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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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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*

Key Learning Points

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.**

Background

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

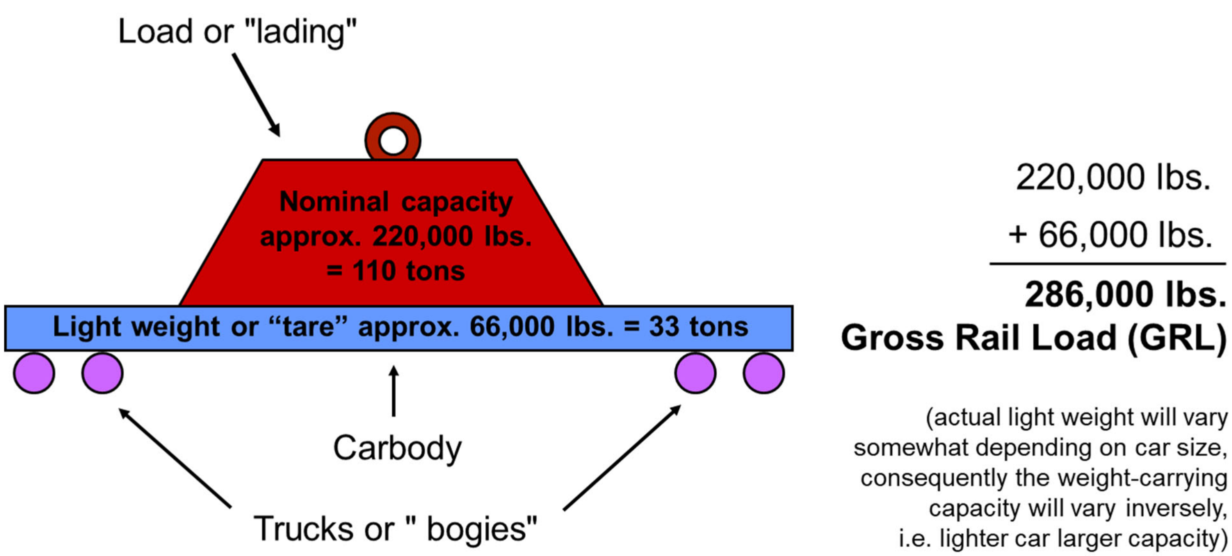

Figure 2: Gross Rail Load (GRL) is composed of empty railcar weight and lading weight

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:

$$\textit{Density} = \textit{Mass} / \textit{Volume}$$

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.)

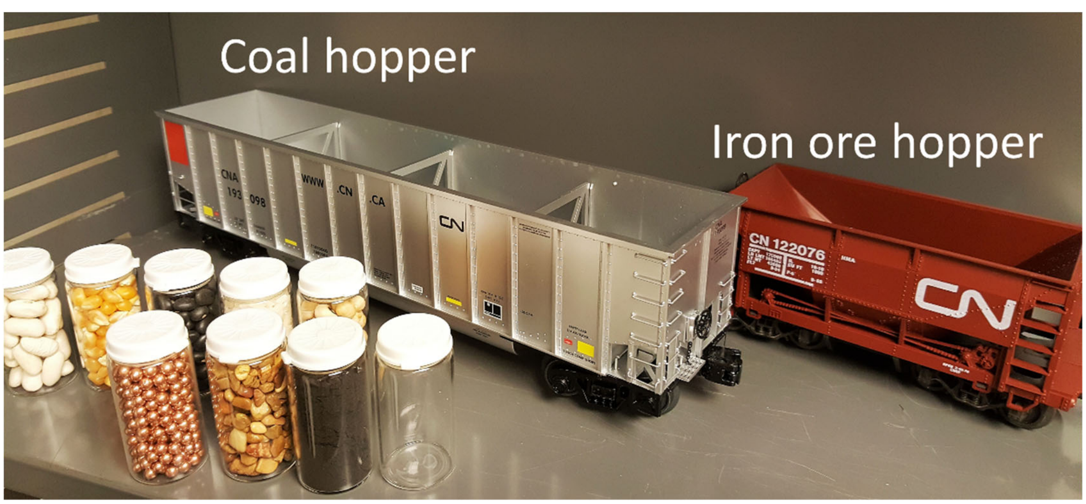

Figure 5: Model railcars and materials used for railcar size and weight exercise

<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.