions by gently pulling on the track with the spring scale. Record the observed values in the worksheet. The observed averages should be higher than when the track was sitting on the table or bare cookie sheet but will still be relatively low. If the skeleton track drags across the top of the sand, be sure to re-level the sand layer between each measurement.

6. After the resistance values for the track on top of the sand subgrade have been recorded on the activity worksheet, add a layer of aquarium gravel on top of the sand subgrade. The layer should be approximately ½" thick and represents the ballast layer underneath the track. Test both resistances and record the values.

Figure 5: Students pour a layer of aquarium gravel on top of the sand subgrade during step 6.

7. Set the skeleton track section on top of the aquarium gravel ballast layer. Using the same approach as in Step 5, measure the lateral and longitudinal resistance of the track on the ballast layer by gently pulling on the spring scale. Record the values in the worksheet and compare to the previous observations at different stages in the track construction process.

8. Next, add aquarium gravel between the rail and ties (the area is known as the "crib") but not around the ends of each crosstie. Note that the tops of the ties should remain uncovered.

9. Measure the lateral and longitudinal resistance values for the track with ballast in the cribs only and record them on the worksheet. Pull gently to avoid pulling the track out of the ballast.

10. Finally, add aquarium gravel along the sides of the track around the ends of the ties. This gravel represents the shoulder ballast which is critical in resisting lateral movement of the track structure. The section of track structure is now complete (Figure 7)! Test with a G scale wheelset or railcar if one is available (Figure 8).

11. Measure the lateral and longitudinal resistance values for the track with full ballast and record them on the worksheet. Pull gently on the spring scale to avoid displacing the track.

12. Compare the results. The resistance values should progressively increase as ballast is added to the track. Longitudinal resistance should improve significantly after the addition of crib ballast, while lateral resistance should improve significantly after the addition of shoulder ballast.

Figure 6: Students fill in the crib with ballast for step 7.

Figure 7: A section of completed track including shoulder ballast.

Figure 8: Students test a G scale railcar on their completed track sections.

<u>Questions to Stimulate Student Thought</u>

1. What would happen if railroads ran trains at high speeds on skeleton track?
2. Why do we add ballast along the sides of the track?
3. Why do we take three measurements when determining each resistance?

<u>Adjusting for Time and Participant Age</u>

1. This activity can be set up in a display format by constructing both skeleton track and ballasted track adjacent to one another. Students can then try moving the track sections while discussing the purpose of ballast and other track components.
2. If there are many students participating in the activity, try dividing them into groups and having each group construct a track section. At the end of the activity, if the students carefully observed all track dimensions and layer thicknesses, all of the track sections can be aligned end-to-end and be tested with a railcar (Figure 8).
3. To reduce the time required for this activity and focus on the track construction aspect, the various steps involving measuring lateral and longitudinal resistance can be omitted or only performed for the base skeleton track and final fully ballasted track section.
4. Also try our edible version of this activity!

Railroad Track Construction Activity Worksheet

Skeleton Track on Top of Bare Table:

	Longitudinal Resistance	Lateral Resistance
Measurement 1		
Measurement 2		
Measurement 3		
Average		

Skeleton Track on Top of Sand Subgrade:

	Longitudinal Resistance	Lateral Resistance
Measurement 1		
Measurement 2		
Measurement 3		
Average		

Skeleton Track on Top of Gravel Ballast:

	Longitudinal Resistance	Lateral Resistance
Measurement 1		
Measurement 2		
Measurement 3		
Average		

Track with Ballast in Cribs Only:

	Longitudinal Resistance	Lateral Resistance
Measurement 1		
Measurement 2		
Measurement 3		
Average		

Fully Ballasted Track:

	Longitudinal Resistance	Lateral Resistance
Measurement 1		
Measurement 2		
Measurement 3		
Average		

Edible Railroad Track Construction

Build your own section of "railroad track" from the subgrade up to the rails using cereal and candy!

Number of Participants: 2 or more **Recommended Age:** 3+

Setup Time: 0 minutes **Activity Time:** 10 minutes

STEM Concepts:

- *Science: pressure is the amount of force applied over a given area*
- *Technology: track is a structure designed to support the weight of railway rolling stock*
- *Engineering: track components reduce pressure by distributing forces over a greater area*
- *Mathematics: measuring materials and fractions*

Key Learning Points

1. **Understand the basic components of railroad track (rail, ties, ballast) and their purpose.**
2. **Track components take very high forces and gradually spread them out over a large area.**
3. **Track ballast is effective at resisting lateral and longitudinal forces.**

Background

Railroad track is designed to support the weight of heavy locomotives and railcars moving at speed. The components of the track structure must be able to resist large forces created by trains in both the vertical and lateral directions:

- Rails guide the train wheels and transfer their weight across multiple crossties.
- Crossties (also simply called "ties") support the rails, hold them the proper distance apart, and distribute the weight of the train over a larger area, reducing pressure on the ground below.
- Ballast, the crushed rock gravel that is underneath and between the crossties, supports the crossties, and provides resistance to the forces created by the train.

This activity demonstrates the effectiveness of ballast at restraining the track and helps the participants understand the different components of track and their purposes.

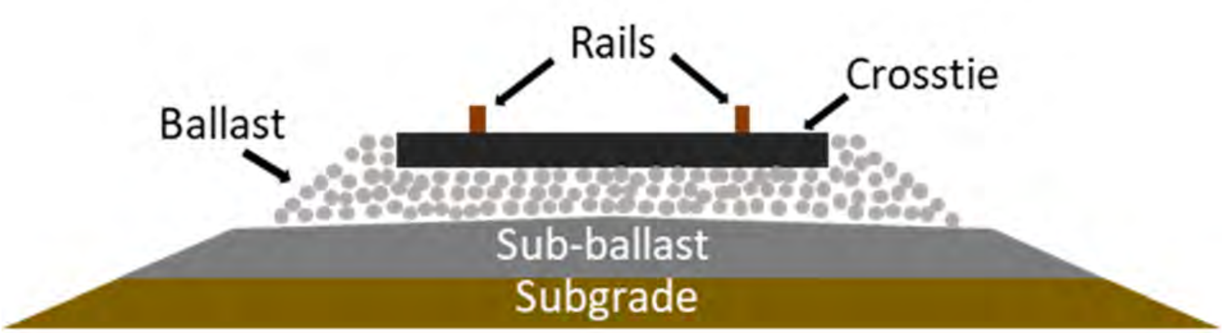


Figure 1: Typical railroad track cross-section showing the main components of the track structure

<u>Materials List</u>

Materials:

- The following materials and quantities are required for each participant to build their own edible track structure model:
  - Paper plate
  - Kit Kat bars (2 snack size bars)
  - Twizzlers twists (2 – fun size pieces)
  - Rice Krispies Cereal (1/4 cup)
- Royal icing (optional)
- These materials (Figure 2) are most economically obtained in bulk to cover multiple participants.

Figure 2: Recommended materials

<u>Script</u>

1. Construct the skeleton track (track without ballast) by spacing out the "ties" (two Kit Kats snapped in half to form four pieces) on the paper plate "subgrade" and laying "rail" (Twizzlers) on top of them. For best results, construct a track that is approximately 4-6 inches long (Figure 3).

Figure 3: Skeleton track

2. Optionally, put a dab of royal icing between the rail and each crosstie to secure the connection. After the icing hardens, try sliding the track side-to-side without lifting it off the plate. There will be little resistance to movement. This is not ideal for real track as it could cause a derailment!
3. Next, cover the track with Rice Krispies cereal (1/4 cup for the length shown in Figures 3 and 4). This represents the ballast (stone) that covers real railroad track and helps prevent the track from moving around underneath a train.

Figure 4: Ballasted track

4. After adding ballast, try moving the track side-to-side again. You should notice that it takes more force to move the track since you also must displace the "ballast" around the crossties. Real ballast serves this same purpose: to resist lateral and longitudinal movement of the track.
5. Enjoy your railroad track snack!

Single-Track Railway Operations Simulation Game

This activity highlights the economic and engineering challenges of operating single-track railway lines.

Number of Participants: 5-6 **Recommended Age:** 7+

Setup Time: 20 minutes **Activity Time:** 30-45 minutes

STEM Concepts:

- *Technology: movements on a single-track rail line are controlled by a dispatcher who communicates movement instructions to trains through a wayside signal system*
- *Engineering: passing sidings are expensive and must be placed in locations that maximize their effectiveness*
- *Mathematics: calculating the run time of each train on a line is important for minimizing delay*

Key Learning Points

1. **Trains travelling in opposite directions on a single track pass each other at "passing sidings".**
2. **The number of trains per day that can travel across a single-track corridor, also called "railway line capacity", is primarily dependent upon siding length and location.**
3. **The length of freight trains, both in terms of feet and number of railcars, is often dictated by the length of passing sidings between the origin and destination of a particular train.**
4. **Railway civil engineers have an important role in planning new sidings.**
5. **Railroads, like most other businesses, use math and economics in their day-to-day operations, and to make strategic decisions on investments to construct new track infrastructure.**
6. **Railroads benefit from economies of scale that lead to longer trains.**

Background

In the United States, freight railroads are private, for-profit businesses that earn money by transporting carloads of freight from a shipper to a consumer. In 2015, the major U.S. freight railroads transported 1.7 billion tons of freight. To transport this volume of freight, the major freight railroads use 161,000 miles of track on 94,000 miles of principal routes known as "mainlines". Each day, railroads draw upon a fleet of 29,000 locomotives and 1.5 million railcars to form over 5,000 freight trains. Simultaneously moving thousands of trains across the railroad network is a nontrivial engineering and operating challenge. This activity aims to simulate a single-track railroad mainline from a business perspective while highlighting some of the engineering and operating challenges that railroads face.

When crossing a railroad line or travelling by train, you may have noticed that most railway lines consist of a single track with a pair of rails. Trains must be able to travel on this single track in either direction. This is unlike highways where there are separate lanes for each direction of traffic and drivers can freely pass cars and trucks travelling in the opposite direction. Some railway mainlines do have a second track with each track assigned primarily to trains operating in a particular direction. However, these "double-track" mainlines, also called "two main tracks" are only found on roughly one-third of the major mainline routes in the United States. Double track, and the even rarer sections with three or four main tracks, are expensive for railroads to construct and maintain in good condition. Thus, approximately two-third of mainline routes in the United States only have one main track, also called “single track”.

You may be wondering how a railway mainline with one main track can be used to safely and efficiently operate trains travelling in opposite directions. Railways use a detailed set of operating rules and traffic control systems to keep a safe distance between trains. Trackside signals and radio instructions inform the train crew when it is safe to proceed or when they need to slow down or stop their train. Although these systems and procedures prevent trains traveling in opposite directions from colliding, how do two trains in opposite direction pass or move around each other if there is only one track?

On single-track lines, railroads must construct short sections of double track known as “passing sidings” so that trains travelling in opposite directions can pass each other. Usually, the process of two trains passing each other, known as a “meet”, begins with one train arriving at the passing siding and stopping clear of the main track. Usually, this train has a lower priority than the one that is not stopping.

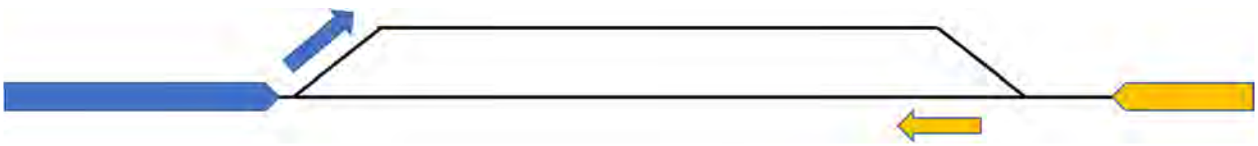


Figure 1: Example train paths when approaching a passing siding

Figure 2: Lower priority train (blue) stopped in a passing siding while waiting for higher priority train (orange) to pass in other direction

Once the lower priority train is stopped, it will wait until the higher priority train has cleared the end of the siding before proceeding.

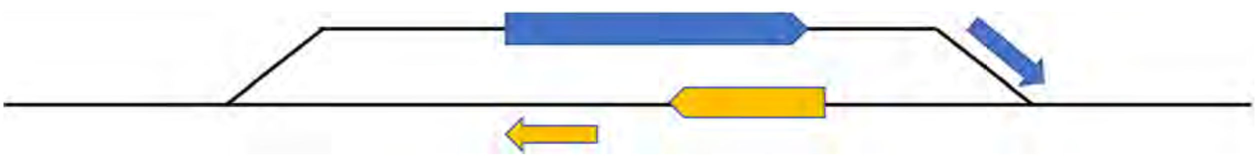


Figure 3: Lower priority train resuming travel

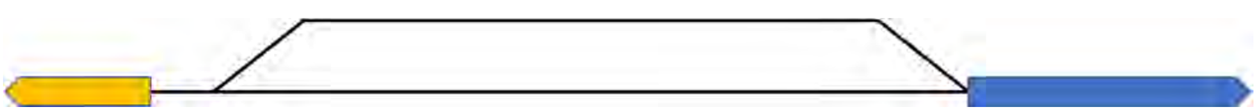


Figure 4: Meet process completed

In this activity, students will learn the importance of passing sidings to railway operations and how their length and frequency (or spacing between sidings) relates to the capacity or ability of a mainline to transport a given number of trains each day.

Figure 5: Perspective from train approaching one end of a railroad passing siding with a low-priority train waiting on the short section of second track

Figure 6: Locomotive engineer's perspective of overtaking another train waiting on the passing siding

Roles and Responsibilities

This activity uses wooden BRIO-style toy trains to simulate train movements (including meets) along a rail line. The simulation activity relies on several "officers" to act as external suppliers and business executives. These roles may be filled by students if the group size allows.

- Chief Operating Officer (COO): Runs the game and provides additional traffic
- Chief Engineer: Operates the Track Store where students can buy sidings
- Chief Financial Officer (CFO): Fills out cash flow spreadsheet
- Banker: Oversees payments to students
- Dispatcher: Directs train movements over the railroad

<u>Materials List and Setup</u>

- Track setup as described below
- Wooden, toy or model trains depending on the selected track material
- Play money
- A room with ample space to construct a long rail line spanning multiple movable tables arranged in an "S" or "C" shape configuration.

Track Setup:

Depending on the resources and materials available, there are several options for creating the track setup used in this activity:

- Wooden BRIO-style track with compatible trains (preferred)
- Paper track layout taped to a table with wooden trains
- Tape on tables to represent track with wooden trains
- Model trains with EZ-Track sections
- Lego trains with Lego track sections

The remainder of this description assumes the activity will use BRIO-style track with compatible wooden trains. Most of the track and train materials listed below can be ordered through online retailers but can often be found at local toy stores that specialize in wooden and/or imported educational toys.

The suggested track layout is designed to create an S-shaped pattern on multiple tables occupying an 11 foot by 11 foot space as shown at right. The exact track layout can be tailored to fit your group size and available space. Be creative! The main track should be long enough for students to feel like the train is going somewhere but not so long that the process of running trains becomes overly time consuming. Regardless of the length or shape, both ends of the main track should feature a "balloon loop" to turn trains around before their next trip. The balloon loop may contain additional stub "spur" tracks to store additional trains until they are needed.

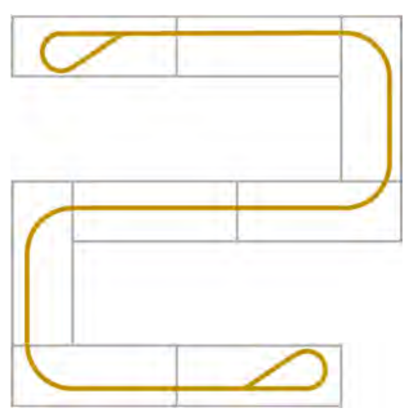


Table 1: Common BRIO Track Pieces		
Letter Designation	Length (inches)	Description
A	5.5”	Straight
A1	4.25”	Straight
A2	2”	Straight
A3	2.75”	Straight
B2	2”	Male-to-male adapter
C2	2”	Female-to-female adapter
D	8.5”	Straight
E	6.5”	Curve
E1	3.5”	Curve (1/2 E)
L	5.5”	Turnout (opposite connectors of M)
M	5.5”	Turnout (opposite connectors of L)

- The S-shaped mainline approximately 35 to 40 feet long including two 180° curves requires the following track sections (although any length of straight sections can be used as required to fit the available space):
  - ~60 x D
  - ~8 x E

- Each end of the mainline requires a “balloon track” terminal with optional stub tracks. A single balloon track with two stub tracks (as shown in Figure 7) requires the following track sections:
  - 2 x A
  - 1 x A2
  - 1 x A3
  - 1 x C2
  - 3 x D
  - 5 x E
  - 2 x L
  - 1 x M
  - 2 x A1 (optional, depending on Terminal design selected from Figure 7)

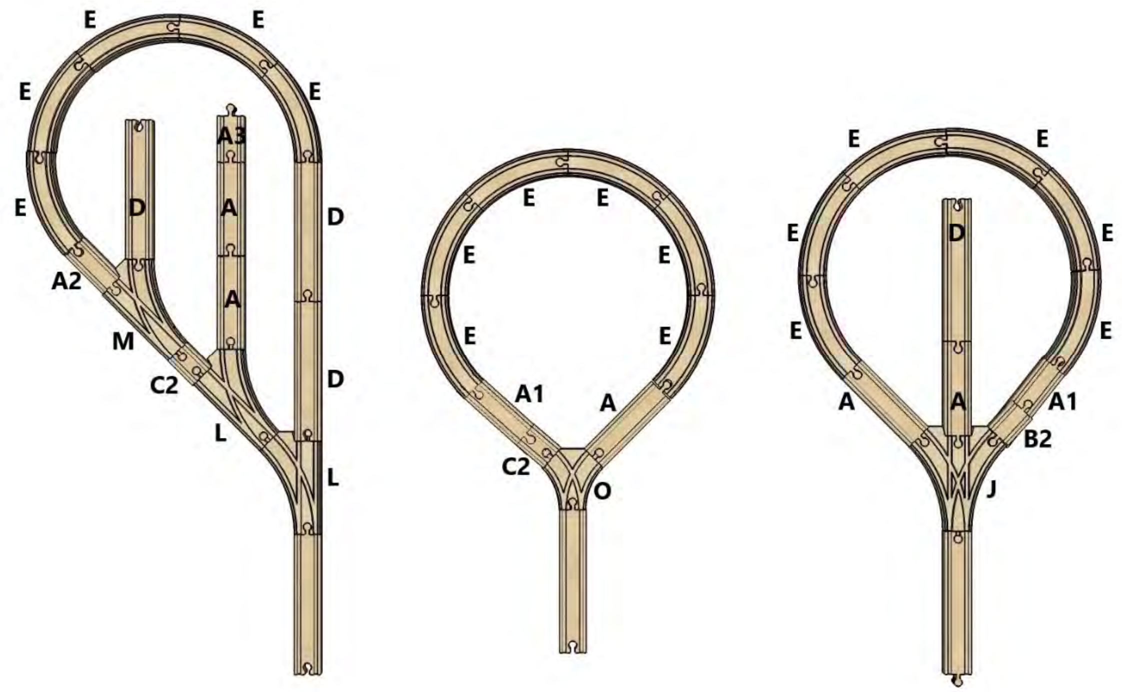


Figure 7: "Balloon Track" Terminal Designs

- During the activity, students will modify the mainline by constructing passing sidings. Initially, they will construct passing sidings long enough for a 4-car train, but they will later discover the benefits of long sidings that can hold a 6-car train. The sidings as shown in Figures 8 and 9 will replace either four or five "A" sections in the mainline, respectively. The following materials are required for one 4-car siding (a total of five passing sidings are required for the preferred layout, requiring all values below to be multiplied by five):
  - 1 x L
  - 1 x M
  - 3 x A
  - 2 x E1

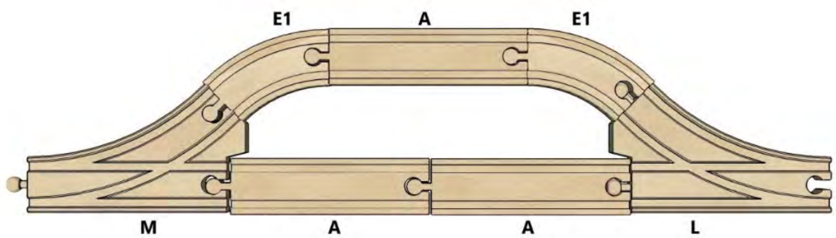


Figure 8: Siding design for a 4-car train

- A longer 6-car siding can be constructed with two additional "A" sections as shown below.

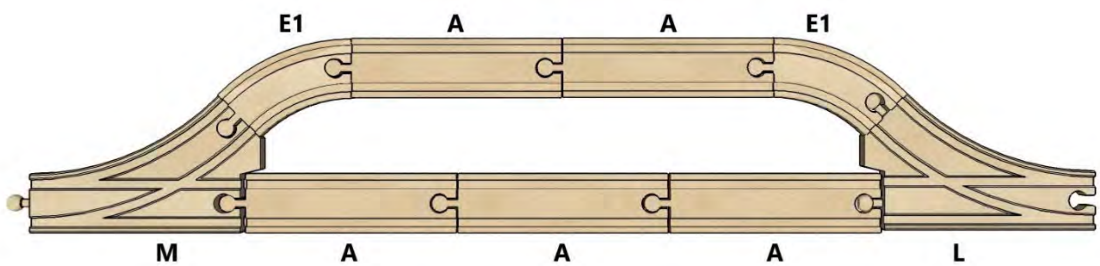


Figure 9: Siding design for a 6-car train

- Locomotives and rolling stock:
  - 4 x locomotives
  - 18 x freight cars
  - 1 x passenger train of any length

Initial Setup:

1. Build a route that is around 35 to 40 feet long with no sidings. You can perform this step in advance or also have the students help construct the initial route according to a drawing.
2. At each end of the line, construct the "balloon track" terminals. A balloon track is a loop of track used to turn a train around so it departs in the opposite direction from which it arrived. These are commonly found at coal mines, grain elevators, power plants and ports where entire trains arrive, are loaded or unloaded, and depart in the opposite direction.
3. Set up a train consisting of one locomotive and three cars at one end of the line.
4. Provide the CFO with $200 of starting capital for the group (we suggest printing out the "play money" in the appendix).

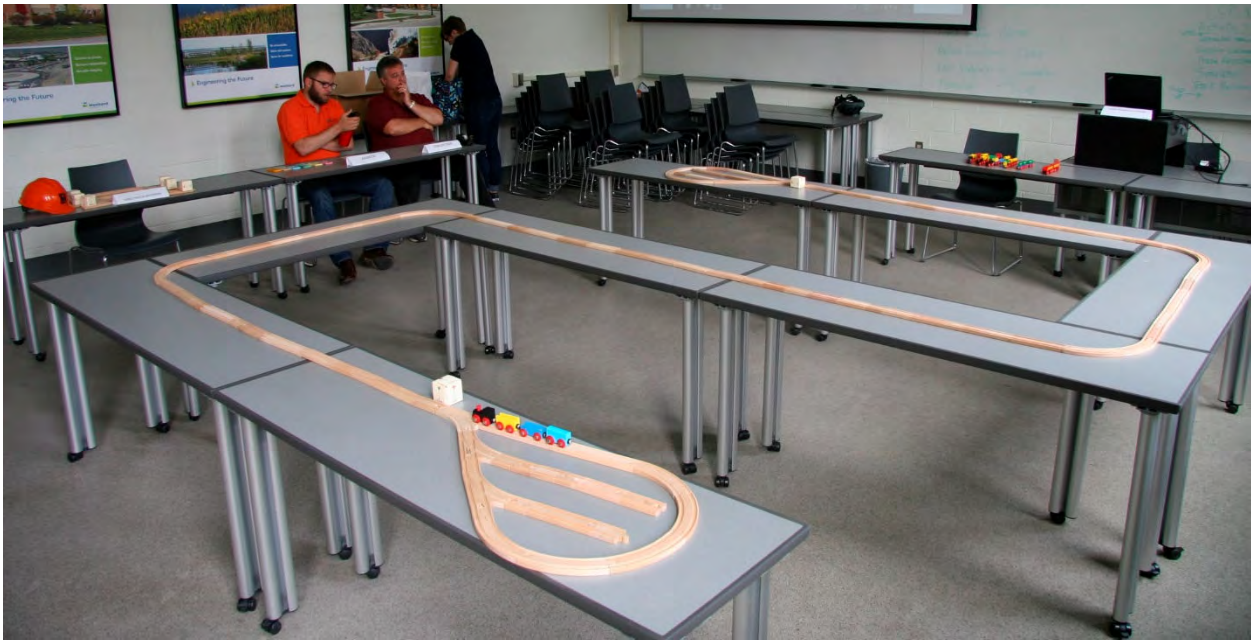


Figure 10: Initial Setup

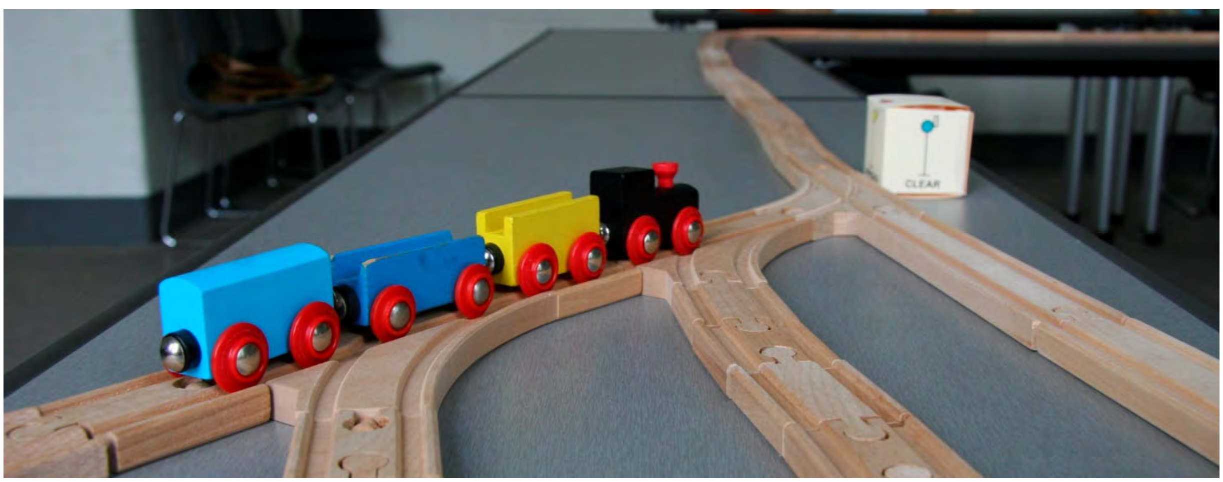


Figure 11: A typical three-car train and signal cube

Activity Script

Stage 1: One Train at a Time

1. Pick a student as "crew" for the train. Instruct them to move the train from the starting terminal to the other terminal with the purpose of delivering the railcars in their train to the customers at the other end of the line.
2. The COO (or instructor) should explain that the railroad earns money by delivering railcars from shipper to consumer. The COO (or instructor) should also explain that the train cannot be operated too fast since they have speed limits and "traffic signals" to follow much like automobiles.

3. Once the train reaches the other terminal, have the banker pay the students $40 for the delivery of the cars ($20 per car minus train crew and fuel costs, see Table 2).
4. If there is time, you may have each student in the group take a turn operating the train from one terminal to the other. Point out to the students that this is a rather slow process and ask them for ideas on how they could transport more freight and earn money faster. If it is not suggested by the students, propose to them that operating a second train could allow them to double the amount of freight moved and make twice as much money. Proceed to Stage 2 of the activity.

Table 2: Recommended Rewards and Prices

Item	**Reward**	**Cost**
Move one freight car from terminal to terminal	$20	
Pay one train crew		$10
Cost of fuel per three railcars		$10
Construct a new passing siding		$200
Lengthen a passing siding		$100
Operate passenger train	$25	$20

Stage 2: Adding a Second Train and a Passing Siding

1. Add another train consisting of one locomotive and three railcars to the terminal at the opposite end of the line from where the first train is currently located.
2. Choose a pair of students to crew the first and second trains.
3. Instruct both students to run their trains to the other end of the line and deliver their freight cars to the opposite terminal.
4. At some point, they will notice that there is no way to pass the trains traveling in opposite directions without derailing one of them off the tracks. Ask them how they might solve the conflict between the two trains.
5. The students may suggest that one train return to its initial terminal and wait until the other train arrives. This is a valid solution to the problem and the students can try it.
6. Explain that while this is a good strategy, it is inefficient because it requires delaying one train. Explain that the customers would prefer to not have their freight cars delayed.

7. After the students have discussed the problem, explain the concept of a passing siding and that building a short section of second track could allow the trains to pass each other. A picture of a real turnout (Figure 12) next to a BRIO turnout can help illustrate the concept of how trains can switch to the second track at either end of the passing siding.

Figure 12: A typical railroad turnout

8. Once the students understand how a passing siding can make the system more efficient, explain how railroads must pay to construct sidings and such projects can be expensive. Show the students the track store and explain the cost of each siding.
9. Direct the students to purchase one siding from the Chief Engineer. The Chief Engineer will construct the siding at the center of the route so that the two trains can pass each other.
10. If they have not done so already, have the students move the trains to positions on either side of the new passing siding. Ask the students how railroads decide which train should go into the siding and which train should continue on the original main track.
11. Introduce the Dispatcher. Explain that the Dispatcher decides which train should stay on the mainline and which train should go into the siding. Optionally, you can also explain how railroad use trackside signals to communicate these instructions to the trains (a signal cube cutout is provided in the appendix).
12. After the two students successfully pass their trains and run them to the end of the line, explain that with more passing sidings, the railroad can run more trains. Explain that engineers perform studies to determine the best locations to build new passing sidings.
13. Explain that to build more passing sidings, the students will need to earn more money by running their two trains as frequently as possible. Have students take turns running trains and arranging a train meet at the passing siding with the Dispatcher. As each student reaches the end of the line with their train, pay them $40 each time.
14. Once the students have a large bank of savings, move on to Stage 3.

Stage 3: More Trains and Longer Trains

1. Explain to the students that the customers at either end of the line want to ship more freight and add one set of three railcars to each of the two terminals (these should be placed on the track by the COO). There should be a total of 12 railcars on the railroad.
2. Inform the students that their railroad only owns four locomotives (the two being used already plus two more), but each locomotive can pull up to six railcars. (The exact number of locomotives can be adjusted for larger or smaller groups and the size of the track layout).
3. Ask the students how they should transport the new sets of railcars just added to the railroad. Students can choose to run more 3-car trains (up to a maximum of four) or run longer trains (up to six railcars long).
4. If the students choose to run additional 3-car trains with the third and fourth locomotive, have three or four students attempt to run their trains between the terminals at the same time. As they operate the system and the Dispatcher attempts to manage the meets between trains, they will quickly discover that additional passing sidings are needed to efficiently run the trains. Discuss with the students how many new sidings they need and where along the main track they should be located. A total of two or three passing sidings are required for smooth operations with three or four trains.
5. If the students decide to run two longer 6-car trains, they will realize that a passing siding is not long enough to pass two trains of six railcars each (Figure 13). Offer them the option to, at a cost, expand a standard passing siding to a long passing siding which will fit a six-car train.
6. Add two more sets of three railcars to the railroad for a total of 18. This will force the students to operate four trains (two short and two long) and add and lengthen passing sidings accordingly. Once two or three passing sidings have been built, proceed to Stage 4.

Figure 13: Unresolvable siding conflict between two "long" 6-car trains

Stage 4: Operating the Passenger Train

1. With the freight operation fully expanded, the passenger train will be introduced to the line.
2. Explain the concept of priority that requires all freight trains to enter passing sidings and allow the passenger train to pass on the mainline. This can be compared to the real world where Amtrak (Figure 14) should (theoretically by law) have priority over freight trains.
3. The students may realize that they do not have enough sidings for all four of the freight trains to stop in a passing siding while the passenger train passes. If this is the case, discuss with them if they should purchase additional sidings.
4. It is important to time the operation of the passenger train so that there are multiple (ideally three or four) freight trains on the line. Students will receive money for the operation of the passenger train because it takes up "track time" that they could have used to operate a freight train.

Figure 14: A modern regional Amtrak train

<u>Questions to Stimulate Student Thought</u>

1. Why would railroads prefer to run long trains? What limits train length?
2. How do passenger trains affect the entire railroad line? How can railroad companies reduce the impact of these effects on their freight trains?
3. What can railroads do to run more trains over a given rail line?

<u>Adjusting the Activity for Time and Participant Age</u>

Shorter Time: Use a smaller track layout with fewer sidings and fewer trains.

Longer Time: Have participants take more turns running trains and/or reduce the amount they are paid for each railcar transported between terminals.

Younger participants: Eliminate the use of play money and just focus on the track infrastructure required to operate a certain number of trains or trains of a given length.

Older participants: Try creating "string line" time-distance diagrams for your simulated railroad. These diagrams show time on one axis and distance on the other with each line on the graph representing the location of a train at a given time. The slope of the line for each train corresponds to its speed. Stringline diagrams are used to show train movements across a rail line and identify locations where new passing sidings or double track are required. They are also used to plan train schedules and efficient meets between trains. Try setting some scale distances for your wooden railroad and creating a string line diagram for it. An example string line diagram for a railroad with three equally spaced sidings and three trains is shown in Figure 15. Note that each line represents a train, and the slope of that line represents the speed of the train. A flat line means the train is stopped, while a steep line means the train is moving relatively fast. A more complicated string line diagram for a railroad near the east coast is also shown.

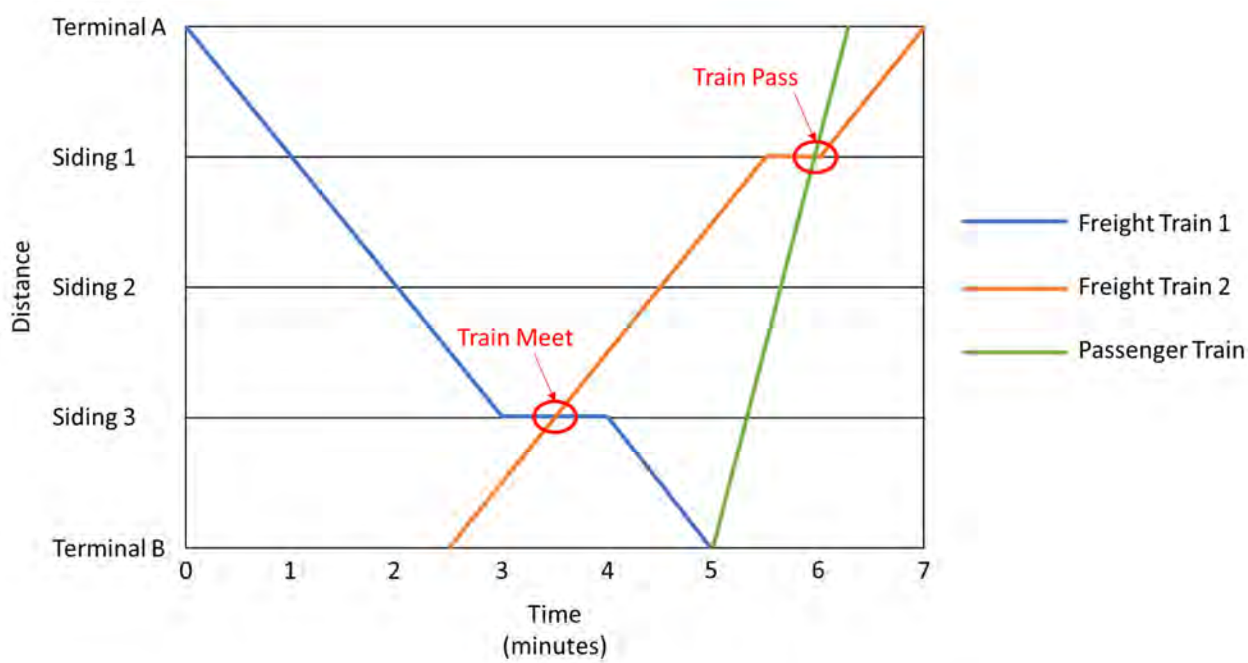
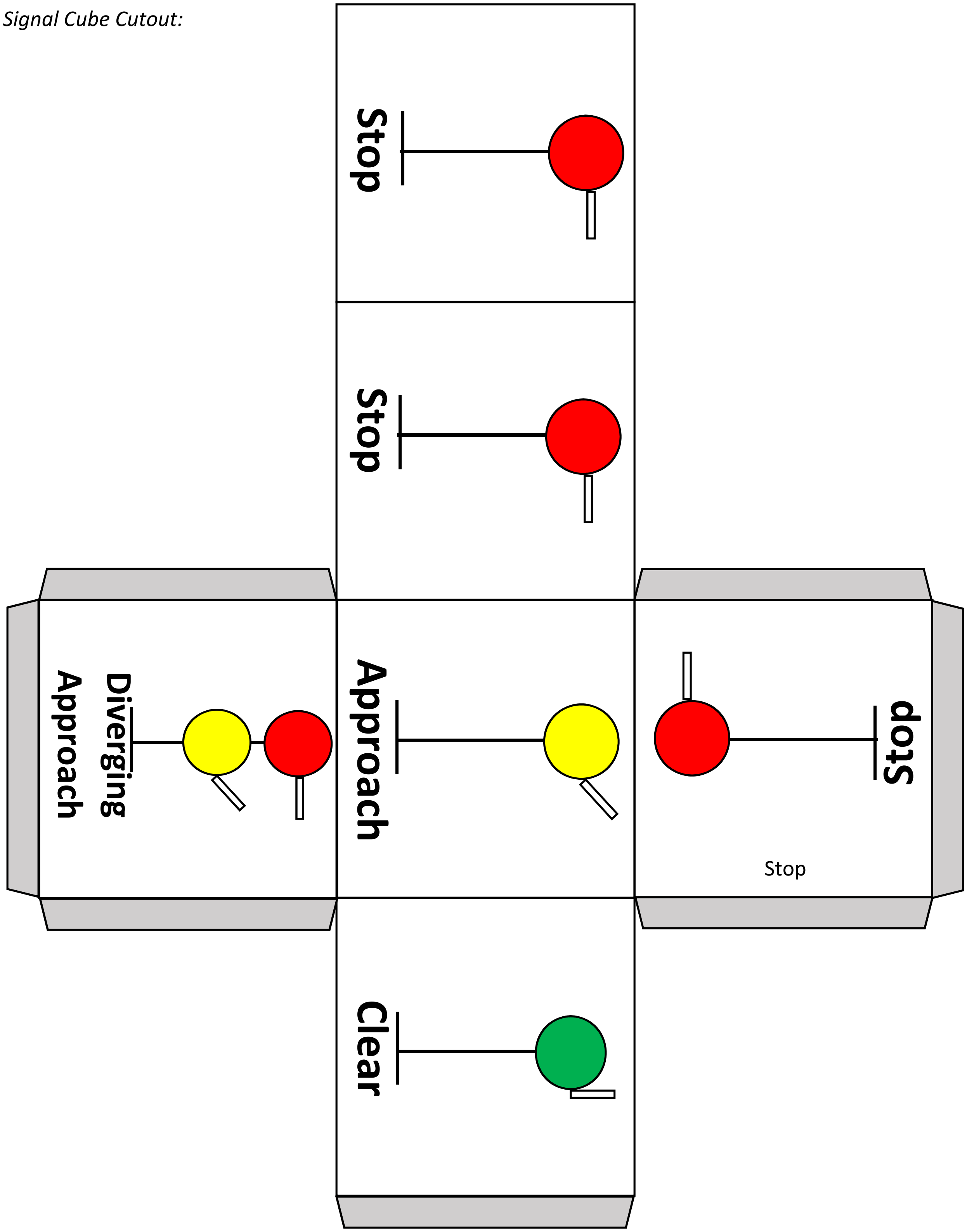


Figure 15: Example string line diagram for BRIO railroad

<u>Appendix:</u>

Monopoly Money:

Signal Cube Cutout:



Classification Yards and Railcar Sorting

Railway yards sort cars into groups based on destination. This activity demonstrates several methods used to sort the cars.

Number of Participants: 1-12 **Recommended Age:** 12+

Setup Time: 5 minutes **Activity Time:** 20 minutes

STEM Concepts:

- *Engineering: flat classification yards become inefficient with large volumes of railcar traffic*
- *Mathematics: matrices can be used to track railcar movements in a classification yard*

Key Learning Points

1. **Classification yards are locations where railcars arriving on inbound trains are uncoupled, sorted by destination, and assembled into new outbound trains.**
2. **Different types of classification methods are used depending on traffic and available infrastructure.**

Background

Railroads are a complex network of main lines, branch lines, local yards, and classification yards that connect thousands of origins and destinations for freight traffic. Unlike trucks that carry a single shipment directly from shipper to receiver, railroads gather dozens of railcars carrying individual freight shipments into a train. Simultaneously transporting multiple freight shipments in a single train allows railroads to be the most energy efficient mode of land transportation.

Some railway customers want to ship an entire trainload of freight at once. These trains can move directly from origin to destination such as those transporting coal from a min to a power plant. However, many customers want to ship a smaller number of railcars at a time, or they want to ship a larger number of railcars to many different destinations at the same time. To move these railcars efficiently, railroads operate a complex network of freight trains that transport railcars between intermediate staging points known as classification yards.

Classification yards are central to the freight railroad network, sorting thousands of freight cars each day into “blocks” (groups of cars heading in the same direction or to the same destination) and ultimately into trains that move them closer to their destinations. A typical classification yard will have many parallel tracks used to sort and store blocks of railcars until they are ready to depart on a train. While some classification yards use gravity to sort the railcars (known as hump yards), others are “flat switching” yards where railcars are sorted by a switching locomotive. Several different sorting methods can be used depending on the available yard track infrastructure and number of possible destinations for the railcars. This activity helps participants familiarize themselves with three of these sorting methods (basic, matrix, and triangular).

Figure 1: A railroad “ladder”, a series of turnouts leading to a group of yard track

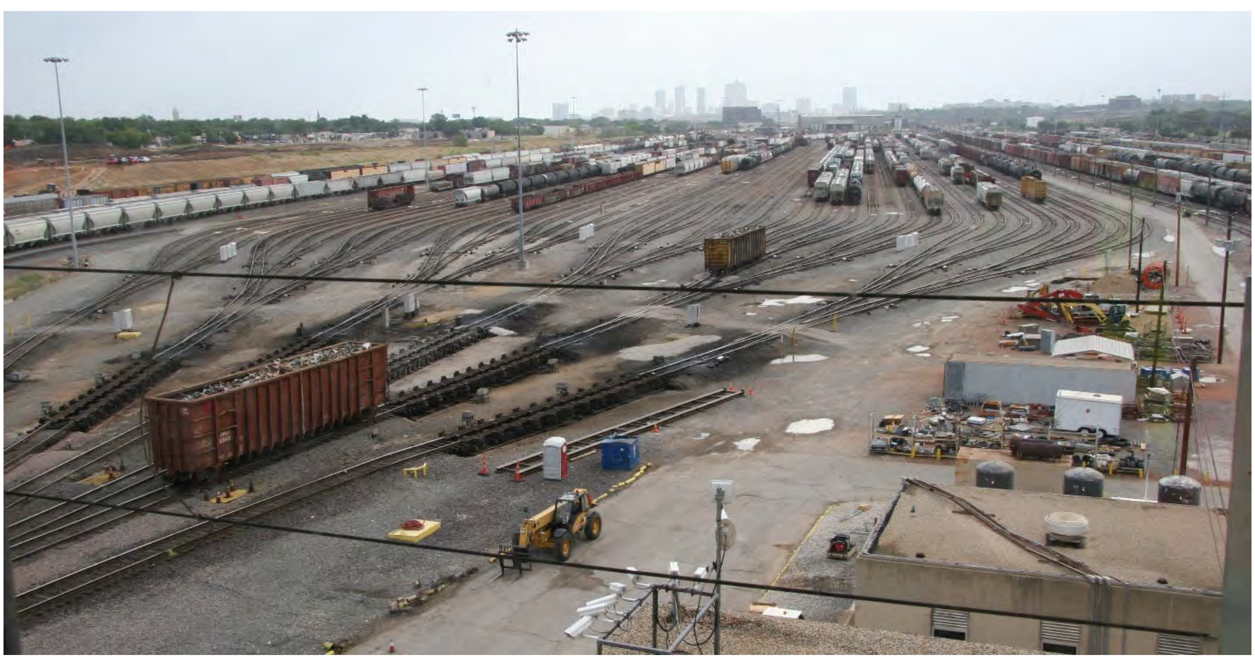


Figure 2: Classification tracks at a hump classification yard

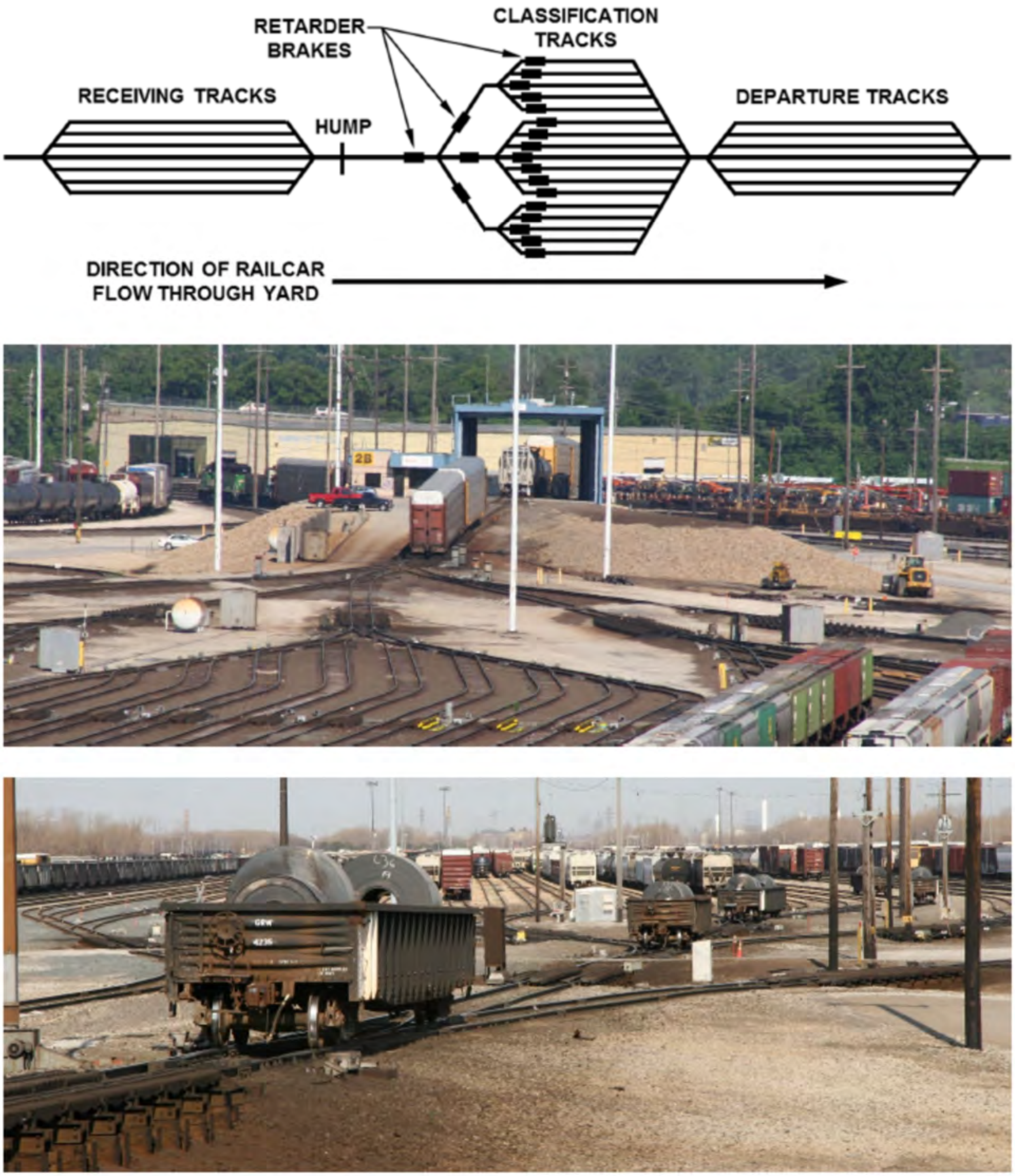


Figure 3: A hump at a classification yard

Figure 4: A switching locomotive at a flat switching yard

<u>Materials List and Setup</u>

For this activity, there are several options for materials to create a simple yard layout for demonstrating different railcar sorting strategies to form blocks in a classification yard:

- BRIO-style wooden track with compatible trains (preferred)
- Tape (for track) and cardboard cutouts (of trains)
- Scale model trains with EZ-track sections

Regardless of material choice, all setups will require 18 railcars to replicate the activity as described. A locomotive is not required but can help illustrate the movements required to switch railcars between the different tracks in the yard.

The remainder of this description assumes the activity will use BRIO-style track with compatible wooden trains. Most of the track and train materials listed below can be ordered through online retailers but can often be found at local toy stores that specialize in wooden and/or imported educational toys.

Yard Track Setup:

At a minimum, a yard layout with three parallel tracks is required to demonstrate all three railcar sorting strategies. For a BRIO setup using three yard tracks, the following track sections are required:

- 30 x D (8.5" straight tracks)
- 8 x L or M (turnouts)
- 2 x E (6.5" curves)
- 1 x Locomotive
- 18 x Railcars

Figure 5 illustrates a three-track yard setup using BRIO track. Other track materials should follow a similar pattern. It is critical that the single track at left, referred to as the "switching lead track", is long enough to hold all 18 railcars at once. Each of the parallel yard tracks at right, referred to as the "classification tracks" must be long enough to hold six railcars.

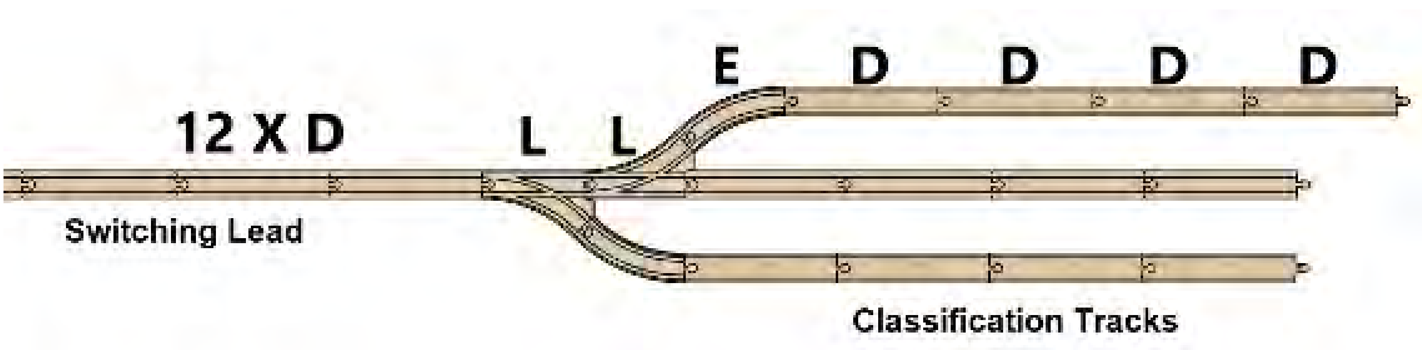


Figure 5: Three-track yard using BRIO track

Additionally, if there are sufficient track materials available, the yard may be set up with nine tracks for the basic sorting portion of the activity as shown in Figure 6.

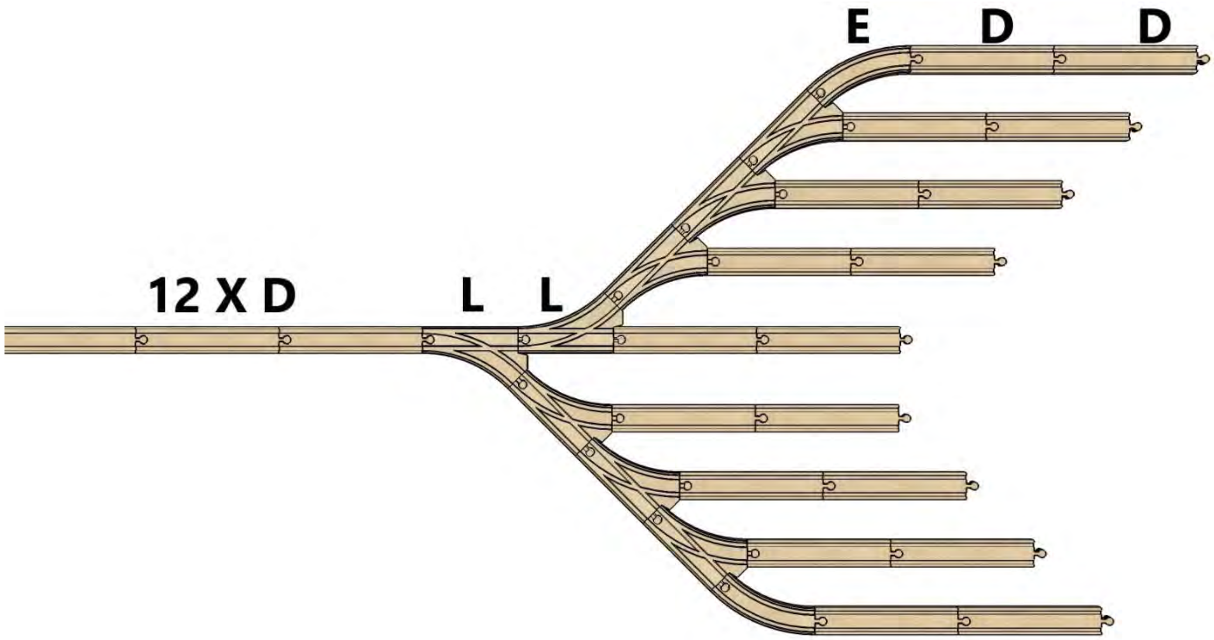


Figure 6: Nine-track yard using BRIO track

*Use of adapter (C2) is recommended if buying new track since turnouts come in pairs of L and M

Railcar Setup:

To help the students keep track of the block assigned to each railcar, affix a tape or sticky label to the top of each railcar with its block assignment written on it in marker.

If you only have enough materials to form a three-track yard, two of the 18 railcars should be assigned to each of the following blocks and labelled accordingly: 1-A, 2-A, 3-A, 4-B, 5-B, 6-B, 7-C, 8-C, 9-C.

If you have enough material to construct a nine-track yard, two of the 18 railcars should be assigned to each of the nine blocks ad labelled accordingly: 1, 2, 3, 4, 5, 6, 7, 8, 9.

<u>Activity Script</u>

This activity will cover three different rail sorting strategies used to form blocks in classification yards: basic, matrix and triangular sorting.

Before proceeding to the sorting strategies, if using wooden or scale model tracks, you may want to have the students assemble the three-track or nine-track yard layout based on a sketch or the diagrams provided earlier. This will allow the students to learn how the turnouts and track sections fit together to form the overall yard layout.

<u>Stage 1: Basic Sorting</u>

1. Assemble the three-track or nine-track yard.
2. Place all 18 railcars on the switching lead track in random order. Make sure the block assignments are sufficiently scrambled. If using wooden BRIO-style trains, make sure the magnetic polarity of each railcar is in the correct orientation. The optional locomotive should be placed at the far end of the string of railcars, away from the classification tracks.
3. Basic sorting is the simplest and most common method to sort cars into new blocks. Figure 7 below shows basic sorting of 18 cars into 3 blocks.

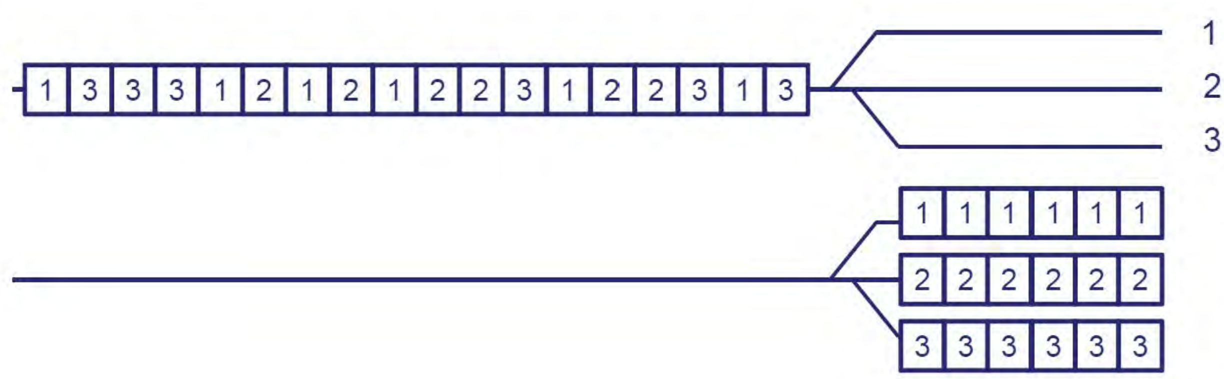


Figure 7: Basic sorting

4. Manually push and pull the railcars into each track based on their assigned blocks using the figure above as a guide.
    a. If using a three-track yard, place all cars with "A" in their labels on track 1, "B' on track 2, and "C" on track 3 to form three blocks.
    b. If using a nine-track yard, place cars labelled "1" on track 1, "2" on track 2 etc.
5. Discuss the advantages and disadvantages of this strategy with the students. Some of these may not become apparent until after the other strategies are demonstrated.
    a. Basic sorting advantages: cars are only handled once, each block on a dedicated track
    b. Basic sorting disadvantages: relatively large number of tracks to produce same number of blocks as other methods
6. To prompt the students to think of alternative sorting strategies, ask them how they might handle either of the following situations:
    a. For the three-track yard, how can you make more than three blocks on three tracks?
    b. For the nine-track yard, how can you still make nine blocks using fewer tracks?

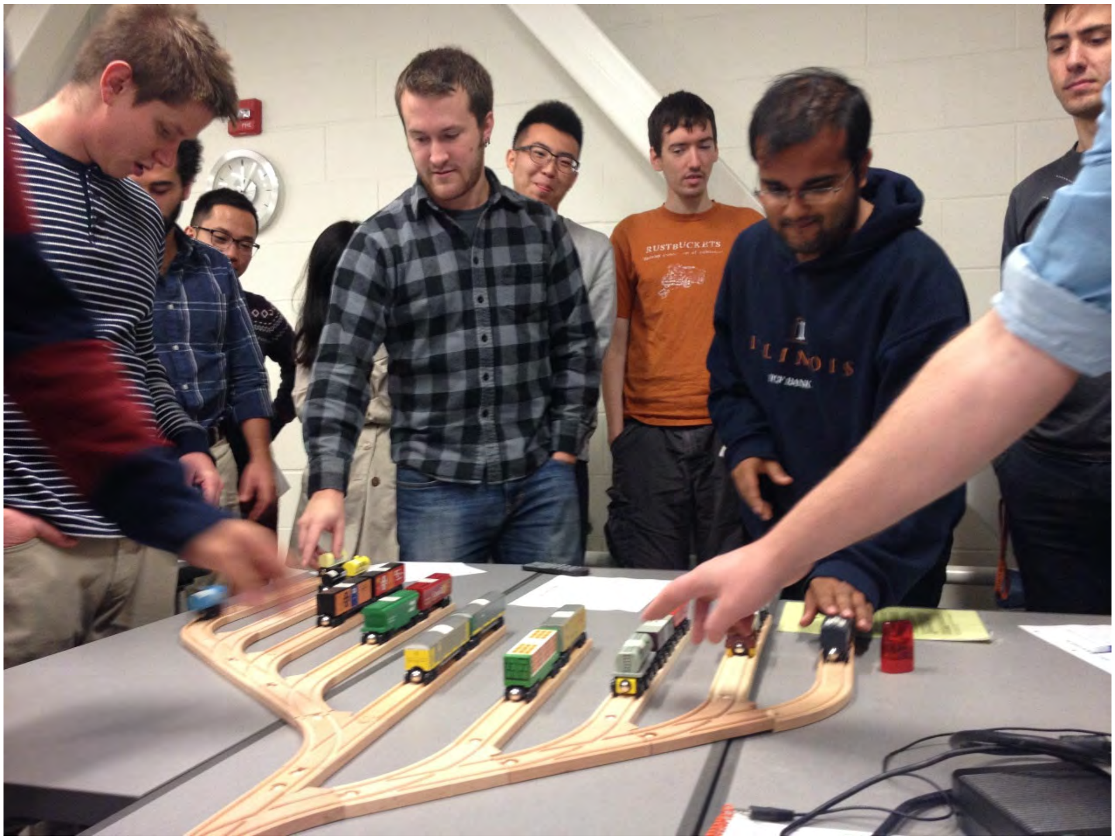


Figure 8: Sorting railcars into nine blocks on nine tracks.

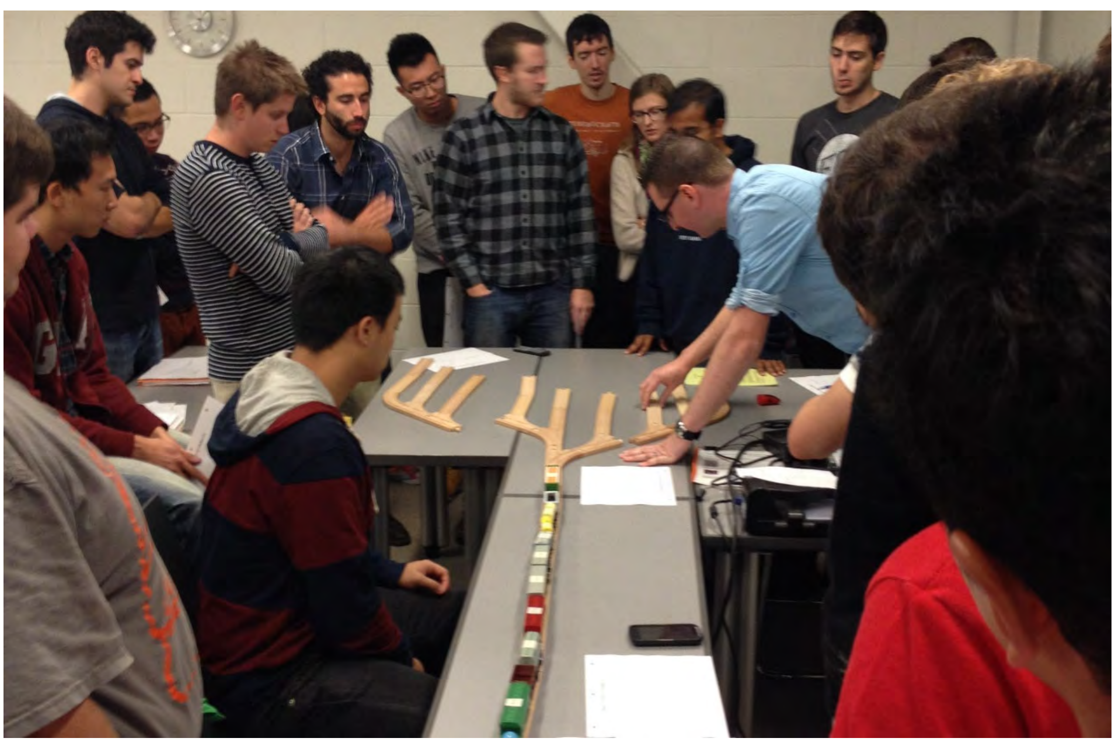


Figure 9: Removing six of the nine tracks for the challenge of forming nine blocks on three tracks.

<u>Stage 2: Matrix Sorting</u>

1. If a nine-track yard was used for Basic Sorting (Stage 1), remove six of the yard tracks (three from either side) to form a three-track yard (Figure 5). If a three-track yard was used for basic sorting, continue with the same layout.
2. Place all 18 railcars on the switching lead track in random order as done for Stage 1 (it does not need to be the exact same order).
3. Since there are only three tracks, there not enough tracks to form nine blocks independently using basic sorting. The railcars must be sorted multiple times using a multi-stage sorting technique called Matrix Sorting.
4. In the first stage (shown in Figure 10), the cars are sorted into groups of three blocks, although cars in the same block will not necessarily be adjacent to one another after the first sort. Using the figure as a guide, manually push and pull the railcars labelled 7, 4 and 1 into Track 1; 8, 5 and 2 into Track 2; and 9, 6 and 3 into Track 3.

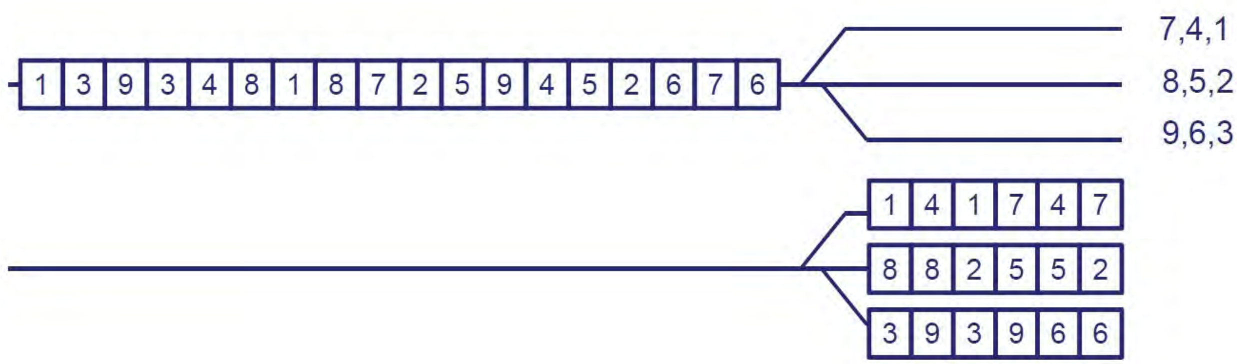


Figure 10: Matrix sorting stage 1

5. Pull the railcars from Track 3 back to the switching lead track, followed by the railcars from Track 2 and then the railcars from Track 1. Note that in an actual yard operation, the following moves must be made:
   a. The locomotive couples to the railcars on Track 1,
   b. The locomotive pulls the Track 1 railcars back to the lead, and then push them forward to couple on to the cars from Track 2.
   c. The locomotive pulls the Track 1 and Track 2 railcars back to the lead.
   d. The locomotive pushes the Track 1 and Track 2 railcars forward to couple to the railcars from Track 3.
   e. The final move involves pulling all 18 railcars back to the switching lead track.
6. Ask the students to inspect the order of the railcars on the switching lead track. Do they notice anything that might help them sort the railcars into blocks?
   a. Note that each third of the train is only composed of railcars from three different blocks.
   b. This pattern allows basic sorting to be used on each third of the train to form three separate blocks in succession on each yard track.

7. During the second stage (Figure 11), the cars will be correctly blocked with three blocks "stacked" on each yard track. Using the figure as a guide, manually push and pull the railcars labelled 1 into Track 1, 4 into Track 2, and 7 Track 3 for the first third of the train, followed by 2 into Track 1, 5 into Track 2, and 8 Track 3 for the middle third of the train, and finally 3 into Track 1, 6 into Track 2, and 9 Track 3 for the final third of the train.

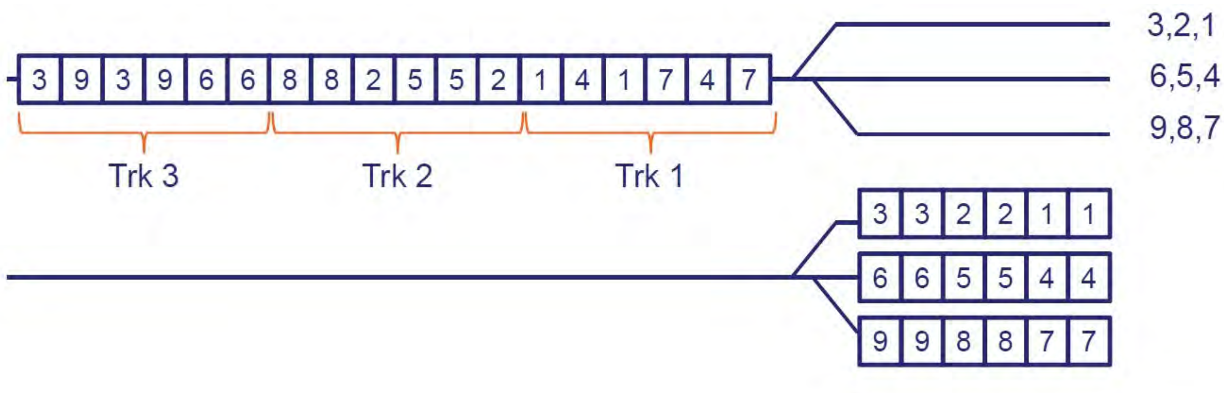


Figure 11: Matrix sorting stage 2

8. Discuss the advantages and disadvantages of this strategy with the students. Some of these may not become apparent until after the other strategies are demonstrated.
   a. Matrix sorting advantages: can create more blocks than there are tracks available (if there are n yard tracks, one can create n^2 blocks)
   b. Matrix sorting disadvantages: railcars are handled twice, more horsepower required to pull all cars at once during the final move to setup the second stage sort (i.e. when Tracks 1 , 2 and 3 are all pulled back to the switching lead).
9. To prompt the students to think of alternative sorting strategies, ask them how they might handle either of the following situations:
   a. Is there a way to sort railcars without pulling all of the tracks back at the same time?
   b. If only six blocks are made, does this open up additional possible strategies?

Stage 3: Triangular or Geometric Sorting

1. Continue using the same six-track yard used for Matrix Sorting.
2. Select 12 of the 18 railcars, either those labelled blocks 1 through 6 or blocks 1-A through 6-B, and place them on the switching lead track in random order. The cars labelled for blocks 7-9 and 7-C to 9-C can be set aside.
3. Since there are only three tracks, there not enough tracks to form six blocks independently using basic sorting. The railcars must be sorted multiple times using a multi-stage sorting technique called Triangular Sorting (also known as Geometric Sorting).
4. Triangular sorting takes place in three stages.
5. In the first stage (shown in Figure 12), the cars are sorted into three groups of blocks, one on each track. Cars in the same block will not necessarily be adjacent to one another after the first sort. Using the figure as a guide, manually push and pull the railcars labelled 1 into Track 1; 4 and 2 into Track 2; and 6, 5 and 3 into Track 3.

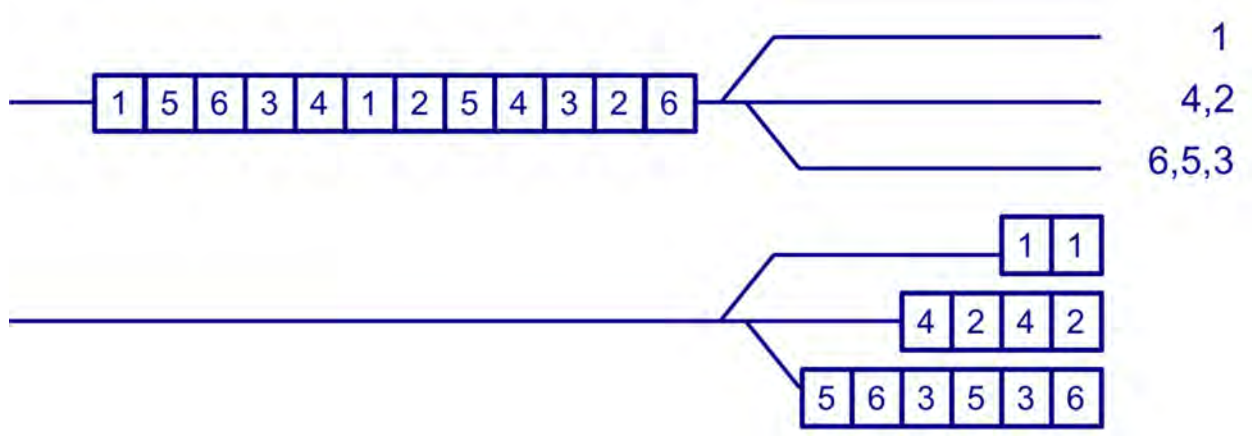


Figure 12: Triangular sorting stage 1

6. Ask the students if any blocks have been formed in the yard after the first sort.
   a. Note that the railcars in Block 1 are already sorted together on Track 1.
7. Pull the railcars from Track 2 back to the switching lead track.
8. Ask the students to inspect the order of the railcars on the switching lead track. Do they notice anything that might help them sort the railcars into blocks?
   a. Note that only cars for blocks 2 and 4 are on the lead track.
9. In the second stage (shown in Figure 13), the cars on the lead are sorted into two blocks: one on Track 2 and one on Track 1 "stacked" on top of Block 1. Using the figure as a guide, manually push and pull the railcars labelled 4 into Track 1, and 2 into Track 2.

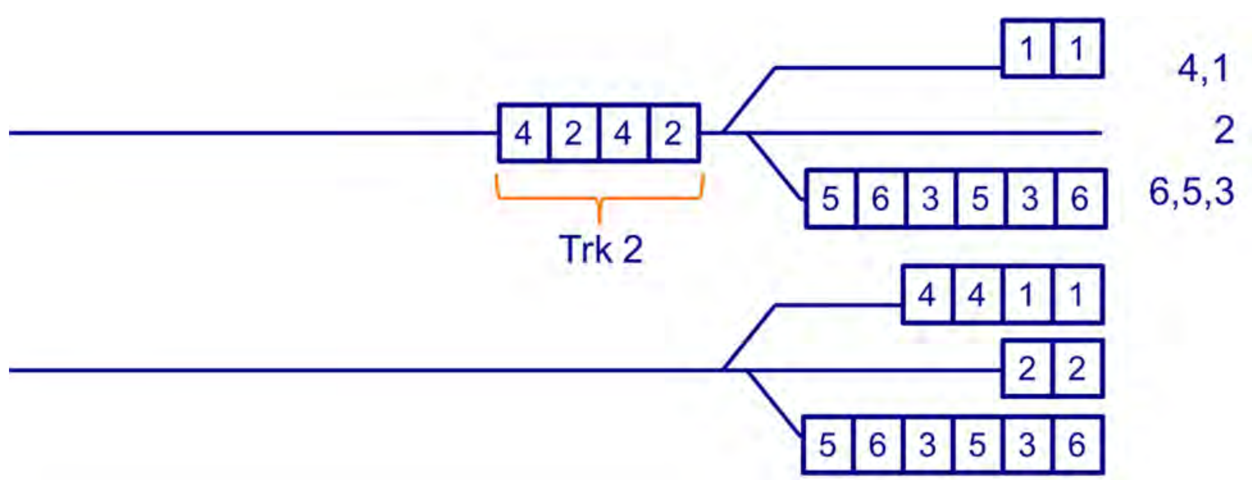


Figure 13: Triangular sorting stage 2

10. Ask the students if any blocks have been formed in the yard after the second sort.
    a. Note that the railcars in Block 2 are now sorted together on Track 2.
    b. Blocks 1 and 4 are sorted on Track 1 (but stacked).
11. Pull the railcars from Track 3 back to the switching lead track.

12. Ask the students to inspect the order of the railcars on the switching lead track. Do they notice anything that might help them sort the railcars into blocks?
    c. Note that only cars for blocks 3, 5 and 6 are on the lead track.
13. In the third stage (shown in Figure 14), the cars on the lead are sorted into three blocks: one on Track 3, one on Track 2 "stacked" on Blocks 2, and one on Track 1 "stacked" on top of Blocks 4 and 1. Using the figure as a guide, manually push and pull the railcars labelled 6 into Track 1, 5 into Track 2 and 3 into Track 3.

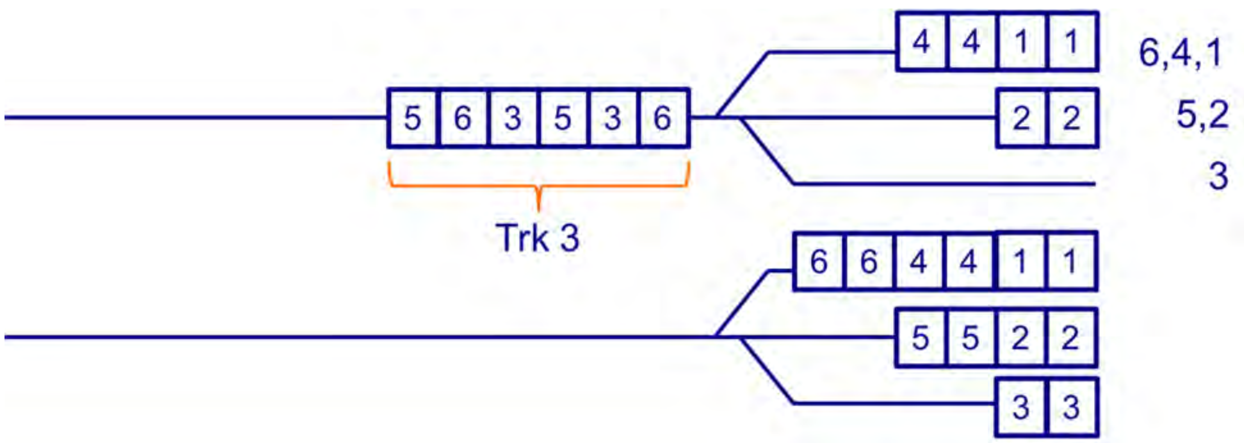


Figure 14: Triangular sorting stage 3

14. Note that all of the railcars have been sorted into six blocks.
    a. Blocks 6, 4 and 1 are stacked on Track 1.
    b. Blocks 5 and 2 are stacked on Track 2.
    c. Blocks 3 is alone on Track 3.
15. Discuss the advantages and disadvantages of this strategy with the students. Some of these may not become apparent until after the other strategies are demonstrated.
    a. Triangular sorting advantages: uses fewer tracks than basic sorting to create the same number of blocks, only one track is pulled at a time.
    b. Triangular sorting disadvantages: cars can be handled multiple times, all cars must be in the yard before the second and third stage sorts begin.

Questions to Stimulate Student Thought

1. Why do railroads care about how fast a classification yard can sort cars?
2. How can railroads increase the number of cars a yard can sort over a given time period?
3. Would the sorting methods discussed in this activity be more useful in a flat switching yard or a hump yard?
4. To demonstrate the n^2 blocks property of Matrix Sorting, show how four tracks can be used to form 16 blocks and five tracks used to form 25 blocks using this strategy.
5. How many tracks are required to sort the original nine blocks using Triangular Sorting?

<u>Adjusting for Participant Time and Age</u>

1. For younger participants or to shorten the activity, try eliminating one of the methods discussed above. Basic sorting can be skipped if time does not allow, or either triangular or matrix sorting could be skipped for younger groups.
2. To expand the activity, try increasing the number of cars or tracks available for sorting. Discussion of the questions in the previous section can also lead to some insightful discussions about the role of rail yards in overall rail network capacity.
3. As described previously, have the students assemble the yard layout at the start of the activity to become more familiar with how turnouts and track sections are used to form a yard.

The following paper is an excellent resource for more information about multistage soring techniques:

Daganzo, C.F., R.G. Dowling, and R. W. Hall. Railroad classification yard throughput: The case of multistage triangular sorting. *Transportation Research Part A: General,* Vol. 17, 2, 1983, pp. 95-106. DOI: https://doi.org/10.1016/0191-2607(83)90063-8

Intermodal Transportation Game

This activity compares the efficiency of intermodal freight transportation using trucks and rail to the efficiency of truck-only transportation.

Number of Participants: 2 (minimum) **Recommended Age:** 5+

Setup Time: 10-25 minutes **Activity Time:** 10 minutes

STEM Concepts:

- *Technology: containers allow intermodal shipments to use multiple transportation modes*
- *Engineering: different modes of transportation are more efficient at certain tasks and combining them through intermodal service can increase overall efficiency and performance*

Key Learning Points

1. **Containers are designed to be transported by truck, rail, and marine transportation.**
2. **Intermodal transportation can be more effective than transportation by a single mode.**
3. **Railroads are more effective for long-haul and high-volume transportation than trucks.**

Background

Intermodal transportation is the movement of products using multiple types of transportation such as land, sea, air and water, also known as "transportation modes". Typically, in the context of North American freight rail transportation, intermodal transportation is the movement of products loaded into containers via at least two of truck, rail, or marine (ship or barge) transportation.

Intermodal transportation takes advantage of the strengths of each transportation mode. For example, ships can transport a large number of containers at a low cost but are limited to oceans and some inland waterways. Railroads can transport large volumes of freight over land at a low cost but are usually unable to provide door-to-door service to many shippers and customers. Trucks are capable of providing door-to-door service but are most effective at transporting smaller volumes of freight over shorter distances. By using each of these modes where they are most effective in the routing of a container, a shipper gets the best service and typically at a lower cost. The goal of the Intermodal Transportation Game is to demonstrate how intermodal transportation using rail and truck provides more effective service than trucks as a single mode of transportation.

Figure 1: A typical intermodal train

Figure 2: A truck carrying an intermodal container

Figure 3: A loaded container ship

Figure 4: Containers being transloaded from ship to truck chassis at a port intermodal terminal

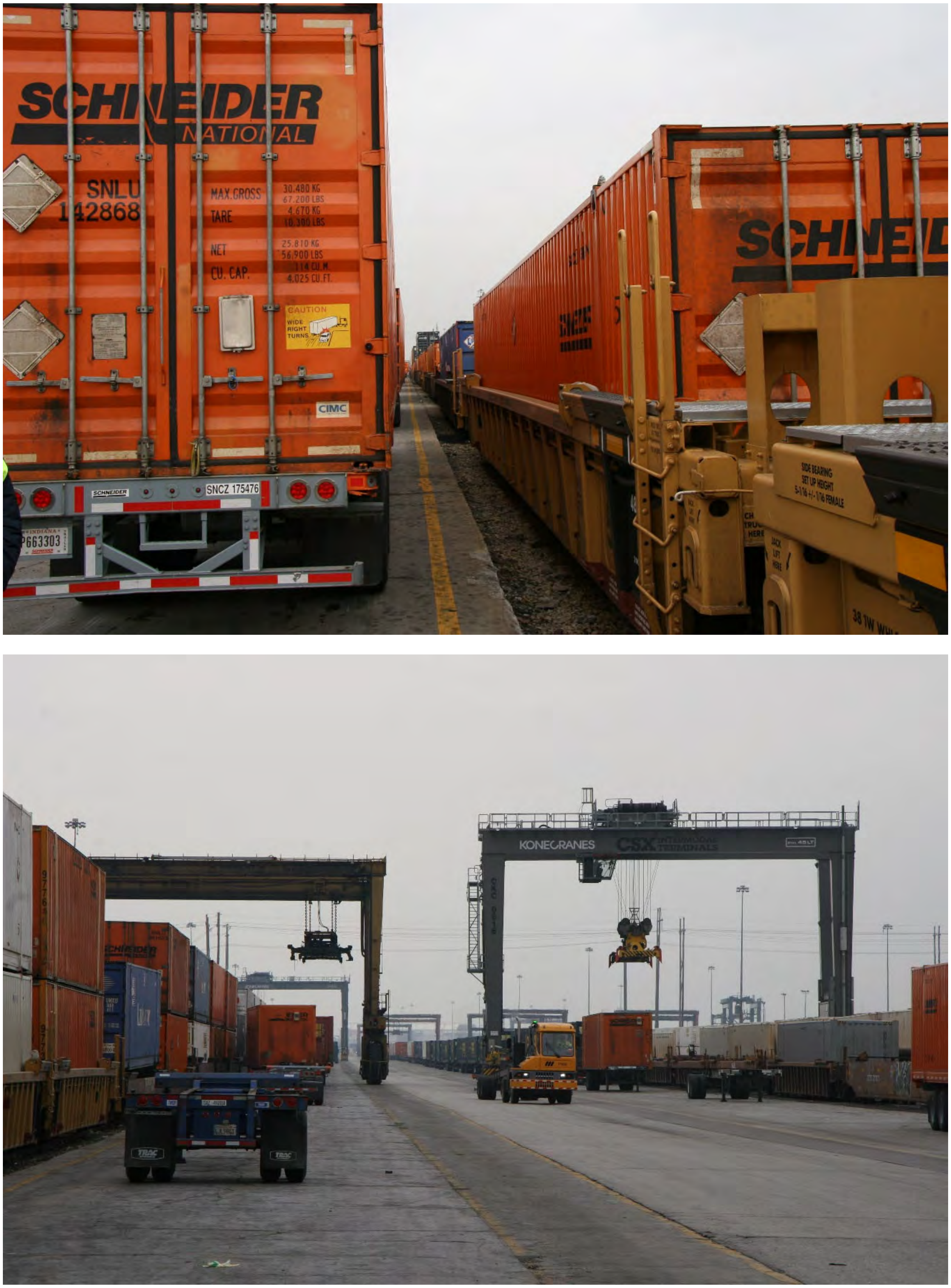


Figure 5: Transloading containers from railcars to truck at a rail intermodal terminal

<u>Materials List and Setup</u>

Materials:

The Intermodal Transportation Game requires the following components:

- Playing board
- 12 containers
- 2 three-car trains
- 2 trucks
- 1 container ship

The playing board serves as a surface for the truck and rail vehicles to transport containers between a "container ship" and a container yard. A primary function of the board is to define the routes for the trains and trucks to follow. The game is designed to cover two folding tables placed end to end. There are several options for playing board materials such as:

- Plywood boards with balsa wood strips to define the railway
- Foam core boards with hand drawn road, track, container ship and container yard areas
- Long roll of paper with features drawn or printed on a roll plotter (can also be laminated)
- Masking tape routes directly on table tops

There are several options for creating the trucks and trains.

- Pinewood derby car kits (available through Amazon, Scout Shops, and a variety of retail stores including Hobby Lobby) can be used to create the truck, the locomotive and each railcar in the train. Metal hooks or hooks and eyes can be screwed into the ends of the railcars and locomotive to act as couplers.
- Containers can be represented with wooden blocks sized appropriately to be carried by the truck and railcars. The containers can have magnets embedded on both the top and bottom of them so that they will stick together when stacked on the train. An additional magnet can be embedded on the train cars and trucks to make the containers stick to the train car or truck. Wooden pegs and dowels with appropriate holes in the containers can also be used to facilitate stacking and holding containers in place on the trucks and railcars.
- LEGO vehicle kits and train kits can also be used for the various vehicles and to build boxes to serve as containers.

The "container ship" serves as an area where the containers are stacked at the start of the game. The ship can be a platform fabricated from scraps of wood, or simply a representation of the ship drawn, printed or painted on the playing board. The ship should have some separation to divide the containers into two separate groups of stacks, one for each of the two players.

The container yard or stacking area is where the containers end up at the conclusion of the game. Specific spots for each stack of containers should be designated with colored squares or outlines in the container stacking area. Ideally the container spots are coded with colors or letters to match certain containers. Two containers should be designated for each stacking point in the container yard.

Setup (Plywood Board with Pinewood Derby vehicles):

This setup uses a playing board made from four plywood sections supported by tables. Each section is 40 inches wide by 48 inches long. The railway track is represented by thin strips of balsa wood sticks spaced so that the pinewood derby wheels of the locomotive and railcars run between them.

Figure 6: Intermodal Game Board

Figure 7: Trains and Container Ship

<u>Playing the Game</u>

Rules:

1. There are two rounds with the same two participants in each.
2. The objective of the game is to be the first player to deliver six containers from the container ship to the container yard.
3. Each train is one locomotive plus three cars. Each car can carry two containers (one stacked on top of the other), so one train can handle six containers total.
4. A truck can only handle one container at a time.
5. The containers should be color coded so that they have a designated spot in the container yard.
6. The vehicles must follow the paths shown in Figure 7. Note the position of Truck 1 adjacent to where Train 1 stops for transferring of containers from train to truck. Truck 1 must return to this spot from the container yard before it can be loaded with another container from the train. Note that Truck 2 must drive all the way around the end of the track before heading to the container yard… no shortcuts!
7. For the first round, one player will use a combination of Train 1 and Truck 1 to deliver their six containers, while the other player will only use Truck 2 to deliver their containers.
8. For the second round, both players can use any combination of their train and truck to deliver the containers.
9. Both players should be told that they may only handle one container at a time (enforced by placing one hand behind their back at all times) and that **they may not run**.

In Figure 7, for the first round, the path for Player 1 is shown by the red arrow, while the path for Player 2 is shown by the blue arrow. In round two, each player may use a combination of these paths.

Theoretically, Player 1 (truck and train) should win the first round. This is the purpose of the game because it shows how combining trains and trucks to deliver freight is more efficient than only using trucks. Player 2 is at a disadvantage because trucks do not have the capacity to move large amounts of freight at once. Player 1 is able to take advantage of that capacity, which gives them an advantage.

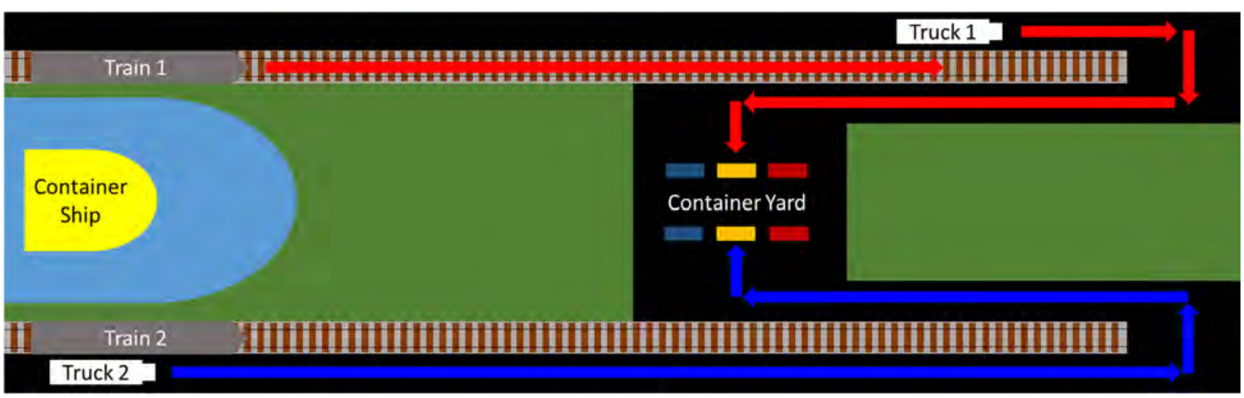


Figure 8: Intermodal Game board layout

The second round is mostly the same as the first round except that Player 2 is allowed to use Train 2 and Truck 2 to deliver their containers in the same way that Player 1 was allowed to use both Train 1 and Truck 1. This round evens the playing field so that Player 2 has a reasonable chance of winning. If you are short on time or the players do not wish to continue, this round may be skipped.

Extending the Game:

Option 1: Changing Shipment Distance

To demonstrate the influence of distance on the relative competitiveness of truck and rail, extend or shorten the overall length of the playing board to increase or shorten the truck and rail trip.

- Lengthening the board to force the truck to make many long trips should favor the train.
- Shortening the board may make the truck more competitive as it can quickly make multiple trips while the train is being loaded.

Option 2: Changing Shipment Volume

To demonstrate the influence of shipment volume on the competitiveness of truck and rail, have the players both ship an additional pair of containers (this also requires one additional car to be added to the train), or only ship four containers instead of six.

- Increasing the number of containers forces the truck to make many more trips and should favor the train.
- Decreasing the number of containers may make the truck more competitive as it can quickly make multiple trips while the train is being loaded.

Questions to Stimulate Student Thought

1. Other than a shorter transit time for freight, what benefits can intermodal transportation bring?
2. What haul length (short-haul or long-haul) do each of the transportation modes (train, truck, ship) excel at? Why?

Adjusting for Time and Participant Age

1. The activity may be shortened by eliminating the second round since the first round demonstrates the effectiveness of intermodal transportation. The second round functions solely as a “consolation round” to give each player an equal chance at winning.
2. The activity can be lengthened by repeating the first round except the participants will swap roles. In other words, the participant who used only the truck for the first round will use the train and truck for the second round, and the participant using both the train and truck for the first round will only use the truck for the second round. A third round where both participants use both the train and truck can also be played.
3. For older participants, ask them to predict which method is more effective before playing the first round of the game. Then play the game and discuss why their predictions were correct or incorrect.

Railroad Safety, and Potential Collaborators, Educational Opportunities and Resources for Additional Learning

We hope that you find the activities described in this guidebook informative and entertaining. While we presented the methods and materials we used to conduct these activities, we strongly encourage you to experiment with different materials and methods to develop these activities into a learning experience that fits your group. The possibilities for new activities to teach railroad transportation, engineering and STEM concepts are endless, and we hope these activities serve as inspiration for your own activities.

Although this subject is not detailed in any of the activity guides presented earlier, we strongly encourage instructors of any railroad-related activities to discuss railroad safety. Approximately 95% of railroad fatalities are due to pedestrians trespassing on railroad property or highway grade crossing collisions, and the best way to lower these numbers is to educate. Here are some key points to teach:

- An average freight train travelling at 55 MPH can take over a mile to stop. Do not expect a train to stop if there is something on the tracks.
- Railroad tracks and right-of-way is private property and unauthorized access is trespassing, which can result in a fine. Never use railroad tracks as a short cut while walking. Only cross railroad tracks at designated public crossings.
- With modern distractions such as texting or listening to music, it can be hard to hear an oncoming train, so always remember to stay alert near railroad tracks. Expect a train on any track, from any direction, at any time.
- Never try to race a train at a railroad crossing. A train hitting an automobile is about the same as an automobile running over a soda can.

Figure 1: Highway grade crossing with Emergency Notification Sign and crossing number

- If your vehicle becomes stuck, stalled or disabled on a railroad crossing, find the blue and white Emergency Notification System (ENS) sign and call the phone number to let the railroad know the crossing is blocked. Be sure to tell them the crossing number printed on the ENS sign. In Figure 1, the crossing number is 759668R.
- If a train is approaching and your vehicle is stuck on the tracks, leave the vehicle and get clear of the tracks. If you see a train approaching, it is best to walk or run at a 45˚ angle away from the crossing but towards the oncoming train to avoid being hit by debris.

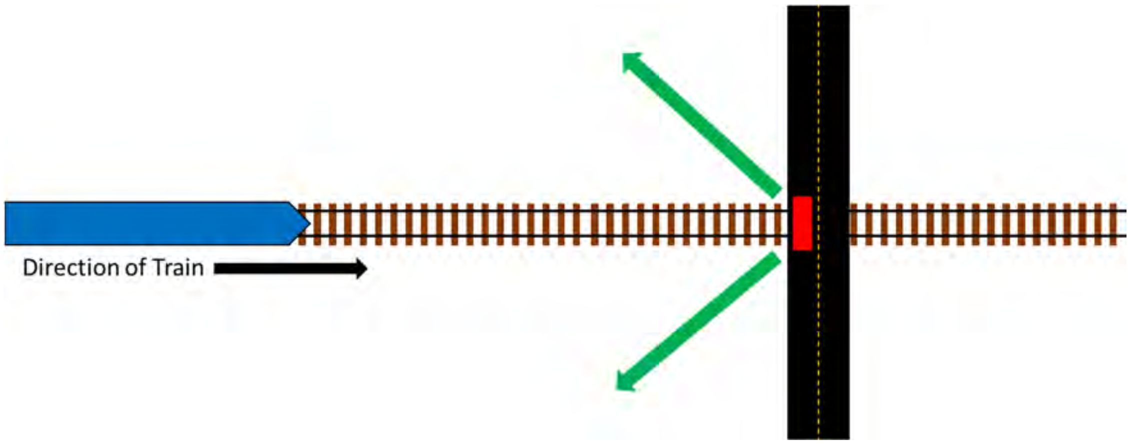


Figure 2: If your vehicle is stuck on a crossing and a train is approaching, move away at a 45˚ angle to avoid being hit by debris as shown by the green arrows.

If you would like to learn more about railroad safety, visit the official website of Operation Lifesaver (https://oli.org/safety-near-trains). Operation Lifesaver is a national organization created by the railroad industry in 1972 to educate the public about railroad safety. Through trained local representatives in communities across the country, Operation Lifesaver offers free youth-oriented railroad safety educational materials and presentations that can be requested for local events and community groups.

Potential Partner Organizations

For railroad safety, an excellent organization to partner with is Operation Lifesaver. However, there are other railroad-related organizations that may be willing to partner with you to educate students about the railroad industry. A few of these groups are listed here.

Railroad Museums:

There are hundreds of railroad museums and tourist railroads across the United States and Canada. Many of these organizations have an educational mission and would likely be willing to assist you in introducing railroad topics to students. For example, at the University of Illinois, students enrolled in railroad engineering classes participate in a work day each year held at the Monticello Railway Museum (Figure 3). These work days provide students an opportunity to learn about track maintenance and tools in a hands-on environment. Many museums and tourist railroads in North America are members of the Heritage Rail Alliance (https://heritagerail.org/). If you are unsure of the nearest railway museum, the Heritage Rail Alliance may be able to assist you in locating an organization nearby.

Figure 3: University of Illinois students replacing crossties at the Monticello Railway Museum.

Model Railroad Clubs:

While it is unlikely that any model railroad clubs in your area have a display or other setup dedicated to education, they may be able to help with recommendations for materials and suppliers for activities involving model railroad products. In some instances, there may be opportunities to use existing model railroad layouts to teach "big-picture" concepts such as rail line capacity, signaling systems, traffic control systems, and train dispatching. These types of opportunities will vary depending on the facilities of each club and the availability of the club membership to support such activities. Many clubs and model railroaders are members of the National Model Railroad Association (https://www.nmra.org/). If you are unsure if there are any clubs or model railroaders in your area, the NMRA may be able to put you in contact with a local club representative or member.

Railway Engineering Firms and Contractors:

There are many engineering firms of various sizes that participate in railway design. These firms may be willing to provide a presentation to your students on the work they perform and about the railroad industry in general. Additionally, many engineers that work for these firms are members of the American Railway Engineering and Maintenance-of-Way Association (AREMA, https://www.arema.org/). AREMA has a committee dedicated to Education and Training (Committee 24) that may be able to put you in contact with a railway engineering professional interested in serving as a classroom speaker.

AREMA also supports a number of student chapters at universities across North America. These student chapters frequently participate in educational events. For a current list of AREMA Student Chapters, please visit: https://www.arema.org/AREMA_MBRR/Students/Student_Chapters_List.aspx

Many railway engineering firms and contractors that construct track, bridges and other railroad infrastructure projects are members of the National Railroad Construction and Maintenance Association (https://www.nrcma.org/) which is another resource for making contacts with local professionals.

Railroad Supply Companies:

In addition to engineering firms, there are many companies that supply the railroad industry with components, systems, and services. You may be able to get a representative from one of these companies to present their work and information about the railroad industry. Many of these companies are members of the Railway Supply Institute (https://www.rsiweb.org/), which may be able to assist you in contacting a local railroad supply company.

Freight Railroad Companies and Passenger Rail Operating Agencies:

While most railroad companies do not have railroad education programs, it is in their interest to recruit students to the rail industry, so they may be willing to participate in educational events if contacted through their public relations departments. There are also two trade associations that occasionally participate in educational events and may help you contact a local freight railroad representative:

- Association of American Railroads (https://www.aar.org/)
- American Short Line and Regional Railroad Association (https://www.aslrra.org/)

Agencies responsible for the management and operation of regional commuter rail and urban rail transit systems (such as light rail and subways) can also be contacted directly or through the American Public Transportation Association (https://www.apta.com/). With a focus on serving the transportation needs of the local travelling public, these organizations may be willing to support educational activities.

Figure 4: A student learns the basics of locomotive operation on the Norfolk Southern Railway locomotive simulator during Engineering Open House at the University of Illinois.

Other Educational Opportunities

If you have students who are interested in learning more about the railroad industry, there are several opportunities for further learning.

Boy Scouts of America Scouts BSA Railroading Merit Badge:

If the student is a member of the Boy Scouts of America, they may be able to obtain the Scouts BSA "Railroading" merit badge. Fulfilling the merit badge requirements will teach them the basics of the railroad industry and serve as a foundation for further education on railroad topics. For more information on the requirements of this merit badge, please visit: https://filestore.scouting.org/filestore/Merit_Badge_ReqandRes/Railroading.pdf

Summer Camps:

Several organizations offer railroad summer camps for youth. These camps typically expose the students to a variety of railroad topics and encourage hands-on learning. Some of these camps include:

- National Railway Historical Society RailCamp: https://nrhs.com/programs/railcamp/
- Michigan Technological University Summer Youth Program in Rail and Intermodal Transportation: http://www.rail.mtu.edu/youth-and-pre-university-programs
- Penn State Altoona Kids' College Railroad Camp: https://altoona.psu.edu/offices-divisions/continuing-education-training/kids-college
- Tennessee Valley Railroad Museum Summer Camp: https://www.tvrail.com/events-exhibits/rides/railroad-summer-camp

University Degree Programs and Courses:

If a student is interested in pursuing a career in the railroad industry, there are specific degree programs in railroad engineering programs at several universities in North America:

- University of Illinois at Urbana-Champaign: Civil Engineering BS/MS/PhD with Railroad Primary, and Master of Engineering in Railway Engineering Degree, https://railtec.illinois.edu/academics/
- Penn State Altoona: Rail Transportation Engineering Degree Program, https://altoona.psu.edu/academics/bachelors-degrees/rail-transportation-engineering
- Michigan Technological University: Minor in Rail Transportation, Rail Transportation Program, http://www.rail.mtu.edu/minor-rail-transportation
- University of South Carolina: Graduate Railway Engineering Certificate, https://sc.edu/study/colleges_schools/engineering_and_computing/academics/graduate_programs/railway_engineering_certificate/index.php

Additional universities may offer one or more specific courses on railway engineering topics but not have specific railroad degree programs. Many of these universities are the same institutions that host AREMA student chapters. A website link to a list of active AREMA student chapters can be found under *Engineering Firms* within the Potential Partner Organizations section of this chapter.

Resources for Additional Learning

If you would like to learn more about the railroad industry and various subjects related to the activities in this guidebook, some additional resources are suggested below:

- "The Railroad: What it is, what it does" (John H. Armstrong) ISBN: 978-0911382044
  - General information about railroading
- "All About Railroading" (William C. Vantuono) ISBN: 978-0911382259
  - General information about railroading
- https://www.csx.com/index.cfm/about-us/company-overview/railroad-dictionary/
  - Definitions of various railroad terms
- https://www.aar.org/aar_news/weekly-rail-traffic-data/
  - Weekly railroad traffic data for the United States
- https://www.bnsf.com/ship-with-bnsf/ways-of-shipping/equipment/
  - Pictures of various railcars and information on the commodities they carry
- http://woodenrailway.info/
  - Information on BRIO wooden railway products

Several television shows on railroad topics have been produced over the years. These shows are typically good sources of knowledge in addition to the other resources provided. Individual episodes may be available on DVD from your local library or available online. Suggested television series include:

- Extreme Trains
- Impossible Engineering: Extreme Railroads
- Rocky Mountain Railroad
- Tracks Ahead

Figure 5: Students from the Next Generation School in Champaign, Illinois attend a rail-focused summer day camp hosted by the University of Illinois Rail Transportation and Engineering Center