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

19-09-2020

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

DISCLAIMER

Funding for this research was provided by the NURail Center, University of Illinois at Urbana - Champaign under Grant No. DTRT13-G-UTC52 of the U.S. Department of Transportation, Office of the Assistant Secretary for Research & Technology (OST-R), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

TECHNICAL SUMMARY

Title

Guidebook for Railway-themed K-12 STEM Outreach Activities

Introduction

Demand for graduates with rail transportation expertise remains strong in North America, particularly in engineering and technical fields. Railway courses are now offered at two dozen universities in the United States, and, for the first time in decades, several universities offer specific degrees in railway engineering. Despite this progress, challenges remain, such as raising student awareness of rail industry career paths. Since most railway engineering courses are senior-level electives, many students are already committed to other engineering disciplines before they are exposed to railway concepts. To raise student interest in rail courses and satisfy industry demands for internships, students must be introduced to railway concepts before they decide on the direction of their studies. One approach to directing more rail-aware students into engineering programs is rail-themed outreach to K-12 students. Railways still hold a fascination for many young people as complex, multidisciplinary systems and numerous interesting science, technology, engineering and math (STEM) concepts can be demonstrated through the lens of railway transportation. Interactive rail-themed classroom activities can illustrate STEM topics while highlighting rail career opportunities and reinforcing railway transportation. The objective of this project is to develop a guidebook that describes rail-themed K-12 STEM outreach activities created by various NURail partners.

Description of Activities

As an initial task, the project team worked with NURail partners and affiliates to identify different railway-themed K-12 STEM Outreach activities being conducted at their respective campuses. The scope included reviewing activities related to classroom demonstrations, summer camps, open houses and other interactions with K-12 students. Many of these activities were harvested from interactions and presentations at previous editions of the American Railway Engineering and Maintenance-of-Way Association (AREMA) Railway Engineering Education Symposium (REES) and APTA Passenger Railway Engineering Education Symposium (p-REES) events, The Railway Academic Conference (TRAC) held by NURail in 2016 (and where multiple K-12 STEM outreach activities were demonstrated live), and prior NURail Annual Meetings. Example K-12 activities were also identified from summaries in published papers on railway education and outreach activities.

Once the various activities were identified, each activity was documented through text, diagrams and images. The documentation will contain enough information for an outside educator or railway engineering professional to incorporate the activity into their curriculum or community outreach program. At a minimum, the documentation for each activity includes the following:

- Activity name
- Main aspect of railway transportation and STEM field
- Appropriate age, group size, setting and duration of the activity
- Key learning points related to STEM topics
- Key learning points related to railway transportation
- List of materials and equipment
- Instructions and diagrams for creating or assembling equipment
- Instructions and/or script for executing the activity
- Images of the equipment and the activity being conducted
- Copies of relevant handouts, data collection sheets etc.
- Ideas for altering the activity to shorten or lengthen the time duration, and adjust for group size
- Questions for additional student through and independent exploration
- References and list of resources for additional learning

Once an activity description is complete, it can be distributed as a stand-alone PDF document.

Future work effort extending beyond the end of this project will be to compile a substantial number of the activity descriptions into a guidebook. The guidebook will organize the activities by different facets of railway transportation and engineering. To supplement the activity descriptions, the guidebook will also include a general list of industry resources and educational references for further study.

Outcomes

The following list presents a number of rail-focused K-12 STEM activities developed at various universities engaged in railway engineering education and research activities. The list is not intended to be comprehensive but instead to demonstrate that the activities can be centered on different railway functions from engineering to operations, and may relate to any number of civil, mechanical and electrical phenomena and their underlying fundamental STEM concepts in physics and mathematics.

- **Track Structure Construction**. Students use sand, aquarium gravel, balsa wood crossties, push-pin “spikes” and 3-D printed (or G-scale model railroad) rails to build a foot-long representation of the railway track structure on a cookie sheet. The students observe how, without the aquarium gravel “ballast”, the skeleton track structure is flexible and unstable. Using a spring scale, older students can measure the change in lateral resistance offered by the track structure before and after adding the ballast.
- **Drinking Cup Wheel-Rail Dynamics**. After demonstrating that a cup on its side will roll in a circle due to different rolling radii, students use plastic drinking cups and tape to assemble simple models of tapered railway wheelsets. The students are encouraged to arrange the tapered cups in different combinations and orientations and then test them by rolling them down a tangent and

curved section of representative railway track. The students can observe how the proper tapered wheelset oscillates to negotiate the tangent and curved sections of track while other combinations are unstable, over-correct and “derail”.

- **Railway and Roadway Rolling Resistance**. This activity compares the rolling resistance of two model railcars: one fitted with standard steel wheels rolling on model railway track, and one fitted with rubber radio-controlled automobile wheels and tires rolling on the table. Students use a spring scale to measure the rolling resistance of the two railcars, demonstrating how the steel wheel on steel rail contributes to the overall efficiency of railway transportation. Older students can change the weight carried by the railcars and the pulling speed to reveal different train resistance relationships.
- **Popcorn Railcar Size and Weight**. This activity demonstrates how the cubic capacity of railcars is optimally sized for the density of the freight commodity it is designed to carry. Containers filled with equivalent volumes of materials with different weights, such as plastic pellets, beans and metal bee-bees, or unpopped and popped popcorn, are used to explain concepts of volume and density. Students then fill two open-top hopper car models of different cubic capacity with granular materials of various densities to determine if the material fills the volumetric capacity (“cubes out”) or, as measured by a kitchen scale, reaches the scaled-down railcar weight limit (“tares out”).
- **Intermodal Race Game**. The purpose of this activity is to demonstrate the efficiency of “intermodal” railway transportation of shipping containers relative to transporting them on individual trucks. In the game, two students race to transport six wooden block “shipping containers” between a port and an inland terminal at either end of a long table. One student uses a single truck while the competing student uses a train consisting of a locomotive and three double-stack railcars. The truck, locomotive and railcars are all fabricated from Pinewood Derby car kits. Typically, in the initial stages of the race, the truck builds a lead making several round trips while the train requires time to load all of the containers. However, by transporting all six containers in a single trip, the train quickly gains the advantage.
- **Wooden Railway Simulation**. In this activity, a small group of students work together to operate trains over a Brio-style wooden railway, earning revenue for every railcar they transport but also incurring expenses for crews and fuel. As the students are prompted to increase their profits, they attempt to run more frequent and longer freight trains, requiring capital investments in additional passing sidings and siding extensions on the single-track route. Students learn basic concepts of transportation and railway economics, railway operations, train dispatching, and railway capacity planning.
- **BRIO Classification Yard**. Using Brio-style wooden railway track and railcars, students construct a representative classification yard according to a schematic layout of tracks and turnouts. The students are then guided through the process of switching an inbound train of wooden railcars labelled by block color or number into the different classification tracks. The basic activity can be extended by reducing the number of tracks and explaining how multi-stage sorting can be used to form more blocks on fewer tracks.
- **Track Circuits and Automatic Block Signals.** Sections of large-scale model railway track, signals and relays can be used to construct working models of the railway signal system. One example display uses approximately five feet of track affixed to a base. The rails are divided

into five block sections separated by four block signals. Batteries and relays are used to create track circuits that are shunted by a turned brass wheelset. Students can roll a wheelset across the track sections, see and hear the relays engaging and the progression of stop, approach and clear signal aspects behind the “train”.

- **Build a Simple DC Motor.** Using D-size battery (or 9-volt with battery snap wire leads), two metal plates or paper clips, about three feet of 20 AWG magnetic wire, a large ceramic magnet and a plastic or wood base, students build a basic DC motor. This teaches students about electro-magnetism and introduces them to the basics of DC motors used in many diesel-electric locomotives. This activity provides a good introduction to the topics of engines, generators, and motors that provide tractive power for a locomotive.
- **Locomotive Simulator.** Various commercial train simulators such as Run8, Trainz and Microsoft Train Simulator provide uses with an interactive, in-cab locomotive engineer perspective of train operations. When combined with a large flat screen display and special commercial desktop controllers that simulate actual locomotive throttle, brake, bell and horn controls, these software packages deliver an effective locomotive simulator experience and help students to quickly recognize the differences in dynamics between different trains (heavy freight versus passenger). Experience suggests that simulations of commuter rail operations are most effective for student groups as each student can quickly take a turn accelerating the train, holding it at speed and braking to a (hopefully) precise stop at the next commuter platform.
- **Virtual Reality Headsets.** Technology companies are rapidly growing the field of 360-degree videos and virtual reality (VR) for use in educational environments. Google, Samsung, and Facebook (Oculus) have all released VR headsets that can provide students with immersive learning experiences. Norfolk Southern and Operation Lifesaver have each created 360-degree railroad-oriented content and Penn State Altoona is now creating a small library of immersive educational videos that will include freight and passenger operations on U.S. railroads as well as European railways. Use of VR is recommended only for students above the age of twelve.
- **Operation Lifesaver and Railway Safety.** While stimulating student interest in railways, it is also important to reinforce fundamental railway safety rules at grade crossings and that trespassing on railway right-of-way is extremely dangerous and is a crime. Operation Lifesaver can provide railway safety educational materials and guest speakers to complement rail-focused K-12 STEM activities. Virtual Reality videos produced by Operation Lifesaver are also available for free on the internet.

Most of the activities listed above have several commonalities:

1) they encourage students to work together in small groups or as a team,

2) they encourage students to physically interact with scale models or representations of actual railway infrastructure and rolling stock,

3) students are encouraged to formulate hypotheses or make decisions on the best design alternative or approach to a particular element of railway technology, and

4) they involve observation and measurement of different trials, potentially analyzing and interpreting qualitative and quantitative data.

This latter point provides an opportunity to adjust the scope of activities for different age groups; younger students can focus on working through the activity and making qualitative observations or simple measurements while middle and high school students may make more detailed measurements, plot or analyze the data, and draw conclusions to reveal the form of underlying relationships. Several universities use these same activities as classroom demonstrations to accompany more detailed explanations of railway engineering phenomena within their rail-focused courses for matriculated students or short courses for industry professionals.

At the time of this report, the NURail scope of effort has led to the completion of final activity descriptions for the Wooden Railway Simulation and BRIO Classification Yard activities. These activities have been included as Appendix A and B to this report. In addition, draft activity descriptions have been developed for the Track Structure Construction, Drinking Cup Wheel-Rail Dynamics, Popcorn Railcar Size and Weight, Intermodal Race Game, and Locomotive Simulator activities. Planned progress on these activity descriptions during spring and summer 2020 was hampered when many student outreach and summer camp events featuring these activities were cancelled due to COVID-19 precautions. Following the conclusion of the NURail grant period, additional grant funding support from the National Railroad Construction and Maintenance Association (NRC) will be used to complete these activity descriptions during fall 2020.

Once the remaining activity descriptions are completed and compiled into the guidebook, the guidebook will be published as a PDF for distribution via the NURail website and those of the rail programs at partner universities. Additional avenues for distribution include the AREMA website, AREMA Committee 24 (Education & Training) contacts, through individual AREMA Student Chapters, and through the National Railroad Construction and Maintenance Association (NRC) website.

Conclusions/Recommendations

Requests for ideas and information on railway-themed STEM outreach activities have been routinely received by the project team during the past year. Draft activity descriptions have been shared with educators and industry practitioners several times during the duration of the project. The descriptions were viewed favorably and user feedback was used to improve them. The Railway-themed K-12 STEM Outreach Activity Guidebook will be an ongoing project and a “living document” as additional activities are developed and educators and industry practitioner presenters invent new ways to deliver, expand and enhance the various activities.

Publications

Dick, C.T., P. Lautala and B.W. Schlake. 2019. STEM K-12 outreach as the root of transportation education: experiences from the railway engineering field. *Transportation Research Record: Journal of the Transportation Research Board*. 2673(12): 558-569. https://doi.org/10.1177/0361198119841564.

Examples

Appendix A: “Single-Track Railway Operations Simulation Game” Activity Description (attached)

Appendix B: “Classification Yards and Railcar Sorting” Activity Description (attached)

Primary Contact

Principal Investigator
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

Other Faculty and Students Involved

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

Pasi Lautala, Ph.D., P.E.
Assistant Professor and Director
Rail Transportation Program
Michigan Technological University
ptlautal@mtu.edu

Bryan W. Schlake
Lecturer
Rail Transportation Engineering Program
Penn State Altoona
bws14@psu.edu

NURail Center
217-244-4999
nurail@illinois.edu
http://www.nurailcenter.org/

Appendix A: “Single-Track Railway Operations Simulation Game” Activity Description

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:

- *Science: distance, time and speed can be used to predict train location and develop schedules*
- *Technology: railroads have an economic incentive to invest in technology enabling long trains*
- *Engineering: optimizing the location of track infrastructure minimizes construction costs*
- *Mathematics: fixed, variable and unit cost calculations*

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.

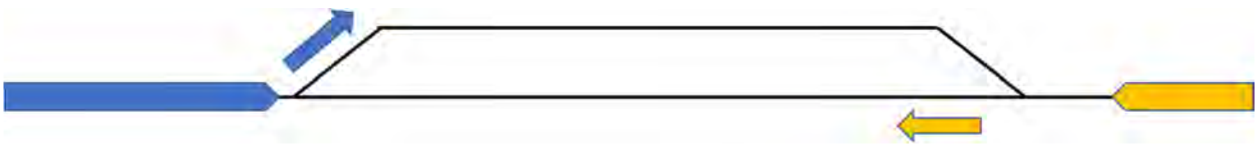

Figure 1: Example train paths when approaching a passing siding

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.

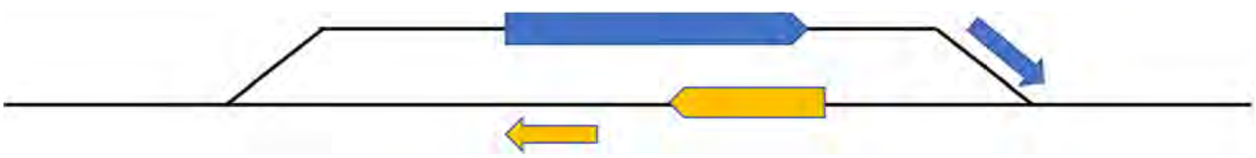

Figure 3: Lower priority train resuming travel

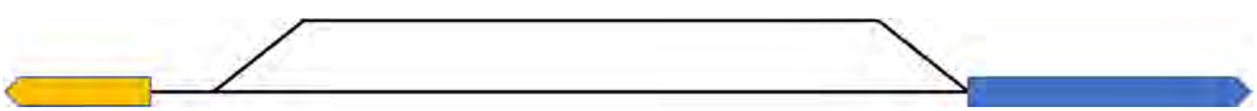

Figure 4: Meet process completed

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.

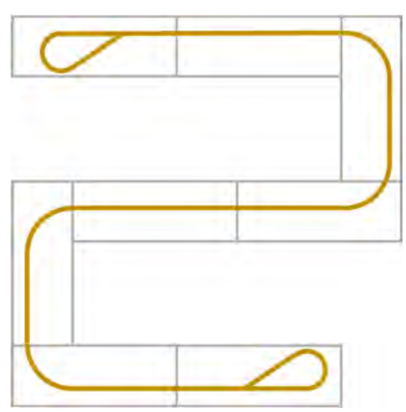

Table 1: Common BRIO Track Pieces		
Letter Designation	Length (inches)	Description
A	5.5”	Straight
A1	4.25”	Straight
A2	2”	Straight
A3	2.75”	Straight
B2	2”	Male-to-male adapter
C2	2”	Female-to-female adapter
D	8.5”	Straight
E	6.5”	Curve
E1	3.5”	Curve (1/2 E)
L	5.5”	Turnout (opposite connectors of M)
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
  - 3 x D
  - 1 x A2
  - 5 x E
  - 1 x A3
  - 2 x L
  - 1 x C2
  - 1 x M
  - 2 x A1 (optional, depending on Terminal design selected from Figure 7)

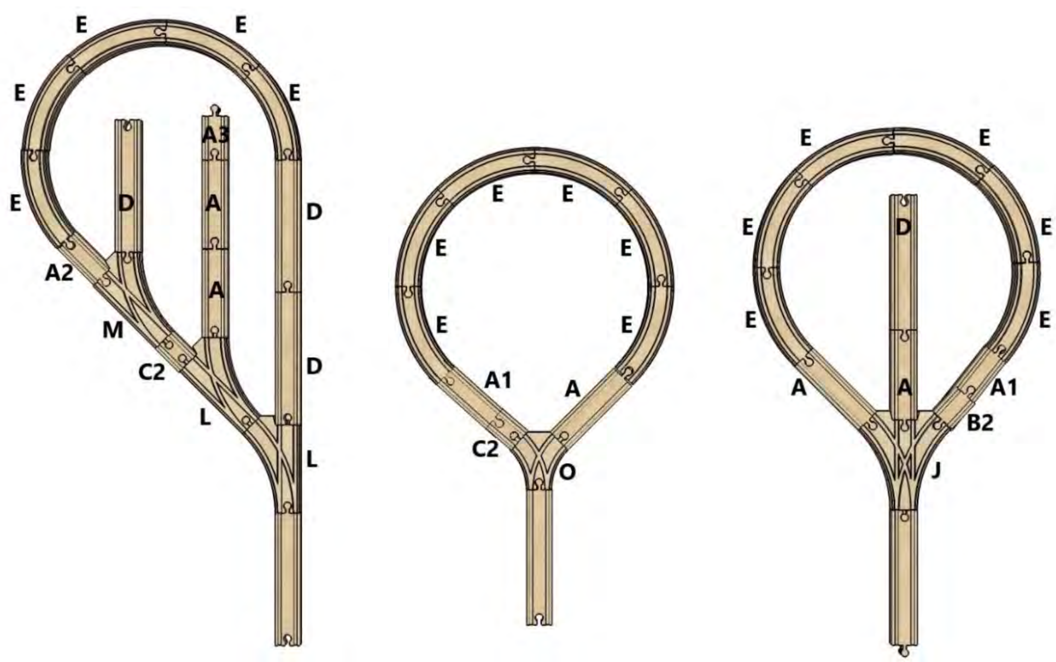

Figure 7: “Balloon Track” Terminal Designs

- 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 be added to the existing mainline as seen later in Figure 13. 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

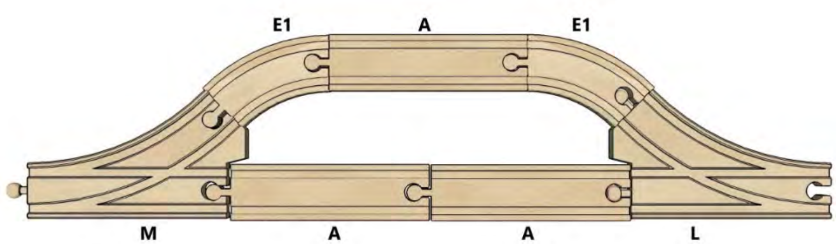

Figure 8: Siding design for a 4-car train

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

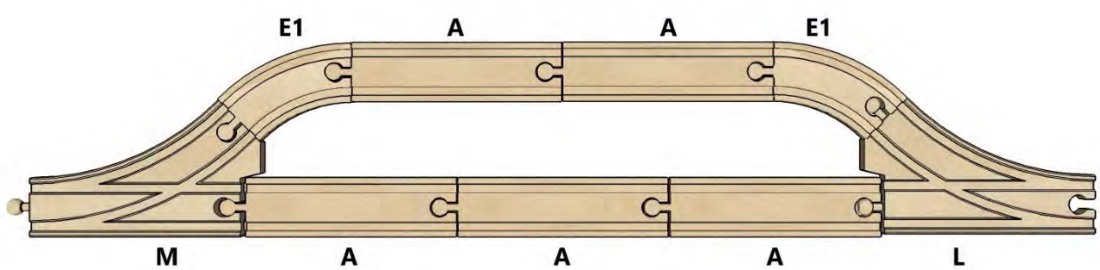

Figure 9: Siding design for a 6-car train

- 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

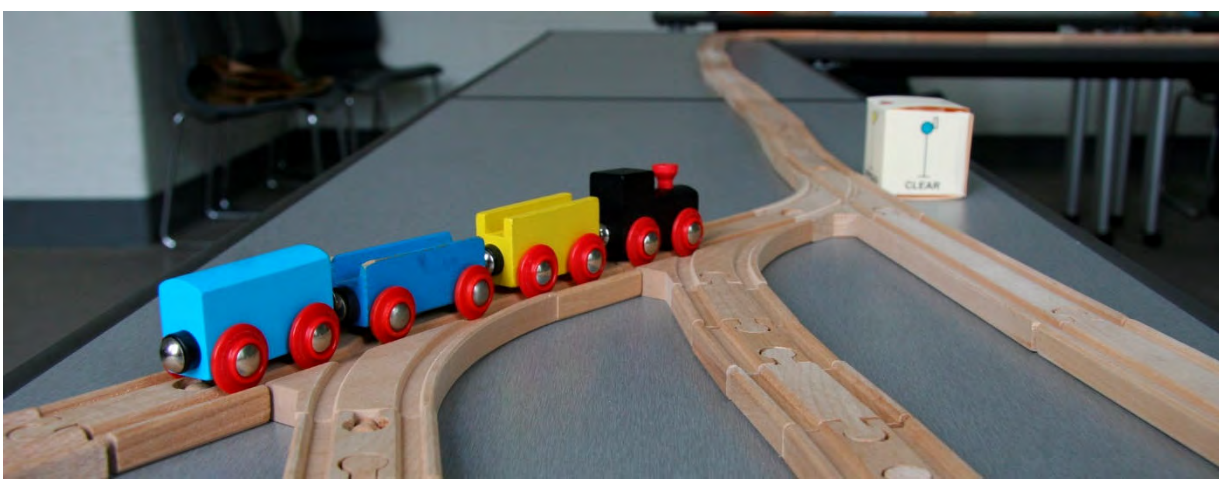

Figure 11: A typical three-car train and signal cube

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.
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 to 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.

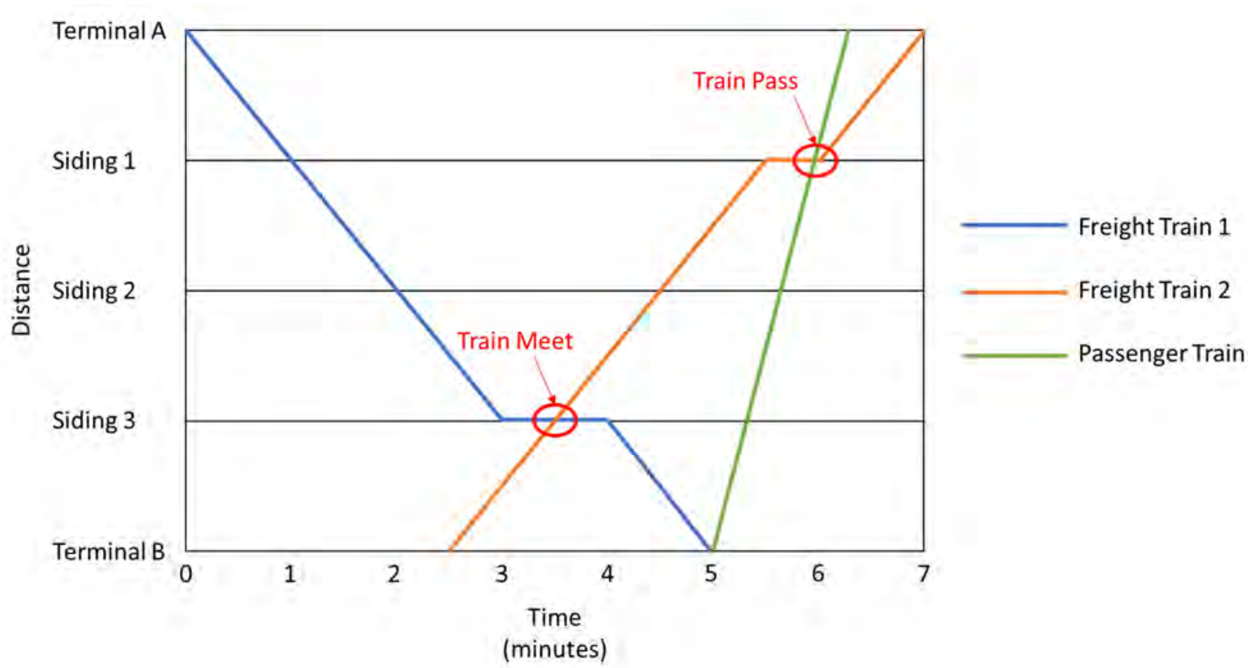

Figure 15: Example string line diagram for BRIO railroad

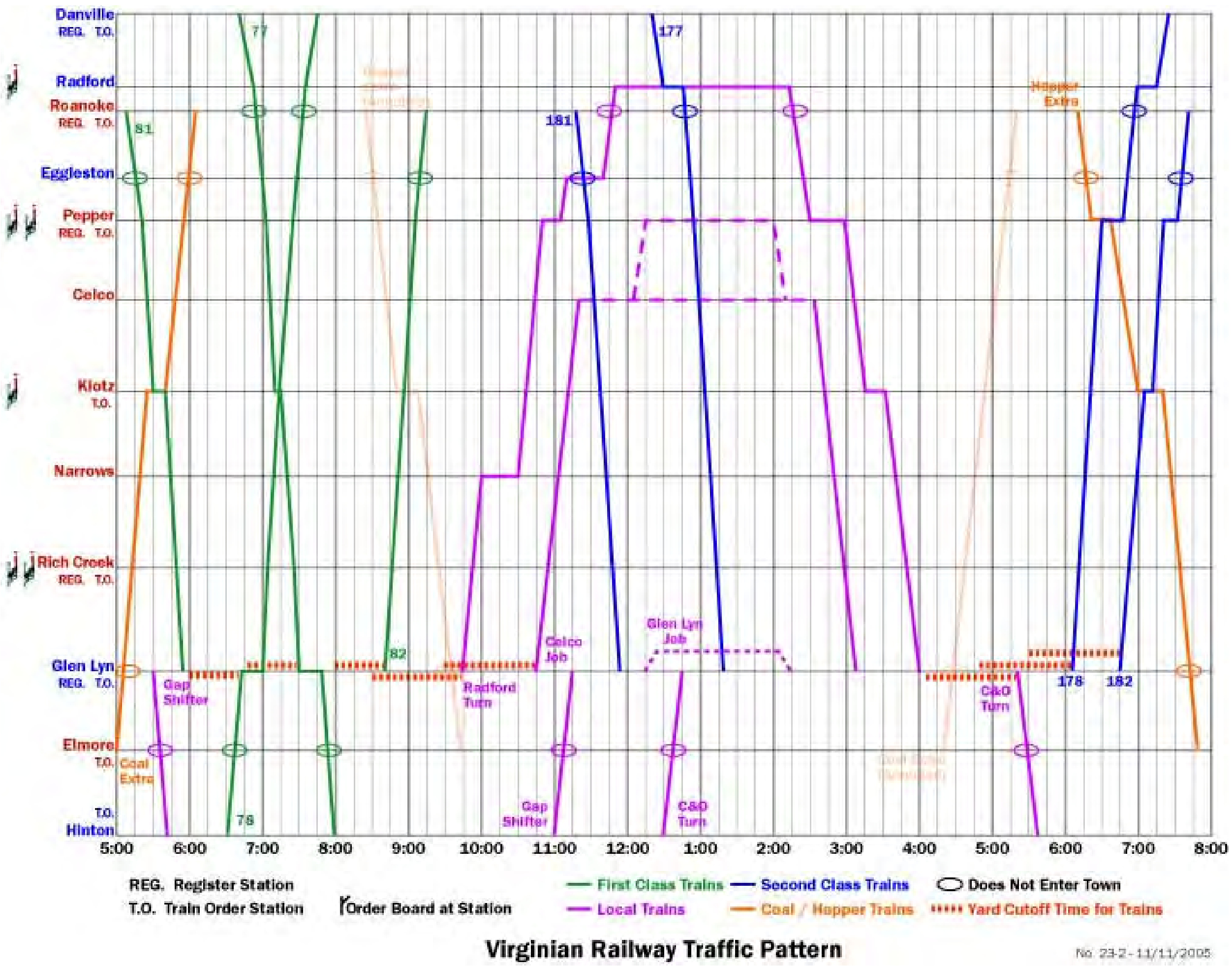

Figure 16: A sample string line diagram from a real railroad line

<u>Resources for Additional Learning</u>

The Railroad: What it is, what it does (John H. Armstrong) ISBN: 978-0911382044

All About Railroading (William C. Vatuono) ISBN: 978-0911382259

CSX Railroad Dictionary: https://www.csx.com/index.cfm/about-us/company-overview/railroad-dictionary/

BRIO Train Information: http://woodenrailway.info/

Rail Traffic Data: https://www.aar.org/aar_news/weekly-rail-traffic-data/

Appendix:


MONOPOLY
5
5
5


MONOPOLY
10
10
10


MONOPOLY
20
20
20


MONOPOLY
50
50
50


MONOPOLY
100
100
100


MONOPOLY
500
500
500

Appendix B: “Classification Yards and Railcar Sorting” Activity Description

Classification Yards and Railcar Sorting

Railway yards sort railcars 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:

- *Technology: computers must use similar strategies to sort stored data in a given order*
- *Engineering: optimizing the use of infrastructure to build the most blocks*
- *Mathematics: sorting strategies relate to matrices, sequences and series*

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

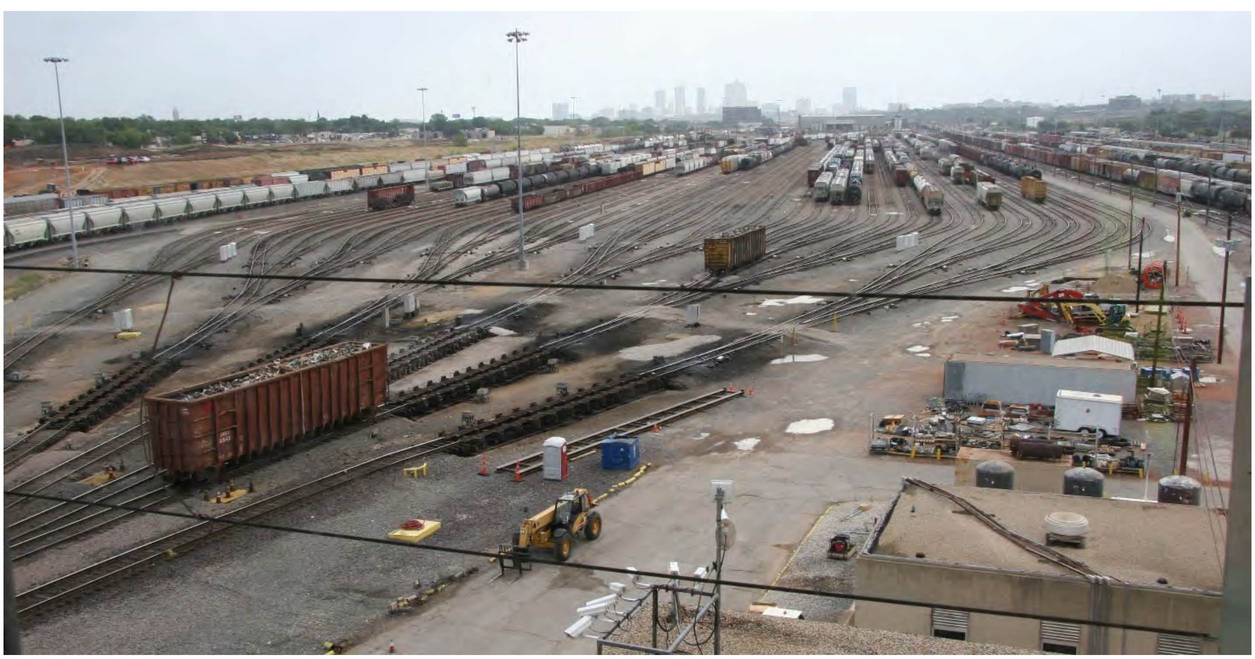

Figure 2: Classification tracks at a hump classification yard

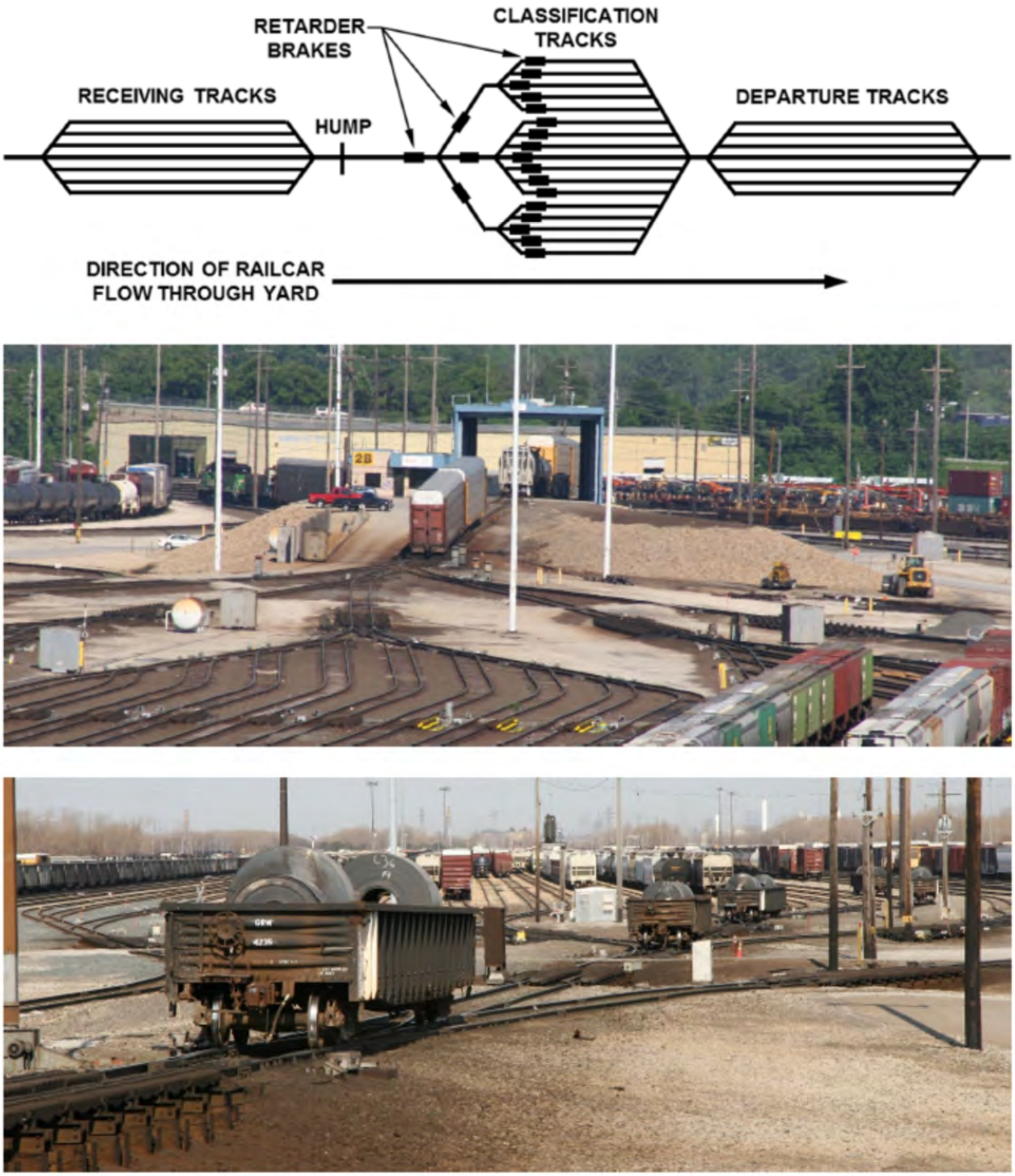

Figure 3: A hump at a classification yard

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.

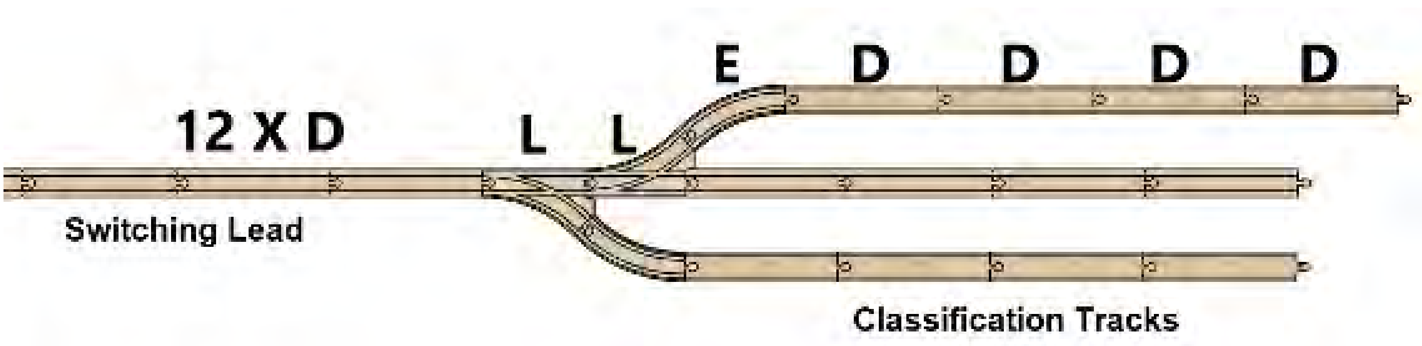

Figure 5: Three-track yard using BRIO track

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.

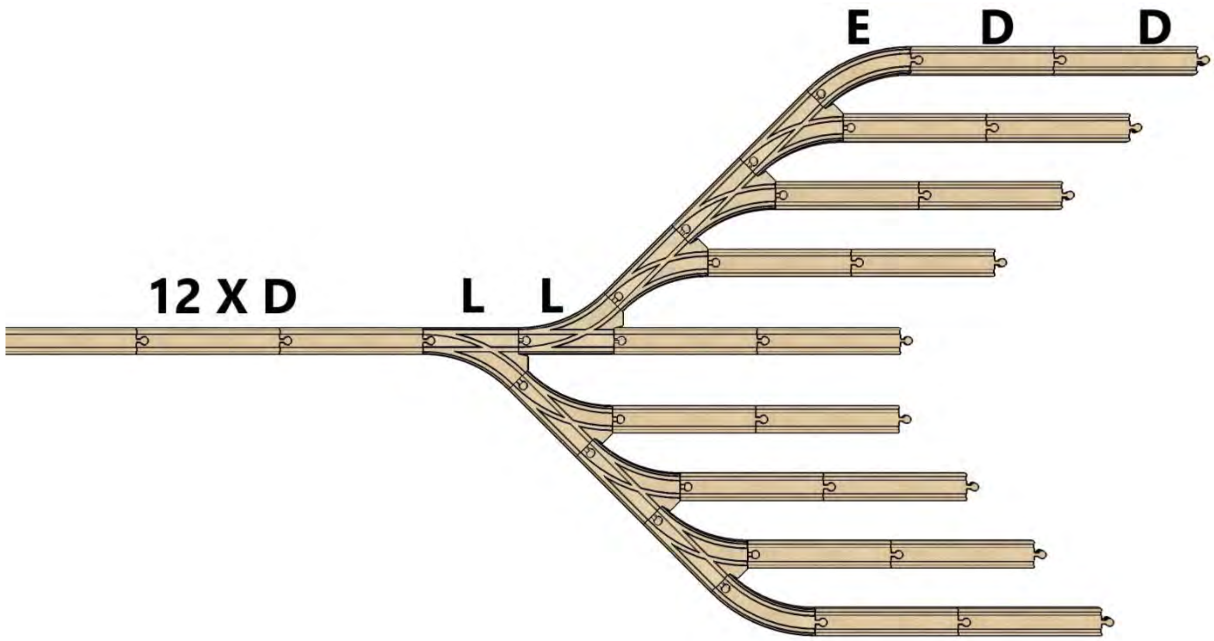

Figure 6: Nine-track yard using BRIO track

*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.

Activity Script

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.

Stage 1: Basic Sorting

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.

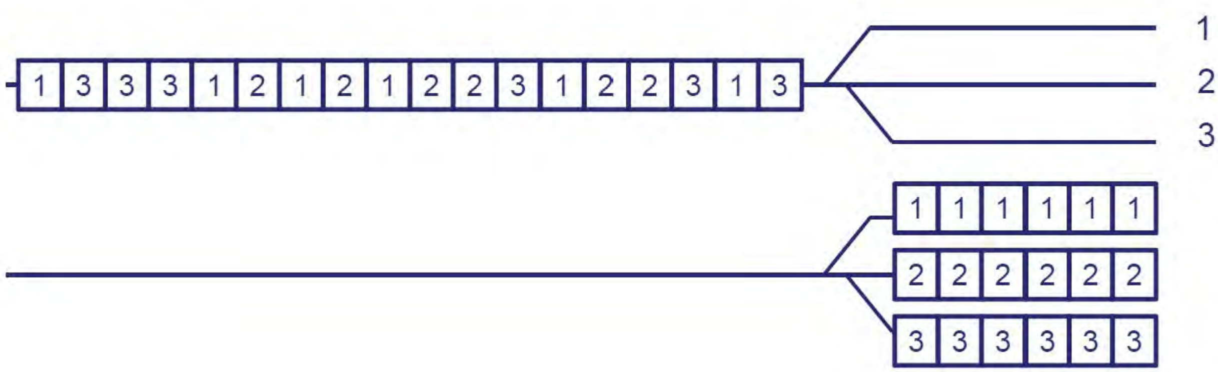

Figure 7: Basic sorting

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?

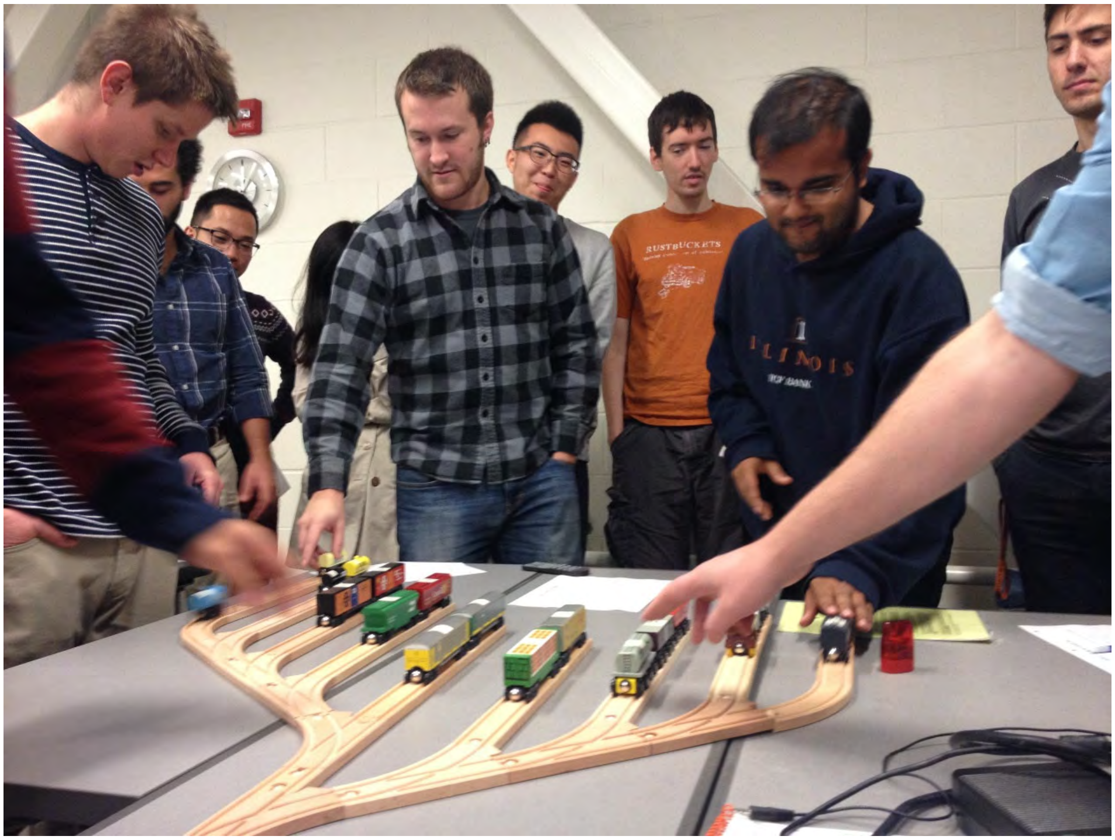

Figure 8: Sorting railcars into nine blocks on nine tracks.

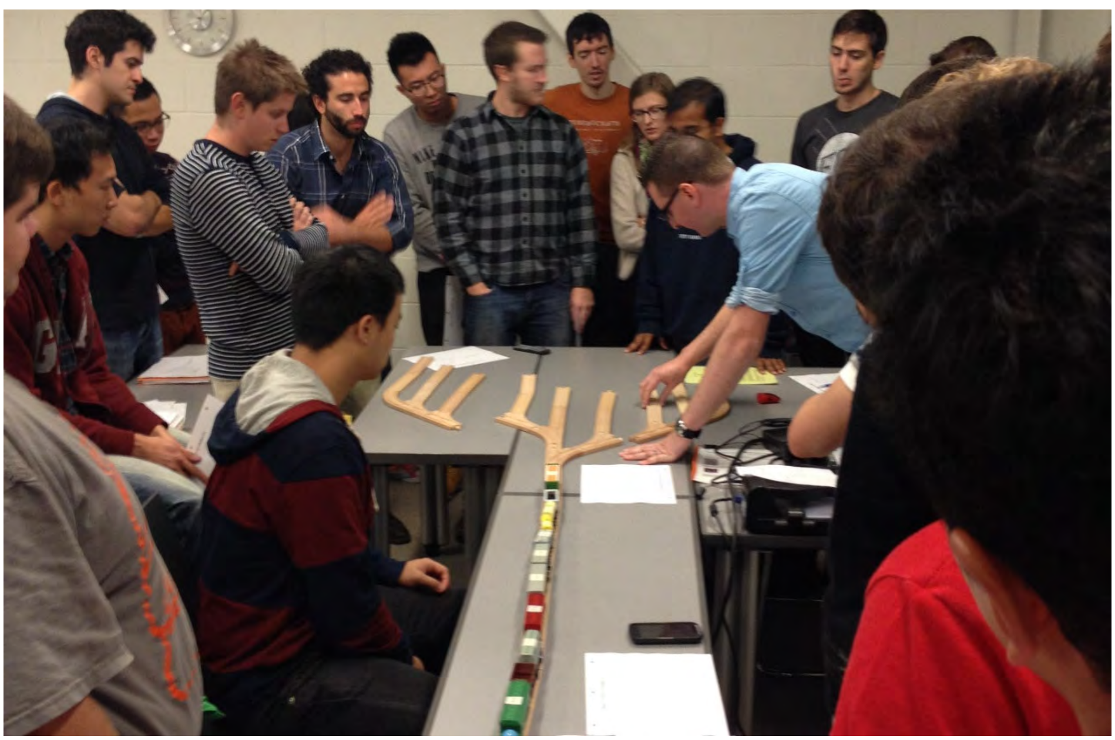

Figure 9: Removing six of the nine tracks for the challenge of forming nine blocks on three tracks.

Stage 2: Matrix Sorting

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.

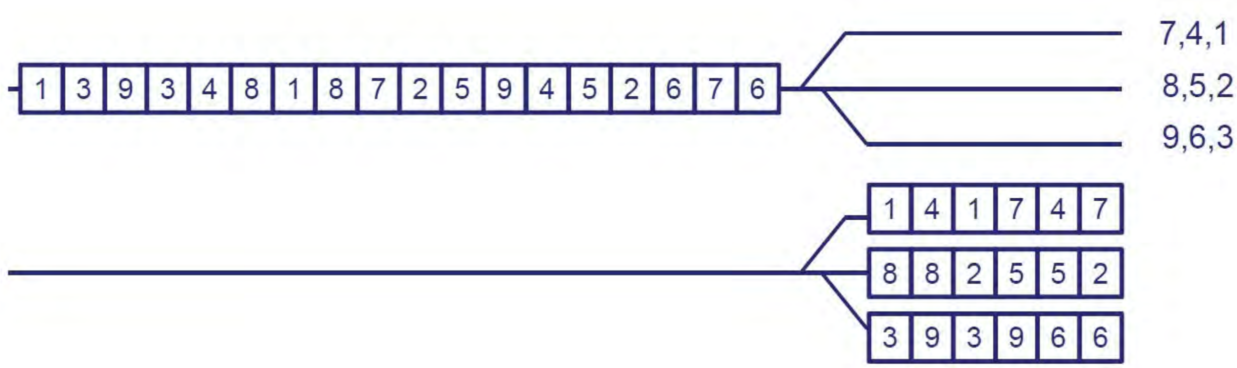

Figure 10: Matrix sorting stage 1

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.

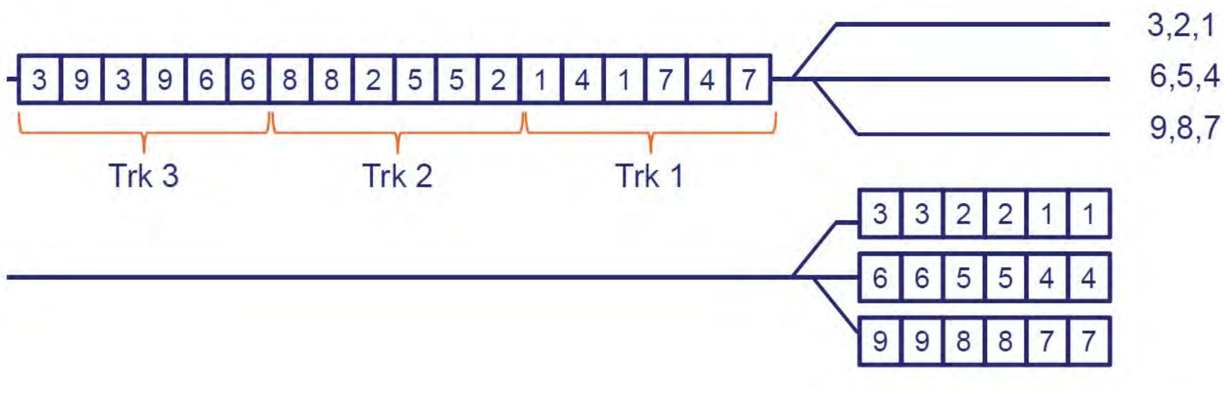

Figure 11: Matrix sorting stage 2

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?

<u>Stage 3: Triangular or Geometric Sorting</u>

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.

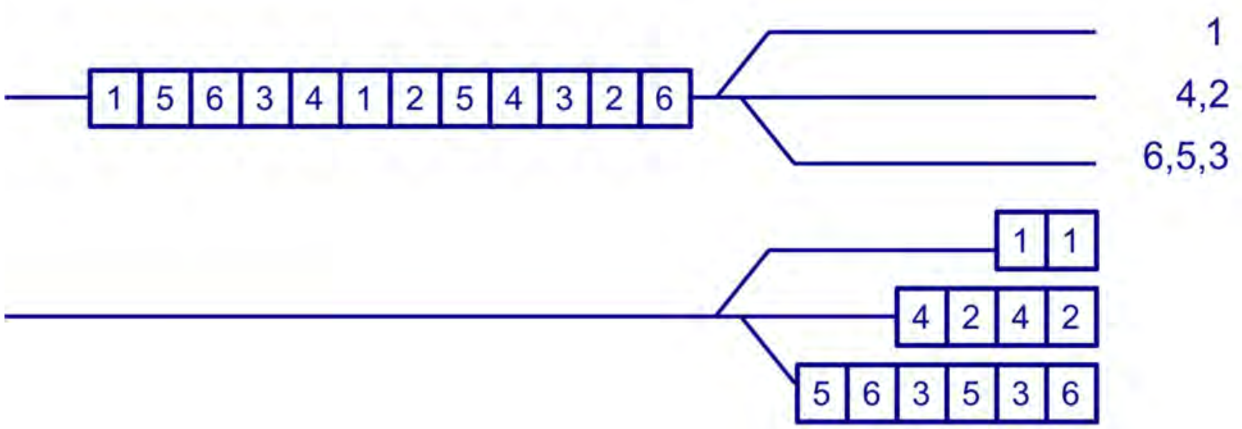

Figure 12: Triangular sorting stage 1

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.

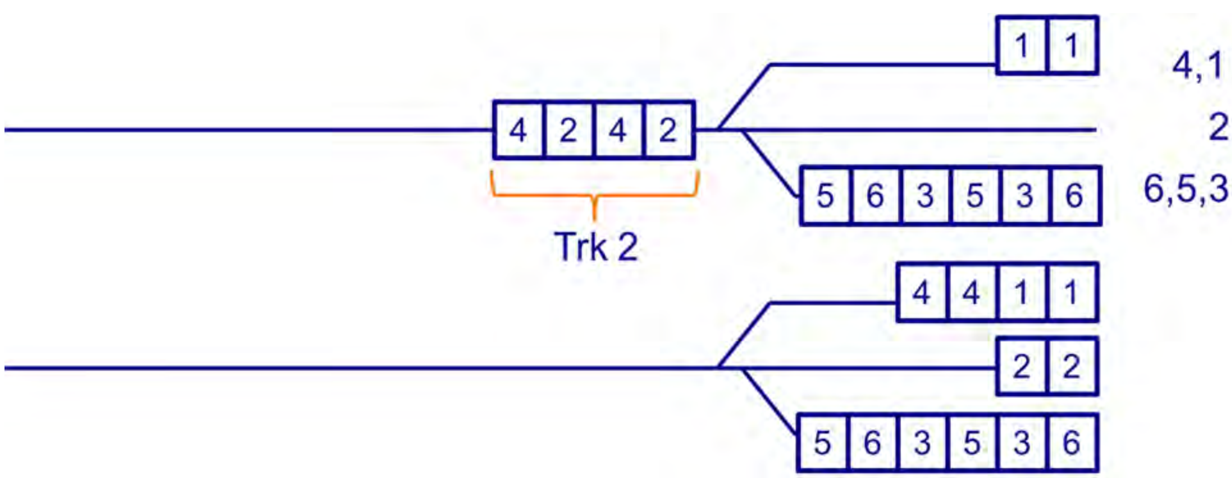

Figure 13: Triangular sorting stage 2

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.

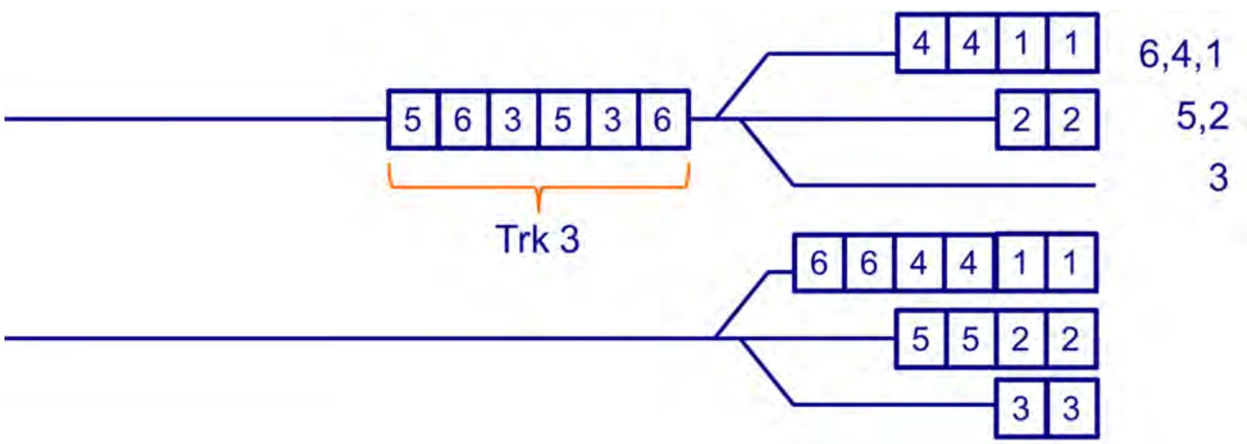

Figure 14: Triangular sorting stage 3

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?

Adjusting for Participant Time and Age

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.

Resources for Additional Learning

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