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Guidebook for Railway-themed K-12 STEM Outreach Activities

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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!

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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.

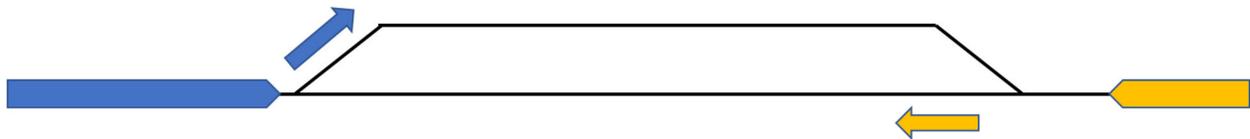


Figure 1: Example train paths when approaching a passing siding

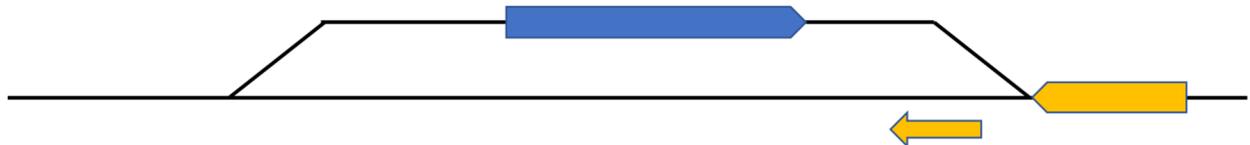


Figure 2: Lower priority train (blue) stopped in a passing siding while waiting for higher priority train (orange) to pass in other direction

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

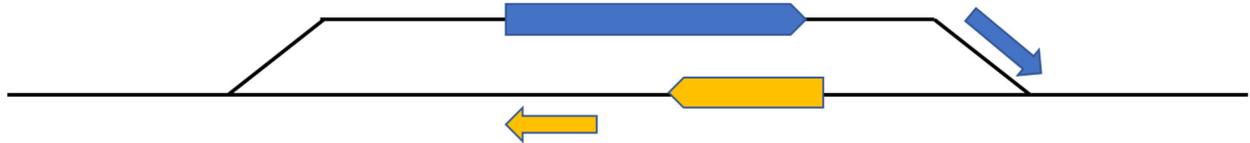


Figure 3: Lower priority train resuming travel

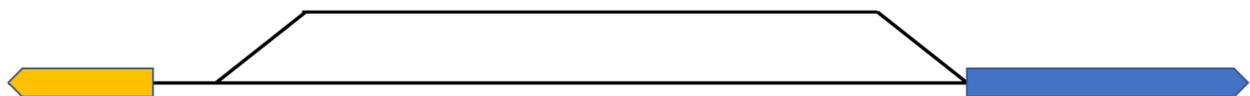


Figure 4: Meet process completed

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

Materials List and Setup

- 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.

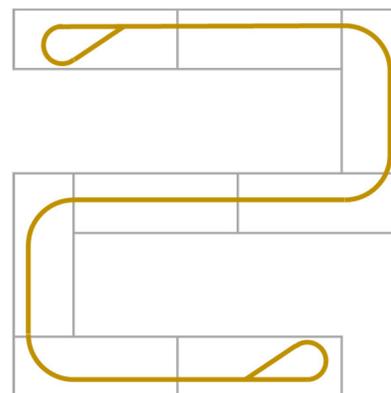
Track Setup:

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.



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)

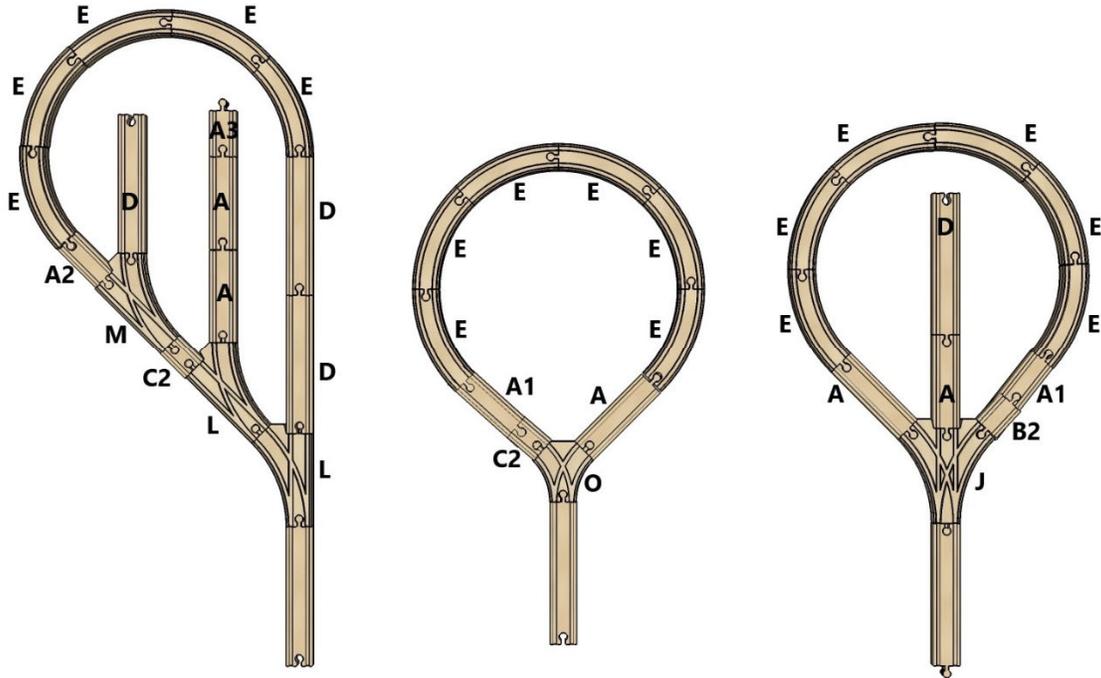


Figure 7: “Balloon Track” Terminal Designs

- 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

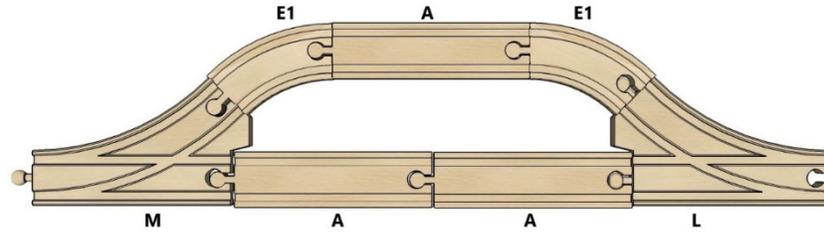


Figure 8: Siding design for a 4-car train

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

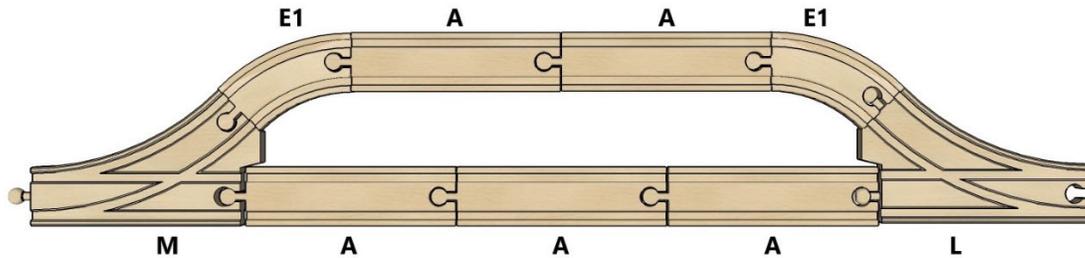


Figure 9: Siding design for a 6-car train

- 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

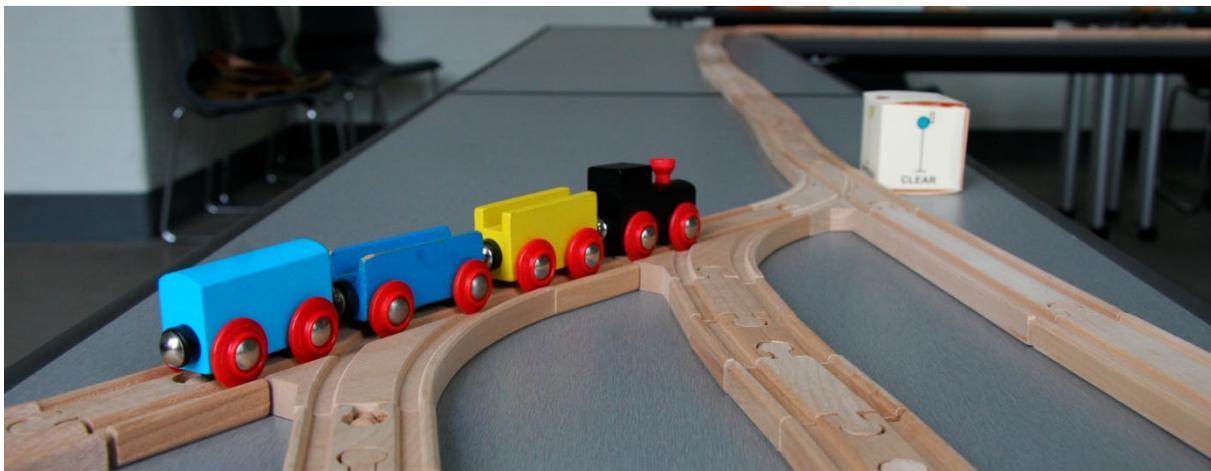


Figure 11: A typical three-car train and signal cube

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 derailling 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.

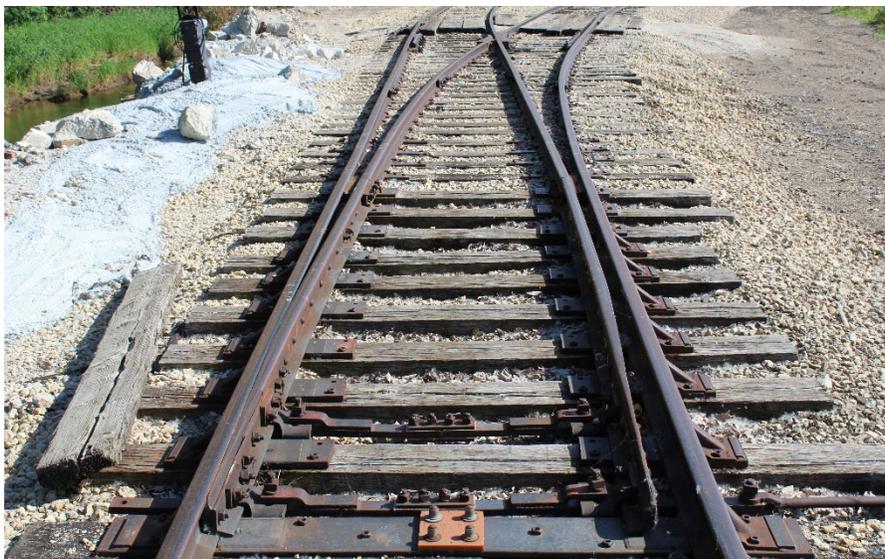


Figure 12: A typical railroad turnout

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 railroads 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

Questions to Stimulate Student Thought

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?

Adjusting the Activity for Time and Participant Age

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.

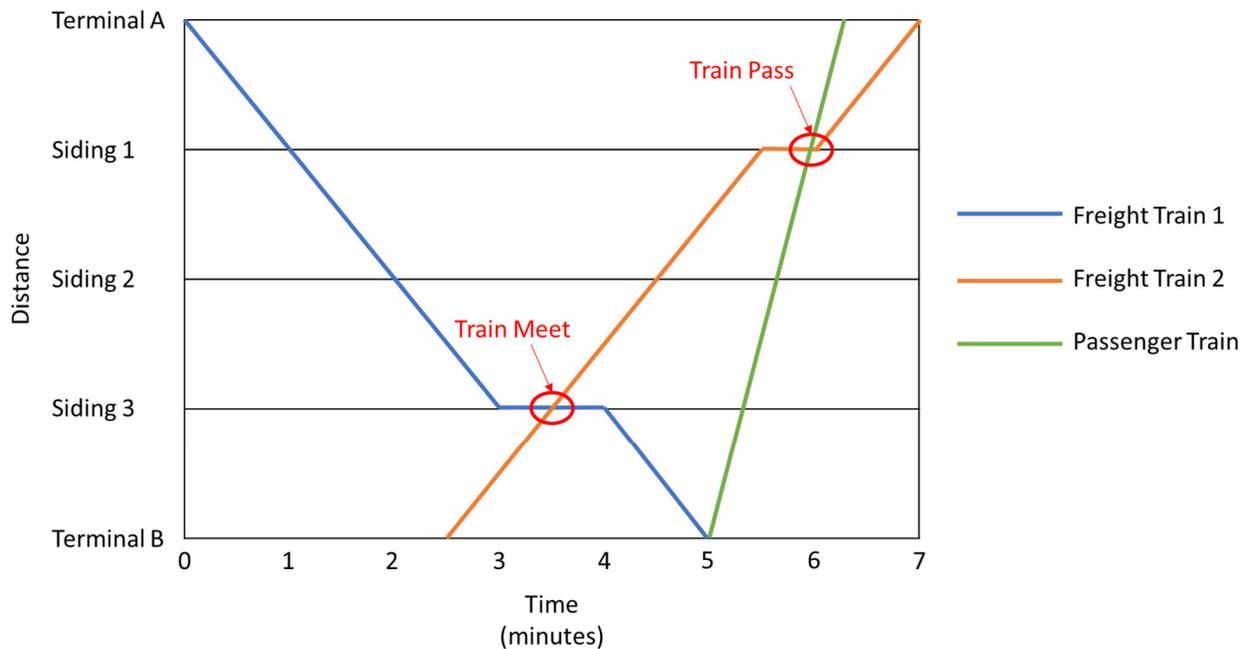


Figure 15: Example string line diagram for BRIO railroad

Appendix:

Monopoly Money:



Signal Cube Cutout:

