Note to the Reader:

This file is a compilation of the materials used in the Full Speed Ahead Program, developed as part of the Interactive Qualifying Project titled Teaching Resources for London Transport Museum. The documents are, in order, the Teacher Handbook, the Resource Handbook, and the Letter to the London Transport Museum Program Coordinator. These are three distinct documents, which are combined in this file for the purposes of online submission.

Full Speed Ahead!

{The Teacher Handbook}

Table of Contents

Project Introduction

The goal of this program, facilitated by the London Transport Museum (LTM), is to inspire students to pursue science, technology, engineering, and mathematics (STEM) by relating real world transportation problems to classroom concepts. The curriculum is designed to have students learn through hands-on research, testing, and inquiry rather than by lecturing and guidance from teachers. To enhance the program's adaptability to many classroom environments, it has a modular design; the depth and number of sessions run in your class is left to your discretion based off of your students' abilities, your available resources, and time you have to spend on each activity. If the program is run in full, however, each group of students, or "engineering firm" will have a rail line featuring a model train, track, tunnel, bridge, station. signaling system, and mathematical analyses. Regardless of the amount of the program students complete, it should enhance their understanding of engineering and the responsibilities of several engineering fields.

Project Instructions

The Full Speed Ahead curriculum is designed to be as flexible as possible, empowering students to be as creative or as explorative as they so choose. The format of the sessions are listed below in the table. Please note that not every activity will have all of these sections in it, and that the written time allocations are merely suggestions.

Section	**Description**
Introduction	Provides context for the activity and is read aloud to the students.
Concepts	Concepts that students will encounter in the activity.
Learning Outcome(s)	What students will understand or gain as a result of the activity. These learning outcomes are as follows: 1. To inspire students to pursue a career in engineering 2. To enable students to see the breadth and depth of engineering as a field 3. To guide students to see the benefits of 'soft skills' in engineering careers 4. To empower students to have the confidence in their ability to pursue careers in engineering.
LTM Exhibit Connection	The LTM has exhibits and handling objects that correspond with the listed activities.

Research Phase	Students explore the concepts they will need to complete the activity.
Design Phase	Students collaborate in groups to create a novel design.
Build Phase	Models are produced. Note that all building materials should be provided by the school, not the London Transport Museum.
Recap/Discussion Phase	Students develop soft skills by communicating their learning to others.
Above and Beyond	Options within each session to further challenge excelling groups.
Suggested Evaluation	Largely the selection of the "best" design is left to your discretion as the time and materials available to each class will greatly affect the students' output. In general, consider concepts such as strength, size, creativity, feasibility, environmental preservation, and cost (again, the relative "cost" of materials is left to your discretion).

In addition to the each sessions' lesson plan, this packet includes:

- **Student Handouts:** This packet contains student activity handouts for each session.
- **Engineer Instructions:** At any point throughout the program, you can request a real engineer from Transport for London to visit your class and speak about their work. This letter outlines the Full Speed Ahead Program for them and explains how their involvement can enhance the students' experiences.

Should students need extra background on a topic or more activities to complete, please refer to the **Resource Handbook**. The Resource Handbook is oftentimes necessary for a session to be successful, either because it contains an activity's description or provides crucial information. This is the other handout you received at the beginning of this program.

Your Role

For the Full Speed Ahead Program, you are the Mayor of London and the groups of students are engineering firms. At the beginning of each session, you should read the introductory paragraph aloud to brief students on the session's unique project. This reading should impress upon students that the activity they will complete is based on a challenge faced by real engineers, and that the solutions developed by these professionals affects ordinary people just like themselves.

Recommendations for running the project:

- Let the students be as creative as possible. If they are stuck or lost, feel free to help them, but try to avoid directly giving them a solution.
- Adding a competitive element to this curriculum may help engage students in the program as a whole, but ultimately the development of a system for awarding points or selecting a winning project has been left to your discretion.
- Requesting a Transport for London Engineering Ambassador to visit your class to provide constructive criticism to the students may well be the highlight of the program, and cement the idea that engineering is both approachable and impactful. A letter describing the project to visiting professionals is included in this packet.
- Visiting the London Transport Museum, this program's sponsor, will allow students to learn how engineers throughout history tackled the same challenges they considered, and how their work literally shaped London.

Project Description

To be read to students at the start of the program.

"London is a bustling city with a long history of public transportation. Since the city's humble beginning, its transportation network has been under constant improvement and expansion as the the system grows to fill the changing needs of London's citizens and visitors. With the city's population ever rising, the number of people using its public transportation system rises every year. Engineers are constantly in demand to design bigger and better systems to make the travelers' experiences safer and more convenient. For the duration of this program assume you, the students, are engineers working to propose a new rail line requested by me, the Mayor of London. This initiative should reduce the congestion of London's train network, cut down on pollution in the city, and ultimately improve the lives of the city's population. You will form engineering firms to compete for this lucrative government contract."

Conclusion

The Full Speed Ahead program was designed to be a departure from traditional, lecture based learning and manifests the philosophy that hands-on, student-led activities can foment a life-long passion for STEM. Thank you for participating in this program.

Engineer Instructions

Goal

The Full Speed Ahead program endeavors to inspire year 10 and 11 students to pursue engineering by developing a multi-disciplined, engineering-centric, project-based curriculum culminating in a visit to the London Transport Museum (LTM). This initiative will help relate real-world engineering concepts to classroom lessons and inspire young minds to explore science, technology, engineering, or mathematics (STEM) fields.

Structure

- In this simulation, the teacher is the Mayor of London. They have requested the construction of a new rail line through the heart of London.
- Students are divided into mock engineering firms competing for the Mayor's contract.
- Perhaps you may join the fun as a professional consultant!
- Depending on their level of progress and the activities selected by the teacher, the students will have created: a train and rail line; a bridge; a tunnel; an electronic signaling system; a station; and a construction schedule. Each of the program's ten sessions is outlined as follows:
    - **Session 1: Business as Usual-** Students are grouped together and form mock engineering firms which are tasked with developing a mission statement, logo, motto, and code of conduct. They are then set in a competitive negotiation game centered around trading for resources to meet contracts. This session sets behavior standards for the rest of the FSAP, and gives students a chance to practice communication and negotiation skills.
    - **Session 2: Train of Thought-** Students design and build a train and track. The train is the key part of the session, and students may be challenged to consider the propulsion and braking methods their train would use.
    - **Session 3: Mixed Signals-** Students build a light-sensing circuit that could be installed on their track as a simple signal. This activity challenges students' knowledge of circuits and encourages them to consider safety on rail lines. This activity introduces students to A-Level content.

- **Session 4: Rail Lines and Line Graphs-** Students relate kinematics to rail line optimization, specifically addressing acceleration and headway, the time interval needed between trains to prevent collisions.
- **Session 5: Mind the Gap-** Students will research some important elements of transportation and the history of bridge design. Then they will design and build a bridge across a small gap. The constructions are evaluated by the weight they can support, the cost of their materials, and the structure's weight.
- **Session 6: Tunnel Vision-** Students design and build a tunnel. This session is analogous to Session 5.
- **Session 7: Station Fixation-** Students research, design, and build a tube station. They can design advertisements for their station to develop persuasive reasoning skills, or determine where to place signs to best inform passengers of important information.
- **Session 8: Time is of the Essence-** Students create a schedule for the construction of a project using a form of mathematical analysis. This is designed to target critical thinking skills and challenge students to consider a real-world application of mathematics outside of their experience with the subject.
- **Session 9: Show Time-** Students present their proposed train, rail line, station, and other components created over previous sessions to the teacher. The aim is to show students the value of communication skills in engineering.
- **Session 10: A Journey through Time-** The final session includes a visit to the LTM where students connect concepts learned in the classroom to London's history of transportation. Relevant exhibits are highlighted throughout sessions, and summarized again in this session for reference.

Your role

- Feel free to contribute to the curriculum however you see fit. Consider some of the ideas below:
  - You may comment on certain elements of a firm's design, suggest additional challenges to thriving teams, or explain relevant scientific concepts.
  - Excite students about the relatability, impact, and diversity of STEM work by sharing your story. What projects have you worked on? How did you enter the

STEM industry? What do you like most about your job? What did you wish you knew in secondary school? What do people not know about engineering?

Suggested List of LTM Handling Objects

These objects, available through the LTM's Learning Office, may be used to compliment your discussion at the school.

Session	**Handling Object/Link to LTM**
Business As Usual	Frank Pick Metroland Exhibit
Train of Thought	Composite Conductor Rail Fact Sheet (T-06) Pandrol Clip Fact Sheet (T-02) (T-16) Pressure Switch Fact Sheet (T-11) (T-12) Rail Fastenings Fact Sheet (T-01) (T-13) (T-14)
Mixed Signals	Capacitors (E-07) (E-08) T-Piece Fact Sheet (T-05) Hawkbox Tuning Unit Component Fact Sheet (S-17) Indication Contact Arrangement Fact Sheet (S-13) (S-14) Indicator Push Rods Fact Sheet (S-0.5.1) (S-0.5.2)
Rail Lines and Line Graphs	Relay Fact Sheet (S-15) (S-16) Wiring Cables Fact Sheet (S-01) (S-02.1-2.9) (S-18.1) (S-18.2)
Mind the Gap	Post Tensioning Cable Fact Sheet (C02)
Tunnel Vision	Concrete Fact Sheet (C-01) Link to Tunneling Exhibit at LTM
Station Fixation	Water Meter (C-07)
Time is of the Essence	Microprocessors / Heatsinks (E-01) (E-06) Random Access Memory (RAM)
Show Time	N/A
Journey through Time	Refer to Session 10 of the Teacher Handbook

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Session 1: Business as Usual

Introduction

"Before you can work on the project at hand, you have to create a logo, motto, code of conduct, and a mission statement. Your logo and motto should be creative, concise, and quickly convey what your company does; of course, your logo should be aesthetically pleasing and iconic as well. Your mission statement should be an expansion of your motto; it should explain your company's goals and pursuits, why they matter, and how your company will reach them. Just as in a real workplace, you are individually responsible for behaving in a professional manner. As a group you should agree upon a code of conduct which describes what is expected of each team member and how potential problems may be resolved."

Concepts

- Teamwork
- Negotiation
- Delegation of responsibilities
- Graphic design

Learning Outcome(s)

- Benefits of soft skills (teamwork, behavior contract, logo design)

LTM Exhibit Connection

- Posters
- Important people: Frank Pick, Albert Stanley (or Lord Ashfield), Robert Hope Selbie
- Edward Johnston Roundel and Font
- Metro-land

List of Materials:

- Paper, Pens, Pencils, Markers, Ruler
- Optional: Computers

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• Have students try out a couple of creative problems (located in the Resource Packet) to get them into a creative, problem-solving mindset • Encourage students to look at logos from a variety of backgrounds (transport, energy, business, film, etc.)
Activity 1 (30 min-1.5 hrs)	Students should research and design a logo, motto, code of conduct, and mission statement.
Activity 2 (30 mins- 1 hr)	Transportation Transaction Game (included in the Resources Handbook)
Recap/Discuss (10 min-30 min)	• What did you learn about companies and the way they function you didn't know before? • Explain the reasoning behind your company name, motto, logo, mission statement, and code of conduct.
Above and Beyond	Create an advertisement for your company. This may be a promotional video or skit.
Suggested Evaluation (5 min)	• What logo is the most creative and laconic? • What slogan is the catchiest? • Which code of conduct is the most professional? Do any include mechanisms for student-led conflict resolution? • Which mission statement is the most focused?

Session 2: Train of Thought

Introduction

"The most essential part of any tube line is the track. The dimensions, path, and capabilities of a track govern much of the design of the remainder of the rail line. Therefore, the first part of this activity will be to design a railway track. After this is done you may then create an accompanying train."

Concepts

- Forces of motion (Physics)

Learning Outcome(s)

- Empower students (Considering design questions)
- Breadth and depth of engineering (Railway engineering)

LTM Exhibit Connection

- Interactive monitors/tablets
- Steam vs. Electric propulsion
  - Steam/Smoke ventilation display
- First through Third class coaches
- Changing straphanger designs

List of Materials

- Acrylic, cardboard, wood, newspaper, ruler, tape, glue, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Optional: Magnets, battery, LEDs, resistors, paint

Session Agenda

Activity	Description
Research (15 min-1 hr)	• Discuss the pros and cons of the ‘cut and cover method’ • Brainstorm other methods of building a railway • If you have access to a train, have students visit it. Otherwise, have student share their experiences/impressions of public transportation.
Activity (30 min-2 hrs)	Research, design, and build a tube line and/or a train. *Note: Constructing a rail line is optional. This means that you do not have the train run on a track or will have to provide a track.*
Recap/Discussion (10 min-1 hr)	• Preform a cost analysis on your train based on the prices of the materials you used. • How well does your train perform relative to your expectations? • How might improve your train’s design? Could you decrease its weight?
Above and Beyond	• Include a curve in your track. • Design a propulsion system to power your train (Ideas: Electric motor, fan, deflating balloon, electric induction). • Design a braking system for your train (Ideas: Felt runners or paper flaps on the rail line). • Examine a map of London’s existing railway network. Where might you place a new line and why?
Suggested Evaluation (5 min)	• Do the trains and tracks meet all the requirements? • Which train carries the most people/items? • Which train is the safest? The fastest? The lightest? The cheapest?

Session 3: Mixed Signals

Introduction

"The next essential part of a tube system is to have a way to direct the trains. Trains need to be able to stop when they reach stations and slow down when another train gets delayed. As a passenger on the tube, we take these scenarios for granted, but who ensures we get to our destination safely and efficiently? That's the role of a signal engineer. Obviously, engineers need to know exactly where every train on a line is located; one way to do this is with signals. I, the Mayor, want the new railway to include such a system. Using a photoresistor, shine a green light when the track is clear, and a red light when a train is on the track and covering the resistor."

Concepts

- Signaling, Circuits (Electronics/Electrical Engineering)
- Algebra (Maths)

Learning Outcome(s)

- Breadth and depth of engineering (Electronics engineering, applications to physics)

LTM Exhibit Connection

- Harry Beck's Tube Map

List of Materials

- Wires, Resistors (Photoresistor), Integrated Circuit, Not Gate, Red and green LEDs , 9V battery, breadboard
- Diagram of a circuit

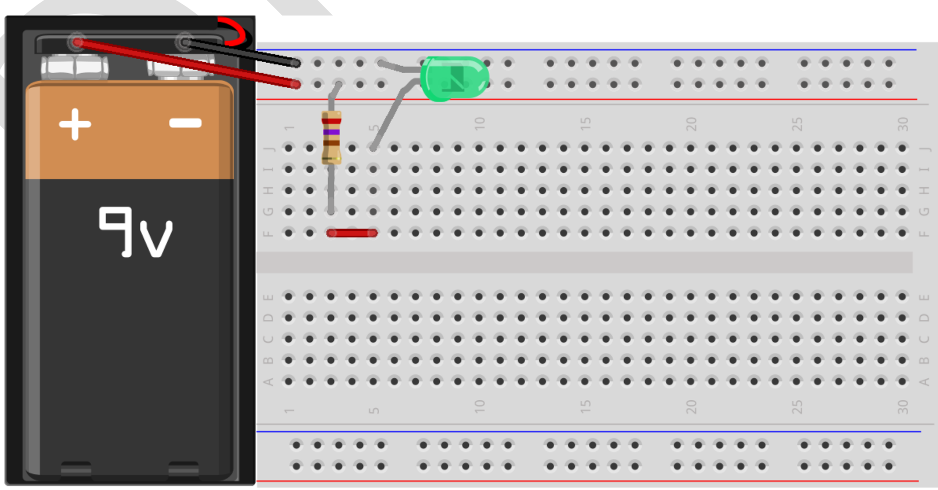
Session Agenda

Activity	Description
Research (10 min-1 hr)	• Research a circuit • Research voltage and current (Ohm's Law and Kirchoff's Laws) • Research railway signaling (see Resource Handbook)
Activity (45 min)	Use the diagram to build the circuit
Recap/Discussion (5 min- 30 min)	• What is the importance of electronic circuits in daily life and train engineering? • How might engineers design failsafe systems for train signaling? • Where else could you use the circuit you created in this activity on trains? • Why might the circuit you designed be impractical for real train applications, especially in the Tube?
Above and Beyond	• Use the circuit to add automatic headlights to your train to light the way through the tunnels.

Solutions

Note these boards use a TL081CP operational amplifier chip with a 3.3 kOhm resistor, two 5 mm LEDs, a 10 kOhm potentiometer, 22 kOhm photoresistor, 9 volt battery and two 270 Ohm resistors. Depending on available components, breadboard connections can change. These image serves as a guide for each circuit.

1.



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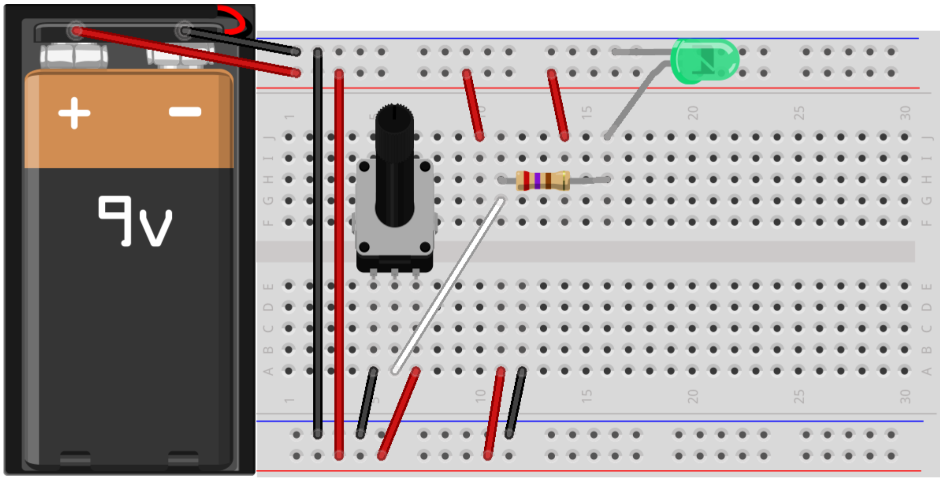

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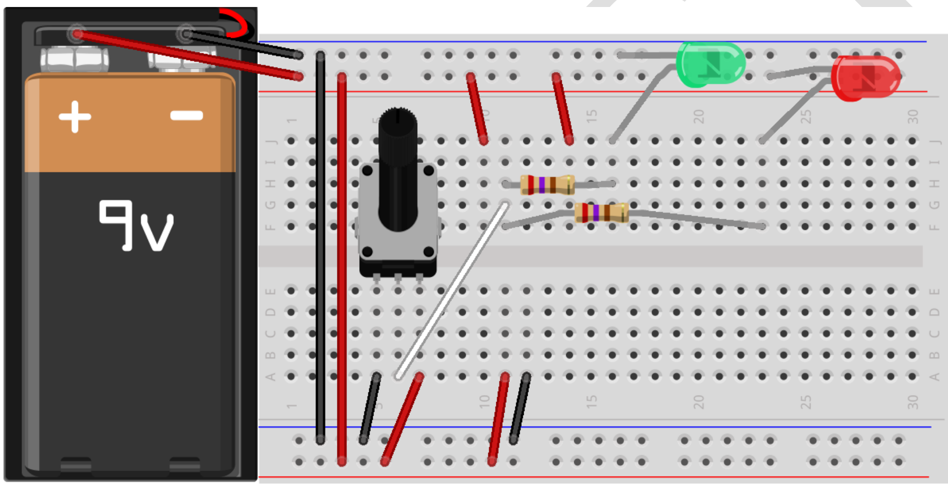

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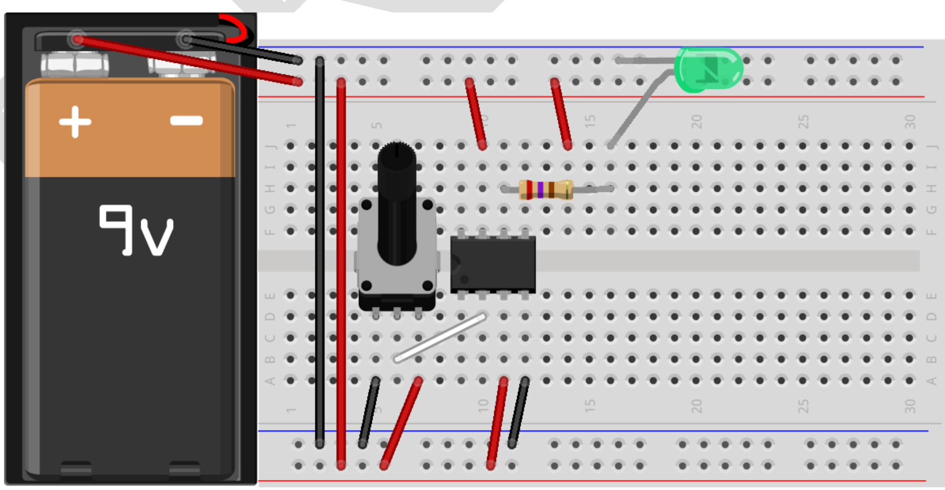

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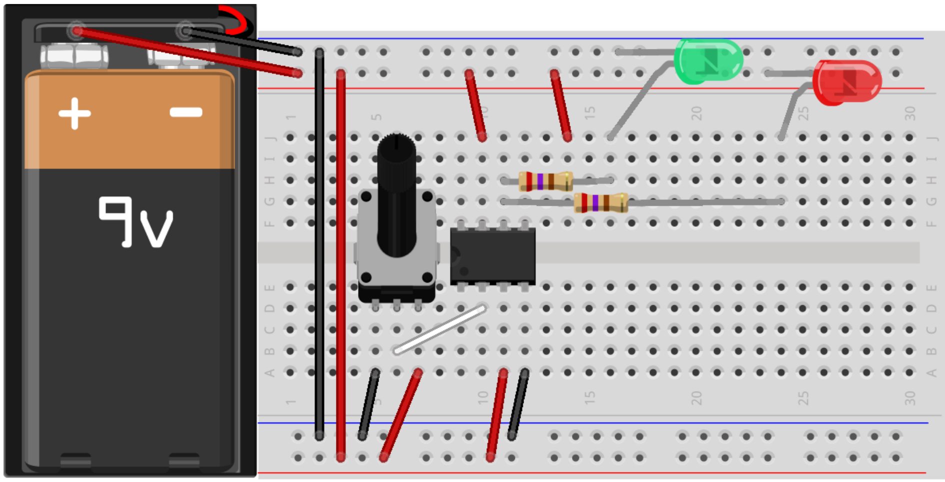

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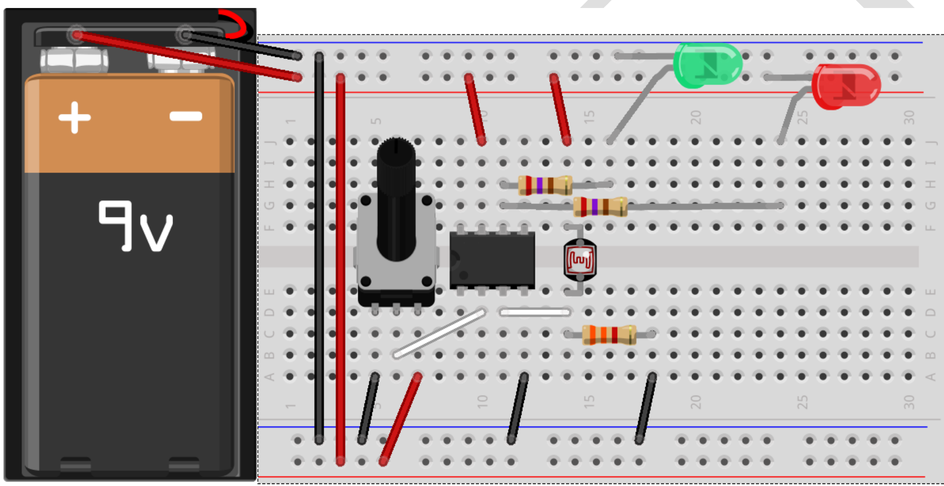


Session 4: Rail Lines and Line Graphs

Introduction

"Clap your hands together. Isn't it clear two objects can't occupy the same space at the same time? This idea is extremely important to transportation engineers; train collisions are almost always catastrophic. Ideally, only one train would run on a single line, but this would be terribly inefficient. Engineers are challenged with maximizing the number of trains that can safely travel on a single line, thereby moving the most people possible.

To visualize this problem, engineers have developed charts called train graphs. These graphs display information about a train's speed, position, distance to another train, speed limitations, and stops on a particular line. Clearly train graphs are extremely useful tools, but they are also very complicated.

I, as the Mayor, want each rail company to be able to understand the basics of train graphs. It is important that you all realize these charts are all formed from basic kinematic equations. Work through the relevant physics problems to optimize a train's stop at a station, and then study the examples of real train graphs."

Note: The train graphs included in this activity are derived from an Excel program developed by Eric Wright, a professional signal engineer. They are modeled off of the London Underground's Victoria Line.

Concepts

- Reading train graphs
- Railway engineering, signaling
- Headway
- Kinematics (Physics)

Learning Outcome(s)

- Empower students (understand concepts used directly on the Victoria line)
- Breadth and depth of engineering (signals engineering)

List of Materials

- Computer (if possible)
- Graphs (provided in Resource Packet)

Session Agenda

Activity	Description
Research (Optional)	Ask students to look into the history of the Victoria Line.
Activity 1 (1 hour)	Physics problems (see below for solutions)
Activity 2 (45 min)	Train graphs (see below for solutions)
Recap/Discussion (1 hour)	• Connect to Mr. Wright's example of a train graph (Victoria line) • Having students summarize relatively complex technical ideas is an important writing challenge.
Above and Beyond	• This activity should show students the tradeoff between digital optimization and hand calculation: o Generate an Excel spreadsheet that can instantly calculate a train's position, velocity, and acceleration based on an assumed mass, breaking force, and kinetic energy. Use the results of Questions 1, 2, and 3. o Plot graphs of position vs. time, velocity vs. time, and acceleration vs. time, with data points at .25 second increments. o What are the benefits of using a computer program as opposed to completing calculations by hand? o Did it take more or less time to set up the computer program than to simply do the math on paper? o When does it become cost effective for your company to develop a computer program to replace manual calculations? • Have students go to a Tube station with a stopwatch and calculate the headway of the trains. Does the headway change throughout the day? • Let students explore Mr. Wright's train graph Excel file (provided via the LTM). Students may experiment with the program by changing the values contained in yellow cells.
Suggested Evaluation (5 min)	• What group wrote the clearest, most reader-friendly technical report?

Solutions to Background Problems

1. A train has a mass of 250,000 kg and is traveling with a kinetic energy of 15.125 MJ. What is the train's velocity?

$$KE = {}^{1}/_{2} * m * V^2$$

$$V = \sqrt{\frac{2 * KE}{m}}$$

$$V = \sqrt{\frac{2 * 15.125\ MJ}{250{,}000\ kg}}$$

$$Ans: V = 11\ {}^{m}/_{s}$$

2. Assume the train's air brakes can exert a force of -200,000 N on the train. At what rate does it decelerate? Include a free body diagram of this scenario.

$$F = ma$$

$$a = \frac{F}{m}$$

$$a = \frac{-200{,}000\ N}{250{,}000\ kg}$$

$$Ans: a = -.8\ {}^{m}/_{s^2}$$

3. Signals tell conductors the condition of the rail ahead. Put very simply: green means "Go"; double yellow means "The next signal is yellow"; yellow means "Slow down. The next signal is red"; and red means "Be at a full stop". Obviously, a station would display a red signal so passengers could enter and exit the train. How close to the station's red signal can a signal engineer place a yellow signal so the train can safely stop? How long does this deceleration take?

$V = V_o + a * t$

$t = \frac{-V_o}{a}$

$t = -\left(\frac{11\ {}^{m}/_{s}}{-.8\ {}^{m}/_{s^2}}\right)$

$Ans: t = 13.75\ s$

$X = X_o + V_o * t + {}^{1}/_{2} * a * t^2$

$X = 11\ {}^{m}/_{s} * 13.75\ s + {}^{1}/_{2} * -.8\ {}^{m}/_{s^2} * 13.75\ s^2$

$Ans: X = 75.625\ m$

4. (Optional Problem) Now assume the electric motor on your train can exert a force of 125,000 N on the train. Draw a free body diagram and find the rate at which your train can accelerate. If your train is 100 m long, how much time does it take for it to fully leave the platform? Assume the platform is the same length as the train. What is the momentum of your train at this instant (Hint: You will need to find the velocity of your train in order to calculate its momentum)?

$F = m * a$

$a = \frac{F}{m}$

$a = \frac{125{,}000\ N}{250{,}000\ kg}$

$Ans: a = .5\ {}^{m}/_{s^2}$

$X = X_o + V_o * t + {}^{1}/_{2} * a * t^2$

$100\ m = {}^{1}/_{2} * .5\ {}^{m}/_{s^2} * t^2$

$Ans: t = 20\ s$

$V = V_o + a * t$

$V = .5\ {}^{m}/_{s^2} * 20$

$Ans: V = 10\ {}^{m}/_{s}$

$p = m * V$

$p = 250{,}000\ kg * 10\ {}^{m}/_{s}$

$Ans: p = 2.5 * 10^6\ {}^{m}/_{s}$

Solution to Train Graphs

Headway is defined as the time between when identical points on two trains pass through the same point on a rail line. A simpler definition is: the time interval between two vehicles (automobiles, ships, or railroad or subway cars) traveling in the same direction over the same route. It can be calculated by finding the difference between the time coordinates of the fronts of two trains on a time vs. distance graph. The train length can be calculated by measuring the distance between the front and rear points in the vertical sections of the time vs. distance graph. The number of stations can be found from the number of vertical sections on the time vs. distance graph or minus one of the number of points with zero speed on the speed vs. distance graph (the first point with zero speed represents the train starting its journey and thus is not considered a station stop).

In all of the graphs, students should recognize the train may only accelerate to a higher speed when entering a high speed limit section of the track if every point on the train is within that new speed limit. Thus the max speed of the train in any given area is also dependent upon the length of the train.

Case 1:

Number of stations = 3

Headway = ~75s

Train length = 150 m

The trains will run without collisions, but either the headway or the length of the train can be changed to maximize the number of people it can serve.

Case 2:

Number of stations = 3

Headway = ~60s

Train length = 250 m

The trains will collide; the train length should be reduced or the headway should be increased.

Case 3:

Number of stations = 3

Headway = ~50

Train length = 150 m

The trains will collide; the train length should be reduced or the headway should be increased.

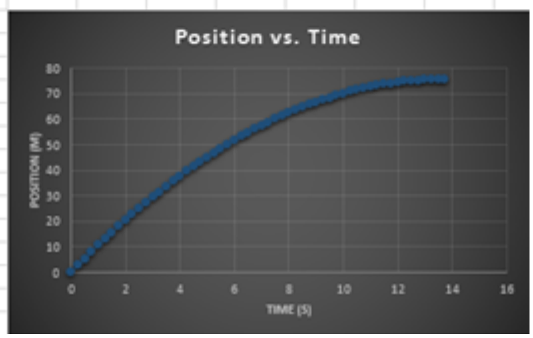
Solution to Digital Optimization

The original Excel file is available upon request at the LTM. A picture of a working Excel spreadsheet is included below. The equations used throughout the spreadsheet are:

- **B9:** =B11/B12*-1
- **B10:** =B11*B9+0.5*B12*B9^2
- **B11:** =SQRT(2*B4/B5)
- **B12:** =B6/B5
- **B15 (Drag down for the remainder of Column B):** =$B$11*A15+0.5*D15*A15*A15
- **C15 (Drag down for the remainder of Column C):** =$B$11+D15*A15
- **D15 (Copied for the remainder of Column D):** =$B$12

Rail Lines and Line Graphs Above & Beyond Excel Sheet

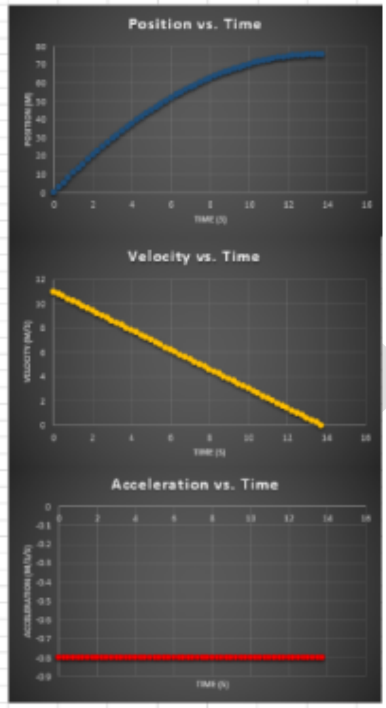
Given			
Kinetic Energy	15125000	J	
Mass	250,000	kg	
Brake Force	-200,000	N	
Calculated			
Time	13.75	s	
Position	75.625	m	
Initial Velocity	11	m/s	
Acceleration	-0.8	m/s/s	
Time (s)	**Position (m)**	**Velocity (m/s)**	**Acceleration (m/s/s)**
0	0	11	-0.8
0.25	2.725	10.8	-0.8
0.5	5.4	10.6	-0.8
0.75	8.025	10.4	-0.8
1	10.6	10.2	-0.8
1.25	13.125	10	-0.8
1.5	15.6	9.8	-0.8
1.75	18.025	9.6	-0.8
2	20.4	9.4	-0.8
2.25	22.725	9.2	-0.8
2.5	25	9	-0.8
2.75	27.225	8.8	-0.8
3	29.4	8.6	-0.8



Rail Lines and Line Graphs Above & Beyond Excel Sheet

Given		
Kinetic Energy	15125000	J
Mass	250,000	kg
Brake Force	-200,000	N
Calculated		
Time	13.75	s
Position	75.625	m
Initial Velocity	11	m/s
Acceleration	-0.8	m/s/s

Time (s)	Position (m)	Velocity (m/s)	Acceleration (m/s/s)
0	0	11	-0.8
0.25	2.725	10.8	-0.8
0.5	5.4	10.6	-0.8
0.75	8.025	10.4	-0.8
1	10.6	10.2	-0.8
1.25	13.125	10	-0.8
1.5	15.6	9.8	-0.8
1.75	18.025	9.6	-0.8
2	20.4	9.4	-0.8
2.25	22.725	9.2	-0.8
2.5	25	9	-0.8
2.75	27.225	8.8	-0.8
3	29.4	8.6	-0.8
3.25	31.525	8.4	-0.8
3.5	33.6	8.2	-0.8
3.75	35.625	8	-0.8
4	37.6	7.8	-0.8
4.25	39.525	7.6	-0.8
4.5	41.4	7.4	-0.8
4.75	43.225	7.2	-0.8
5	45	7	-0.8
5.25	46.725	6.8	-0.8
5.5	48.4	6.6	-0.8
5.75	50.025	6.4	-0.8
6	51.6	6.2	-0.8
6.25	53.125	6	-0.8
6.5	54.6	5.8	-0.8
6.75	56.025	5.6	-0.8
7	57.4	5.4	-0.8
7.25	58.725	5.2	-0.8
7.5	60	5	-0.8
7.75	61.225	4.8	-0.8
8	62.4	4.6	-0.8
8.25	63.525	4.4	-0.8
8.5	64.6	4.2	-0.8
8.75	65.625	4	-0.8
9	66.6	3.8	-0.8
9.25	67.525	3.6	-0.8
9.5	68.4	3.4	-0.8
9.75	69.225	3.2	-0.8
10	70	3	-0.8
10.25	70.725	2.8	-0.8
10.5	71.4	2.6	-0.8
10.75	72.025	2.4	-0.8
11	72.6	2.2	-0.8
11.25	73.125	2	-0.8
11.5	73.6	1.8	-0.8
11.75	74.025	1.6	-0.8
12	74.4	1.4	-0.8
12.25	74.725	1.2	-0.8
12.5	75	1	-0.8
12.75	75.225	0.8	-0.8
13	75.4	0.6	-0.8
13.25	75.525	0.4	-0.8
13.5	75.6	0.2	-0.8
13.75	75.625	0	-0.8



Session 5: Mind the Gap

Introduction

"Your track must have a bridge to cross over a river. It will need to accommodate the weight of your train at minimum though the stronger your bridge is the more likely I, the Mayor, will select it for the new rail line. Consider the cost of the materials you decide to use, as well as their weight, as these will be part of your bridge's evaluation score. I will specify the minimum length your bridge must span, but in general the longer your bridge goes the better it will be judged."

Concepts

- Forces (Physics)
- Static systems (Civil/Mechanical Engineering)

Learning Outcome(s)

- Empower students (consider design questions, using knowledge of forces)
- Breadth and depth of engineering (civil engineering)

LTM Exhibit Connection

- Blackfriars Bridge

List of Materials:

- Acrylic, cardboard, wood, newspaper
- Ruler, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Tape, glue, wire, string
- Optional: paint

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• Discuss different types of bridges. • Guide them to the Additional Resources Packet for more information on bridge types.
Activity (30 min-2 hours)	Research, design, and build a bridge
Recap/Discussion (10 min- 30 min)	• What happened to the Tacoma Narrows Bridge? How has the incident impacted bridge design? • How did the Millennium Bridge in London earn its nickname the "Wobbly bridge"? • What is the longest bridge in the world? What are some of the challenges the engineers responsible for the project faced? • Maintain your company's professional image. Write a letter to the community near the construction site of your bridge that apologizes for any inconvenience, thanks them for their patience, and explains why this project is important and how it benefits them.
Above and Beyond	• Design a drawbridge to allow large boats to pass beneath your bridge. • Add another deck to your bridge. How does this affect the type of bridge you may use?
Suggested Evaluation (5 min- 30 min)	• Consider the weight, length, strength, and cost each of the bridges. • Test each bridge until failure. Which bridge held the most weight?

Session 6: Tunnel Vision

Introduction

"As your track goes through the center of London, it must go underground as there is not enough space for it above ground; thus your train will need to travel through a tunnel like the rest of the Tube. Your tunnel will need to accommodate the size of your train and the weight of the rock and water above it. Longer, stronger tunnels will be more likely to be included on the finished tube line. Be sure that your planned tunnel does not disrupt any existing tube lines!"

Concepts

- Forces (Physics)
- Static systems (Civil/Mechanical engineering)
- Construction materials (Materials science/Engineering)

Learning Outcome(s)

- Breadth and depth of engineering (Civil engineering, materials engineering, applications to physics)

LTM Exhibit Connection

- Brinell reinforcements
- Greathead Shield model
- Cut-and-cover diorama

List of Materials

- Acrylic, cardboard, wood, newspaper
- Ruler, tape, glue, wire, string, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)
- Optional: paint

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	• What is the objects used for? • Discuss various materials used to build the underground tunnels. • Brainstorm new shapes for tunnels.
Activity (30 min-2 hours)	Research, design, and build a tunnel
Recap/Discuss (10 min- 30 min)	• What costs were associated with your structure? • Could your structure have any unexpected impacts on the area around it? • What sort of maintenance might be associated with your structure?
Above and Beyond	• Add lighting to your tunnel with a simple circuit. • Have students research and design a way to dig a tunnel. If possible, have them implement their method/machine to make a tunnel through sand or clay.
Suggested Evaluation (5 min- 30 min)	• Consider the width, length, strength, and cost each of the tunnels. • Test each bridge until failure. Which bridge held the most weight?

Session 7: Station Fixation

Introduction

"I, the Mayor of London, now want your company to design a station which will be the signature station for the line. Your company must design, create, and build a station that is not only iconic but gets passengers off of the train in a timely manner."

Concepts

- Traffic flow (Mathematics)

Learning Outcome(s)

- Benefits of soft skills (Advertisements and persuasive skills)
- Breadth and depth of engineering (Civil engineering)

LTM Exhibit Connection

- Architecture plans
- Escalators/Lifts
- Important people: Charles Holden
- Waterloo Station

List of Materials

- Acrylic, cardboard, wood, newspaper, tape, glue, wire, string
- Ruler, paint, paper, pencils, etc.
- Legos, Kinex, Meccano set, Makedo (cardboard construction kits)

Session Agenda

Activity	**Description**
Research (15 min-1 hr)	Research various stations (i.e.: Baker Street, Tottenham Court Road, Canary Wharf, etc.)
Activity (30 min-2 hrs)	Students will research, design, and build a tube station
Recap/Discussion (10 min-1 hr)	• Can you design signs and directions for passengers at your station? • Where would you place signs to make them the most effective? • What would you name your station? Write a brief speech to give to the public to explain why you picked this name.
Above and Beyond	• Many of London's Tube stations are very old and need to be renovated. Switch stations with another team and see if you can improve their design. Be sure to keep elements that work well! • Sometimes severe storms can flood an underground train station. Can you design a pump/drainage system to quickly get trains up and running again? • Add lighting to your station with a simple circuit.
Suggested Evaluation (5 min)	• Which station is the most environmentally sound? • Which team best addresses the concept of passenger flow? • Which team had the most laconic posters? • Which station has the most innovative design?

Session 8: Time is of the Essence

Introduction

“Planning out the design of a train or railway station does not end with proposing a model and materials involved. Preparing a schedule and planning use of resources for complex projects is an important part of your proposal to make sure your project finishes quickly and efficiently.”

Note: It is critical to the success of this activity that you, the teacher, read through the related materials in the Resource Handbook. There are three handouts for students (Theater Production, Station Design, and Float Time) and an explanation of the Critical Path Method (CPM) for your reference.

Concepts

- Critical Path Method (CPM) (Mathematics, computer science)

Learning Outcome(s)

- Benefits of soft skills (Critical thinking and logistics)

List of Materials

- Paper, pencils
- Sticky notes (Optional, 1 1/2” x 2” or 2” x 2” size will work best)

Session Agenda

Activity	**Description**
Research (15 min)	• Ask students what they think of when they hear the word “schedule”. • Ask students if they have made a schedule, and what methods they used. Collect terms mentioned in this and the previous question that relate to those used in CPM.

Activity 1
(Design)
(30 min)
	• Hand out the Theater Production sheet (from the Resources Handbook).
	• Introduce the definitions for projects, activities, and network diagrams.
	• Work through the steps using the Theater Production sheet as a class.
	    o Look at the tasks involved in creating a theater production. Notice which activities depend on other activities and the logic involved. This can be very brief if the lesson needs to finish quickly.
	    o Create the network diagram using the start provided on the sheet. (Optionally, have students use sticky notes to represent each activity and stick the sticky notes to a sheet of paper to draw in arrows, instead of using the provided diagram.)

Activity 2
(Build)
(1 hr)
	• Hand out the Station Design sheet (from the Resources Handbook).
	    o Companies will work through the station design.
	    o Go over the questions as a group, emphasizing how the students determined their answers.
	    o These questions are motivation for the concept of float time, so it is important that students see the connection between these questions and the next activity.
	• Hand out the Float Time sheet (from the Resources Handbook).
	    o Work through the theater production example together, and have students complete the station design problem in their companies.

Recap/Discuss
(20 min)
	• What patterns did you notice in the float time for different activities?
	    o Activities on the critical path will always have zero float time.
	• What happens to the float time on activities like Rehearsals and Actor Runthrough if choosing a cast takes one day longer than expected?
	• This method is often used with much larger projects containing hundreds of activities. What challenges would you expect with something of this size?
	    o Relate the history information on the CPM from the Resources Handbook, or have students look up its origins.
	• Accidents and delays happen. Which paths are near critical paths, and what are some likely delays for the theater or station schedules that could cause a new critical path to appear?

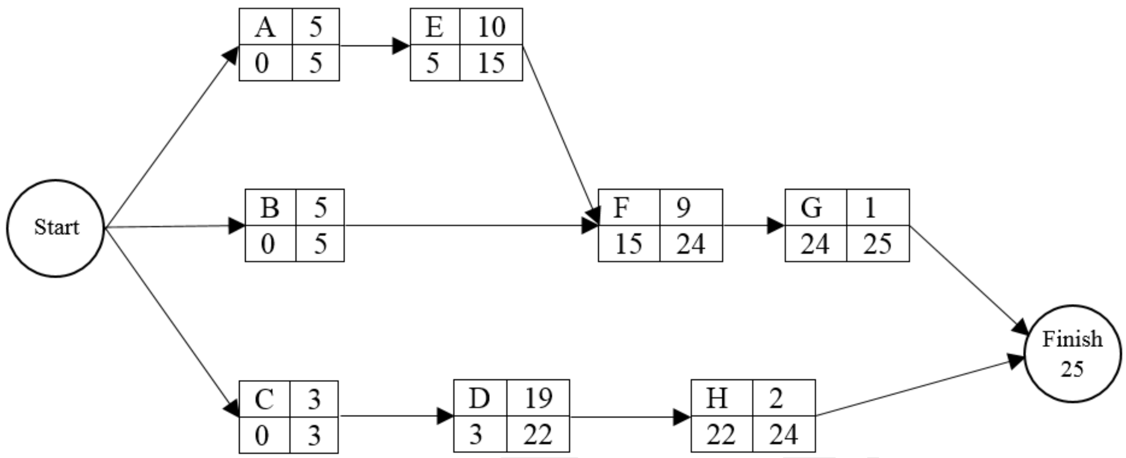
Above and Beyond	• Communicating your ideas clearly to others is important. Present your station design schedule to the Mayor of London, who is unfamiliar with network diagrams and the critical path method.

	- Have students compare their results. Where did each company do well, and what was unclear? • Look further into how scheduling computer programs have developed since the CPM. Create a timeline, or compare the methods used over the years, and look into what motivated the changes. • There are ways to challenge students using additional complications from the method for students particularly strong in logical thinking and mathematics. Providing the cited calculations paper may be useful at this point, or have students conduct research as needed. - Have students modify the station or theater schedule or create a new one to use one of the following concepts: - These examples used finish-to-start links between activities, where the subsequent activity cannot begin until the preceding activity has finished. - Sometimes lag is used to specify a number of time units that must pass between one activity ending and another beginning. Lead time, or negative lag, allows an activity to start before the preceding activity has finished. - The chosen links or lag times should come with brief explanations relevant to the schedule scenario.

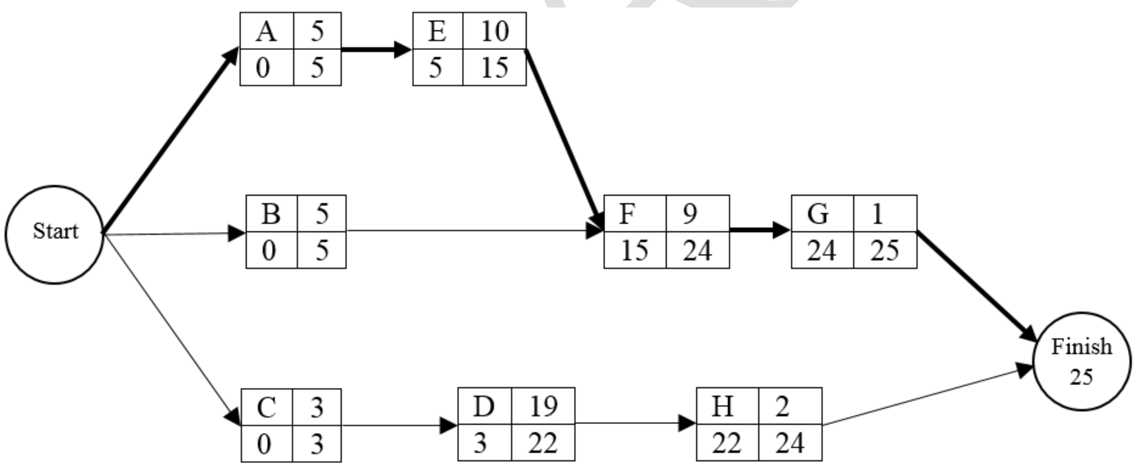
Solutions to Theater Production

Finish adding the remaining tasks in this diagram. What happens when a task has multiple preceding tasks? Choose the latest finish time of the preceding tasks as the start time of the next task.

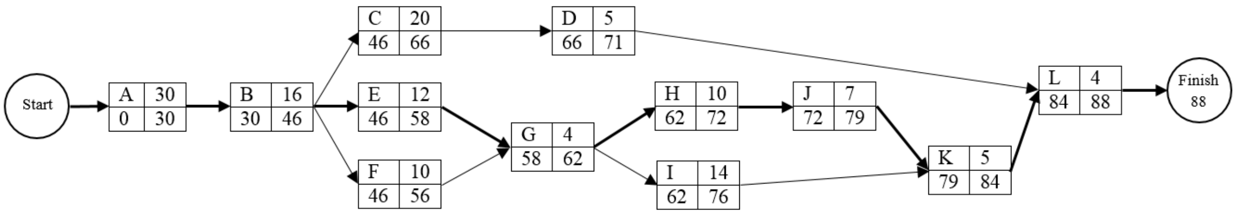
The diagram with all tasks added should look like this:



This version has the critical path marked:



Solutions to Station Design



What is the total time estimate for the project? Which tasks are on the critical path?

Total time is 88 days, critical path tasks are A, B, E, G, H, J, K, and L.

Consider the following questions independently of one another, working from the initial schedule:

- The inspection of the electrical work reveals a safety violation that takes three days to fix. How does this impact the total project time? It adds three days to the total project time.
- The workers hired for the flooring go on strike, causing a delay of four days. How does this impact the total project time? It adds one day to the total project time.
- Under pressure to finish the station, one of the managers brings in a larger and more efficient crew to install fixtures, reducing the time required from seven days to two. How much time is saved by this over the entire project? Three days are saved over the entire project.
- There is a shortage on the materials used for the siding on the station's exterior. How many days can the siding be delayed by without delaying the entire project? The siding can be delayed by 13 days without delaying the entire project.

Solutions to Float Time:

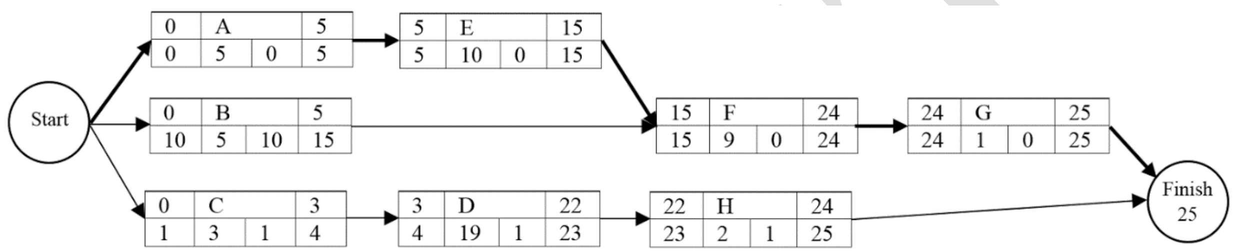
Find the LFT and LST for G and H. From the definition of float given above, what is the float time for G and H? What is the calculation you are using to determine float?

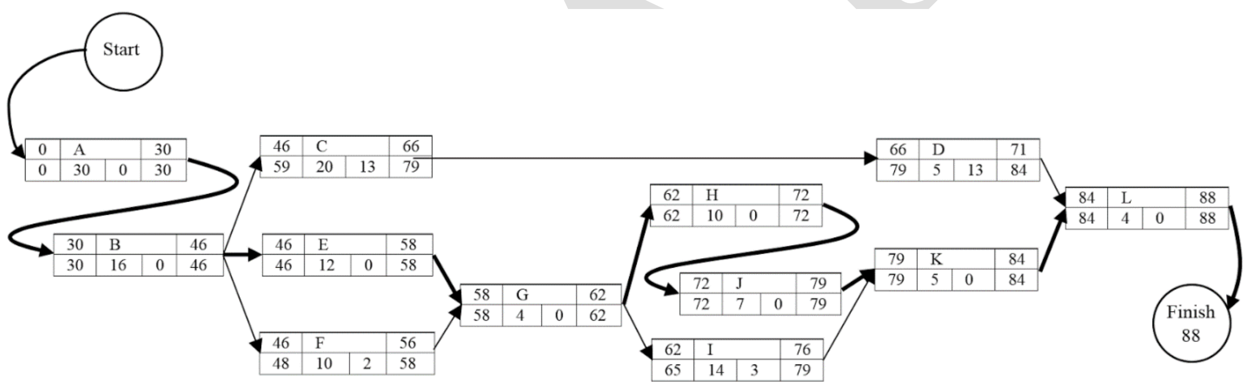
The LFT and LST for G are 25 and 24 respectively, and its float is 0.

The LFT and LST for H are 25 and 23 respectively, and its float is 1.

Float = LST - EST or Float = LFT - EFT

What happens when a task has multiple tasks depending on its completion, as in the start node? The task with the earliest LST determines the LFT of the preceding task.





Session 9: Show Time!

Introduction

"You have worked hard to create what you did, be it a tunnel or a full rail line. You have learned a lot, considered many different ideas, and tested and improved your designs. Now is the time to show off! Present your proposals to myself as well as your competitors."

Concepts

- Public speaking skills
- Persuasive writing skills
- Explain your ideas
- Confidence

Learning Outcome(s)

- Benefits of soft skills (Presentation, communication)
- Empower students (Boost confidence)

Medium

- Ultimately up to the discretion of the teacher. However, some suggestions are:
- Persuasive written justification
- Slide-based presentation; a demonstration
- Submitting a technical report of theorized performance
- Testing data
- Cost analysis

Session Agenda

Activity	**Description**
Main Activity	Present your proposal
Suggested Evaluation	• Once again, up to the discretion of the teacher. • Does the train work? • Did the students show overall improvement in presentations? • Was the team professional? • Did the team engage with their audience? • Did they provide a clear description of the steps they took in designing their railway?

Session 10: A Journey Back in Time

Explore the Museum!

Introduction

"Throughout this program you have been working through real engineering and mathematical problems that have affected transportation infrastructure for centuries. The London Transport Museum beautifully displays many of these concepts, and explains how engineers have tackled these challenges throughout history. As you explore the museum think about your how responses to real problems differ from the engineers', and realize the power engineering has to literally shape a city. "

Learning Outcome(s)

- Inspire students (Hands-on examples of engineering)

On the way to the museum:

Have students consider the transportation that they are taking (Tube, bus, foot).

At the museum:

- Have students consider the following questions:
  - Methods of creating tunnels used over time (Cut-and-cover vs. Crossrail).
  - The effect public transportation has had on the shape, economy, and culture of London.
  - How Victorian-era technology is integrated with modern innovations.
  - Efficient methods of moving the maximum number of people through stations and onto trains.
  - How transportation companies have maintained their image.

Full Speed Ahead!

{The Student Handbook}

The London Transport Museum (LTM) features all modes of transport, old and new

Session Outline

Research Phase

Every session will begin with some background research. Like all engineers, you must do your research first before designing anything. This phase is your chance to learn about how each activity applies to the real challenges engineers face.

Design Phase

Use the information from the Research Phase to fuel your design process. Make sure your design follows the Mayor's specifications.

Build Phase

After designing a railway component, you will build and test it. Be creative and take risks! Oftentimes you will learn more from watching what does not work than merely picking what does. Note that this section may not be present in every session.

Recap/Discussion Phase

This phase will conclude each activity. This is where you will communicate and justify your ideas to other companies and the Mayor in the form of a presentation, essay, or other medium.

Session 1: Business as Usual

Task: Create a company, logo, motto, code of conduct, and mission statement.

From the early days of the roundel to Edward Johnston's custom typeface, the London Transport Museum (LTM) portrays the development of the London Underground brand

Research
- Brainstorm logos (i.e.: sports, transportation, science, film, food, drink, etc).
- What logos and mottos do you find appealing?

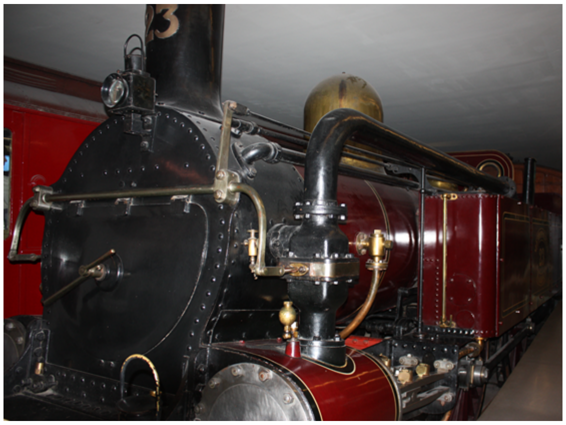
Design
- Create your company. Select a name, choose a motto, and design a logo.
- Collaborate on a company mission statement to convey your company's purpose and goals.
- Deliberate on a code of conduct. How will you handle distribution of labor and disagreements? What other issues might your company face?
- Make sure all of the above elements highlight your company's strengths and help it stand out from its competitors.

Build
- Play the Transportation Transaction game

Recap/Discussion
- What did you learn about companies and the way they function you did not know before?
- Explain the reasoning behind your company name, motto, logo, mission statement, and code of conduct in a brief presentation.

Session 2: Train of Thought

Task: Design and build a train and track.



This specially modified train (left), now housed at the London Transport Museum (LTM), once ran through the first Tube tunnels. As the model on the right shows, pollution in these early tunnels was a major problem.

Research

- What factors are contributing to greater use of London's public transportation systems?
- What is the basis of the modern design of Tube maps? Who introduced this system, and in what year? What was his or her professional background?
- What factors affect a train's performance?
- How have trains evolved since their inception?
- What types of track exist?

Design

- Weigh the benefits and drawbacks of each available material.
- What will you try to optimize with your train's design?
- How will you ensure a safe and comfortable journey for your passengers?
- How can you make your train more environmentally friendly?

Build

- Your train may have a minimum of 2 compartments.
- Your train must fit in an imaginary box 50 cm long, 15 cm high, and 15 cm wide.
- Your track must be at least 1 meter long.
- Your train must be able to carry the amount of weight or number of passengers requested by the Mayor.

Recap/Discussion

- Perform a cost analysis on your train based on the prices of the materials you used.
- How well does your train perform relative to your expectations?
- How might you improve your train's design? How would you reduce its cost or weight? How would you make it more aerodynamic?

Session 3: Mixed Signals

Task: Research rail signaling and construct a light sensor.

A multi-aspect signal from the Victoria line on display at the London Transport Museum (LTM).

Research

- How do engineers really know where a train is at all times?
- What types of signals do trains use and why?
- How does a circuit work?
- What is current and voltage and how are they related (Hint: research Ohm's Law)?
- What objects do you need in a circuit?
- Research and explain in your own words Kirchhoff's Voltage and Current Laws.
- Research the various symbols used in circuit diagrams.

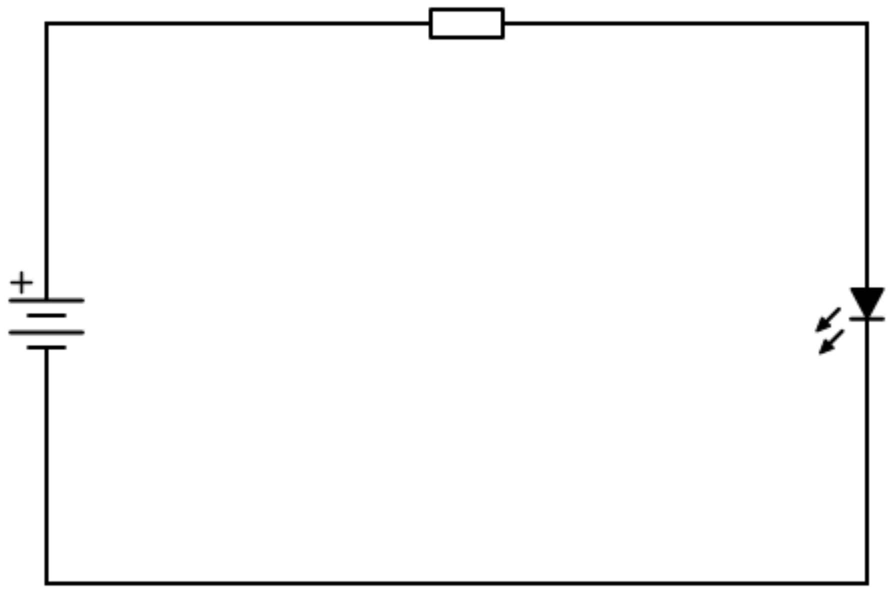
Design

- Design a conceptual signaling system for your train and track.
- Where might you place signals to ensure your train operates safely?
- What is the minimum number of unique signals you need to employ?

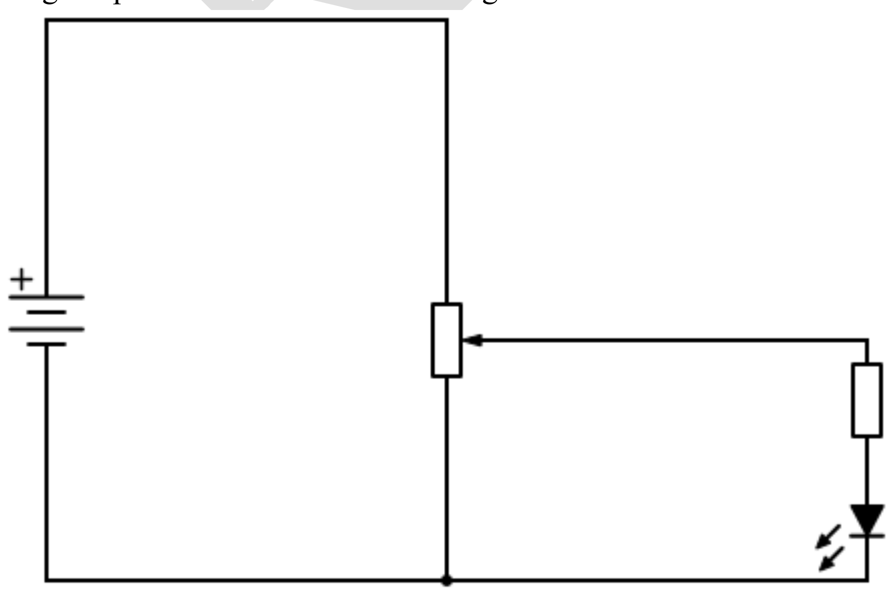
Build

You will need to refer to this session's material in the Resource Handbook in order to build the circuits.

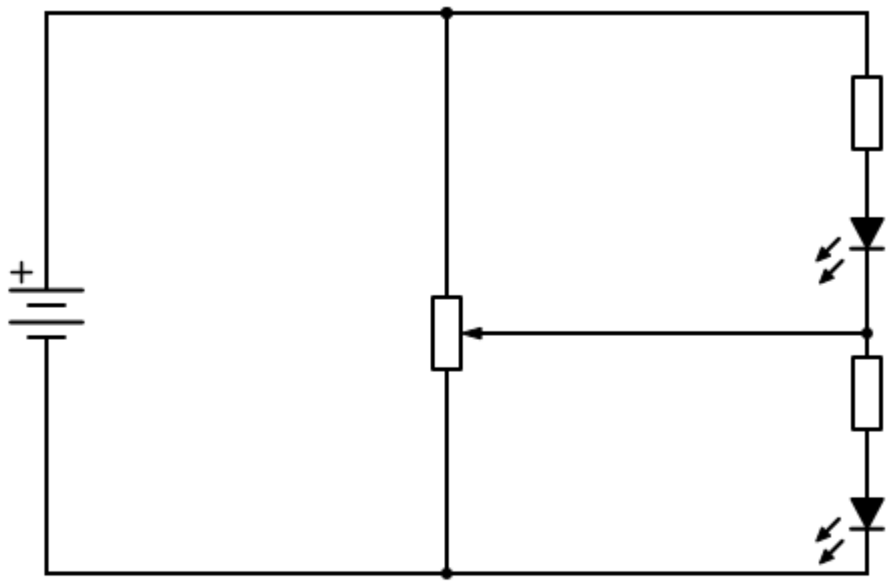
1. Begin by constructing a simple circuit to power a light emitting diode (LED) using the circuit diagram below. Unlike resistors, diodes only let electricity flow in one direction. Make sure you put yours in the right way using the diagram found in the Resource Handbook or you could burn out the component. You can also look there for details on how a breadboard works.



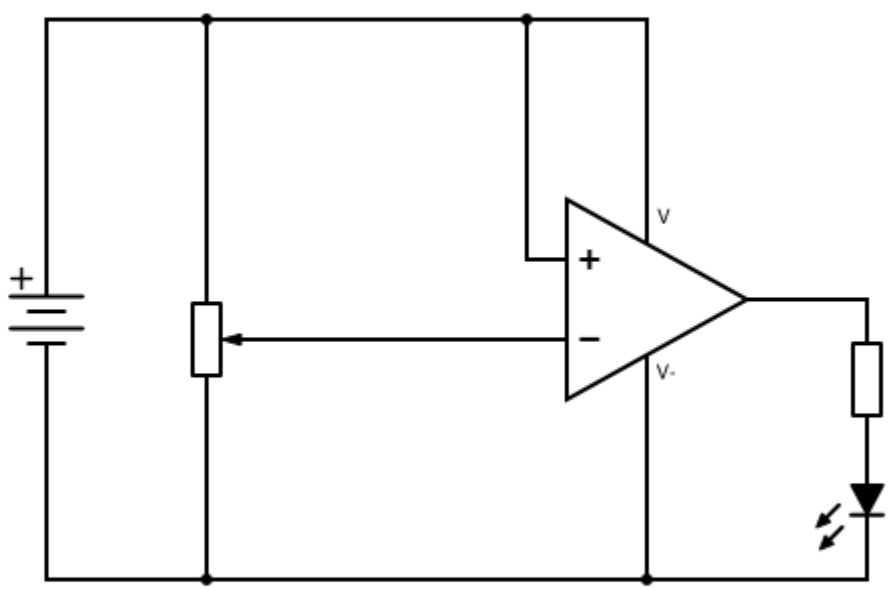
2. Now that you understand how the rows of a breadboard are connected and how to place a diode in a circuit, add the potentiometer to the circuit. This will allow you to dim the led by rotating the potentiometer's knob or using a screwdriver.



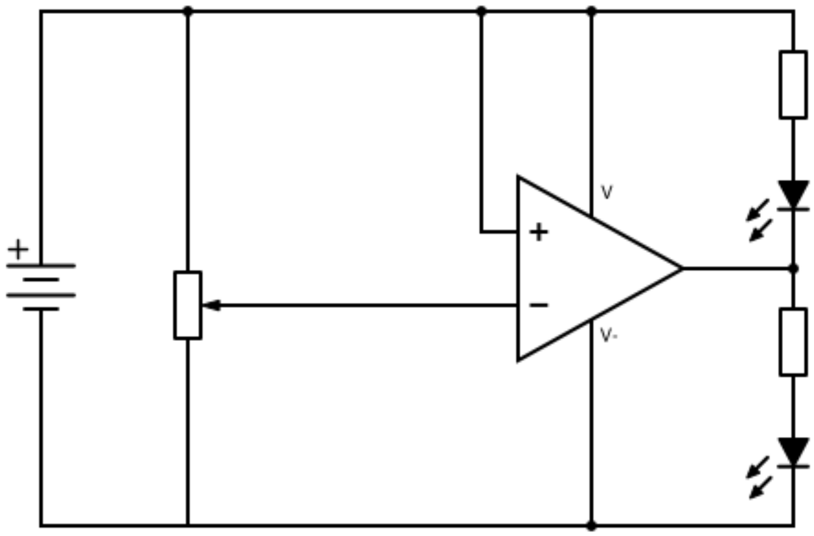
3. The next step is to add another LED to the circuit. You should see the LEDs gradually fade in and out as you rotate the potentiometer. When the potentiometer is completely rotated to either side, only one of the LEDs should be lit.



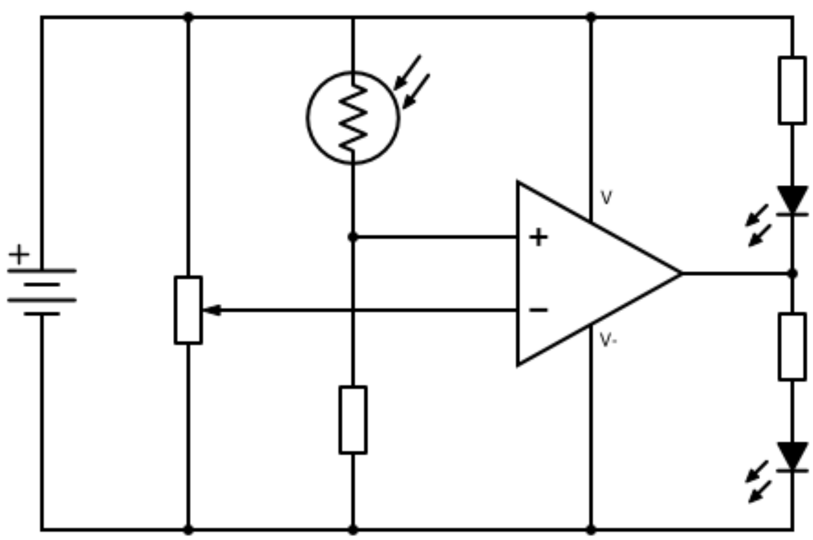
4. Now comes the tricky part, adding the operation amplifier (or the op amp, for short). You will need to look at its datasheet to figure out how to connect each pin, the silvery pieces that insert into the breadboard, of the chip. You will need to connect voltage supply, ground (GND), the + and - inputs, and the output. Your teacher may provide the datasheet or can be found with an internet search of the text on the top of the chip. Notice that the LED only turns off when the potentiometer is rotated completely to one side.



5. Just as you added the other LED in step 3, you will do the same here. Note, only one LED should be on at any one time and they will only change when the potentiometer is rotated all the way to one of its sides.



6. The last two components to add are a resistor and photoresistor. Adding these components will allow your circuit to react to changes in light. You will have to tune your circuit by rotating the potentiometer until the LEDs change.



Recap/Discussion

- What is the importance of electronic circuits in daily life and train engineering?
- How might engineers design failsafe systems for train signaling?
- Where else could you use the circuit you created in this activity on trains?
- Why might the circuit you designed be impractical for real train applications, especially in the Tube?
- Swap the positions of the photoresistor and the 3.3kΩ resistor. How does this affect the circuit?

Session 4: Mind the Gap

Task: Using your gathered research, design and build a bridge.

These pictures at the London Transport Museum (LTM) show how Blackfriars Bridge has changed over time

Research

- What is a truss bridge? Why was this type of bridge so common? Look into three different types of truss designs (Pratt, Warren, Howe, or others). Weigh the pros and cons of each.
- What is a more modern type of bridge design (Suspension, girder, segmental, etc)? Why have these designs become so popular in recent years?
- Why were arches so common in early bridges? Are they still used today?
- What materials are used in bridge design? How do engineers reinforce concrete?

Design

- How will you make your bridge as strong as possible? Remember, in many bridges, including trusses, the main support lies below the deck.
- How can you add a support in the middle of the span?
- What type of bridge will you make? What are the benefits of the style you chose?
- How can you make your bridge aesthetically pleasing? Remember, bridges are highly visible.
- How can you make your bridge more environmentally friendly? Study the solar panels on Blackfriars Bridge for inspiration.

Build

- Your bridge must be at least 30 cm long.
- Your structure should be able to support as much weight as possible.
- You may use any materials the Mayor approves. However, lighter, cheaper bridges will receive more points.

Recap/Discussion

- What happened to the Tacoma Narrows bridge? How has the incident impacted bridge design?
- How did the Millennium bridge in London earn its nickname the "Wobbly bridge"?
- What is the longest bridge in the world? What are some of the challenges the engineers responsible for the project faced?
- Maintain your company's professional image. Write a letter to the community near the construction site of your bridge that apologizes for any inconvenience caused by the construction, thanks them for their patience, and explains why this project is important and how it benefits them.

Session 5: Tunnel Vision

Task: Using your gathered research, design and build a tunnel.

These models at the London Transport Museum (LTM) show two ways to tunnel by hand,
the cut-and-cover method (top) and with a Greathead Shield (bottom).

Research

- Why have arches and tubes consistently been used for tunnels for thousands of years?
- What is the main problem with using coal locomotives in tunnels? How did Victorian engineers attempt to solve this problem?
- Some cities have elevated rail lines instead of underground networks. What are the pros and cons of this system? Is this solution feasible for modern London?
- What is the cut-and-cover method of tunneling? Is this technique feasible today?
- What is tunnel shielding? Who was the engineer responsible for the first successful deployment of this technique, and on what project was it used?
- What materials are used in the construction of tunnels?
- How have engineers been able make bridges and tunnels longer and deeper than ever before?

Design

- How many lanes will your tunnel have?
- How can you maintain the air quality of your tunnel?
- How will you make your tunnel as large and strong as possible?
- What materials are most useful for this application?

Build

- Your tunnel must be at least 30 cm long.
- Your structure should be able to support as much weight as possible. Points will also be awarded for the cheapest and largest tunnel.

Recap/Discussion

- What costs were associated with your structure?
- Could your structure have any unexpected impacts on the area around it?
- What sort of maintenance might be associated with your tunnel?

Session 6: Station Fixation

Task: Design and build a tube station.

Model train stations on display at the LTM

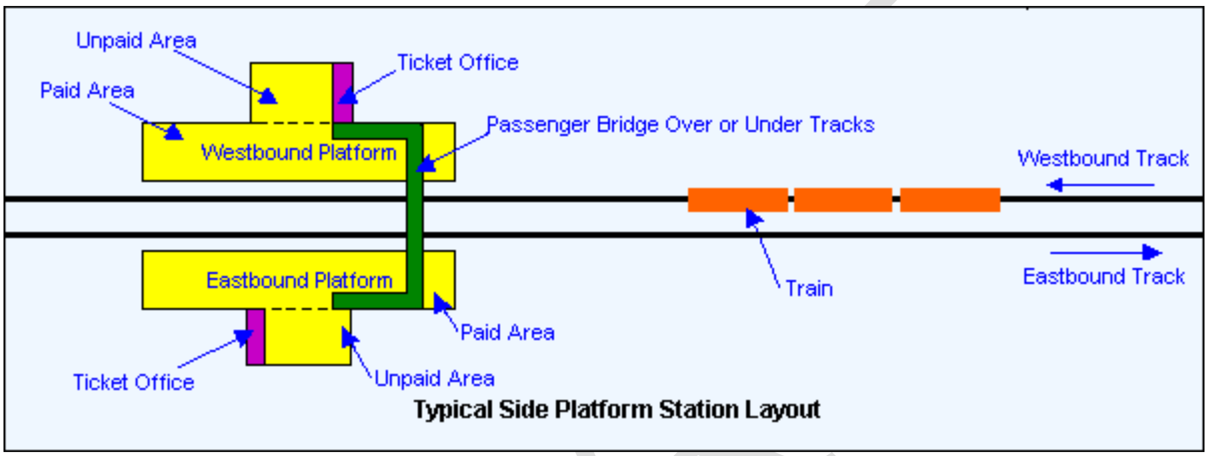
Research

- Brainstorm underground tube stations that you have visited in London. Are there any tube stations that stand out? Why? If not, how would you make them stand out?
- What materials are used in building a station? Think about what materials you would use.
- What area of London will your tube line service? Make sure it goes through all the zones of the tube (zones 1 through 6). Will it cross other tube lines? For each zone, decide where your stations will go. Refer to the Resource Packet for the tube map.
- Decide where your signature station will go. Why did you choose that location? Be prepared to justify this choice.

Design

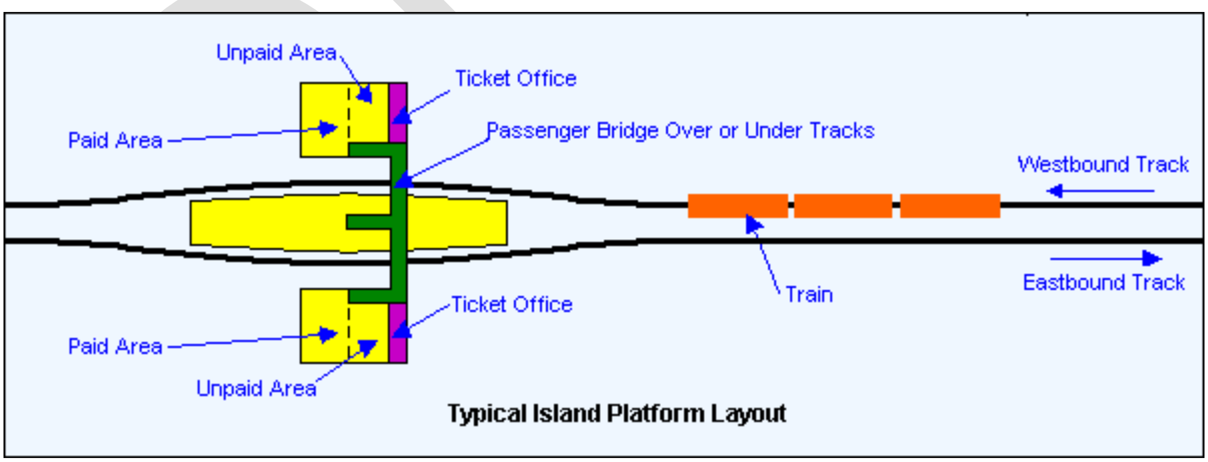
There are multiple designs for station platforms, including: side platform, island platform, elevated platforms, and an elevated with ticket halls below platforms.

- **Side platforms** are the most basic design for a double track railway line. It has two platforms (one for each direction of travel). Each platform has a ticket office and other passenger facilities (i.e.: bathrooms, refreshments, etc.). The two platforms are connected by a footbridge.



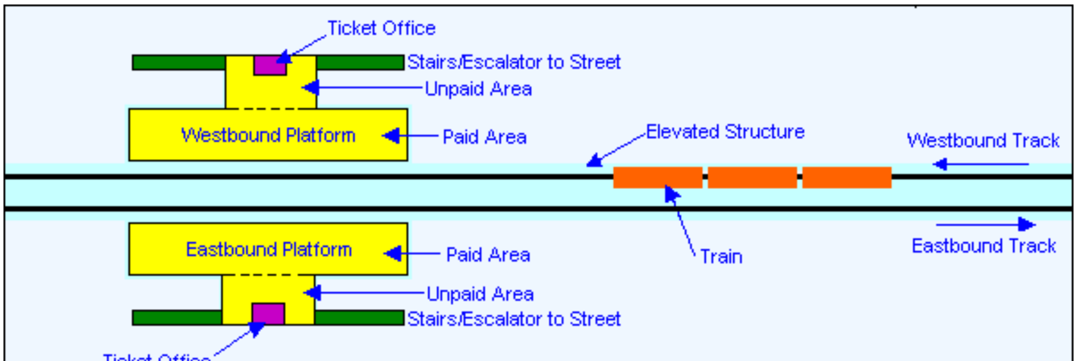
Typical Side Platform Station Layout

- **Island Platform Station** is the cheaper form of station construction. It is a single platform serving two tracks passing on either side. Island platforms are generally wider than single platforms. A bridge or underpass is usually provided.



Typical Island Platform Layout

- **Elevated Station with Side Platforms are popular in cities.** They are cheaper than underground railways and are better at flowing passengers out of the station. *Note: the track is elevated.*



Typical Elevated Side Platform Station Layout

- The **Elevated Station with Ticket Hall Below Platforms** have the ticket office and gate lines above or below the platform level. Because many of the stations are built at road intersections, this station design may have a required height structure to be built in order to allow road traffic (cars, buses, trucks, etc.) to pass beneath.

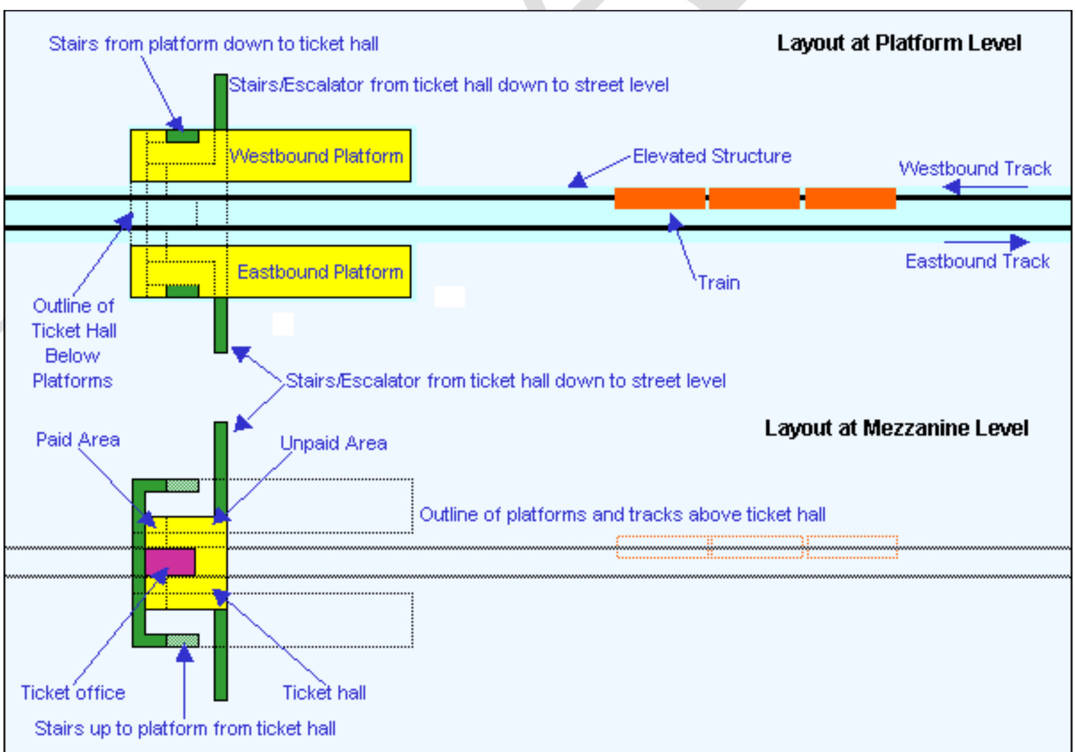


Diagram of Elevated Station with Ticket Hall Below Platforms

Keeping the above platform designs in mind as well as your own experience travelling on the tube, design your platform. Remember, train stations get very hectic during rush hour. How would you guide your crowds around the platform? Create a floor plan of your platform and entrances/exits.

- How will:
    - Passengers reach the trains from street level? And how will you make your station accessible to people with disabilities?
    - Electrical devices in your station be powered? How will you reduce the environmental impact of your station?
    - Customers receive travel updates?
    - Passengers be able to buy tickets or Oyster cards?
- How much will your design cost? When all the elements are put together, perform a cost analysis.

Build

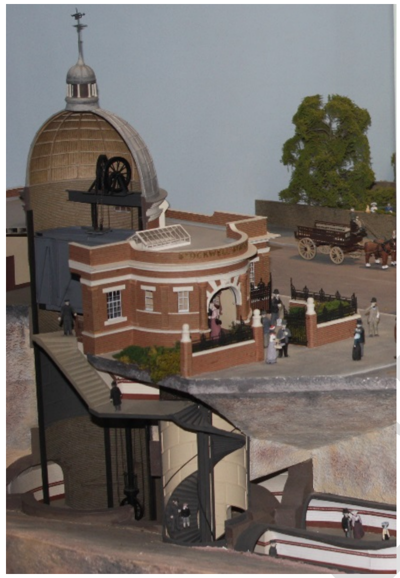
- Your platform must accommodate all cars of your train.
- Include placeholders for escalators, stairs, ramps, and/or elevators.
- Ensure passengers can move about your station quickly.
- Mind the gap! Make sure your train gets as close to the platform as possible.

Recap/Discussion

- Can you design signs and directions for passengers at your station? What would your signs say? Where would you place signs to make them the most effective?

Session 7: Time is of the Essence

Task: Use the Critical Path Method (CPM) to schedule a complex project.



This model at the London Transport Museum (LTM) shows the many complex features of an early Tube station. As modern stations feature ever more amenities, efficiently constructing them has become a complicated challenge.

Research

- Explore your previous knowledge of schedules and your intuitions on how they may be designed.

Design

- As a class, explore the design of the Critical Path Method using the **Theater Production** example.

Build

- Create a schedule for the station design using the provided table.
- What is the shortest length of time required to complete all activities in the station design? Which tasks are on the critical path?
- Answer the remaining questions included with the station design activities, keeping in mind how you arrived at your answers.

Recap/Discussion

- What patterns did you notice in the float time for different activities?
- What happens to the float time on activities like "Rehearsals" and "Actor Runthrough" if choosing a cast takes one day longer than expected?
- This method is often used with much larger projects containing hundreds of activities. What challenges would you expect with something of this size?
- Accidents and delays happen. Which paths are near critical paths, and what are some likely delays for the theater or station schedules that could cause a new critical path to appear?

Session 8: Rail Lines and Line Graphs

Task: Analyze rail graphs.

This model of London at the London Transport Museum (LTM) shows the connection between the city's buildings and the Underground's Tube lines (the front and back of the model are the top and bottom images, respectively.

Research

Work through the next few physics problems using basic kinematic relations. Try to find the necessary formulas online or in your textbooks (Hint: look for the major kinematic equations, Newton's Second Law, and energy and momentum equations), but if you are stuck ask the Mayor for help. How might engineers use the information derived from this mathematical analysis? How might you use it in your own railway design?

1. Your train has a mass of 250,000 kg and is traveling with a kinetic energy of 15.125 MJ. What is the train's velocity? **Ans: V = 11 m/s**

2. Assume your train's air brakes can exert a force of -200,000 N on the train. What rate of deceleration does this cause? Include a free body diagram of this scenario.
   Ans: a = -.8 m/s/s

3. Signals tell conductors the condition of the section of rail ahead. Put very simply: green means “Go”; double yellow means “The next signal is yellow”; yellow means “Slow down. The next signal is red”; and red means “Stop”. Obviously, a station would display a red signal to allow passengers to enter and exit the train. How close to the station’s red signal can an engineer place a yellow signal so your train can safely stop? How long does this deceleration take? **Ans: t = 13.75 s; X = 75.625 m**

4. (Optional Problem) Now assume the electric motor on your train can exert a force of 125,000 N on the train. Draw a free body diagram and find the rate at which your train can accelerate. If your train is 100 m long, how much time does it take for it to fully leave the platform? Assume the platform is the same length as the train. What is the momentum of your train at this instant (Hint: You will need to find the velocity of your train in order to calculate its momentum)?
   Ans: a = .5 m/s/s; t = 20 s; V = 10 m/s; p = 2.5*10^6 kg*m/s

Design

Analyze the simple graphs shown below. For each scenario find:

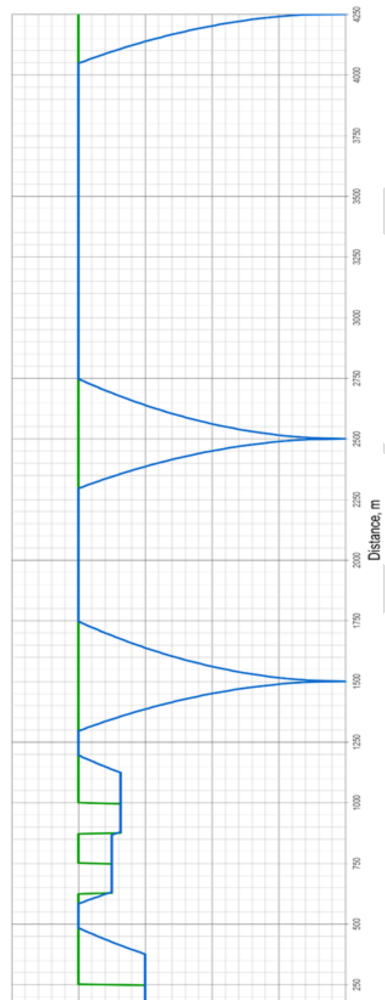
- The number of stations on this section of line.
- The rail line’s headway. Headway is defined as the time between when identical points on two trains pass through the same point on a rail line. A simpler definition is: the time interval between two vehicles (automobiles, ships, or railroad or subway cars) traveling in the same direction on the same route.
- The length of the train being analyzed.
- Whether or not a collision will occur; if so, how can you fix the problem? If there are no collisions, how can you increase the efficiency of the line?
- The trains delay a certain distance before accelerating when they enter a zone with a higher speed limit; why do you think that is?

Identify differences between the speed versus time graphs of successful cases and problematic ones. Compare the train length and headway from each of the three graphs; can either of these values be changed to optimize the line or prevent collisions?

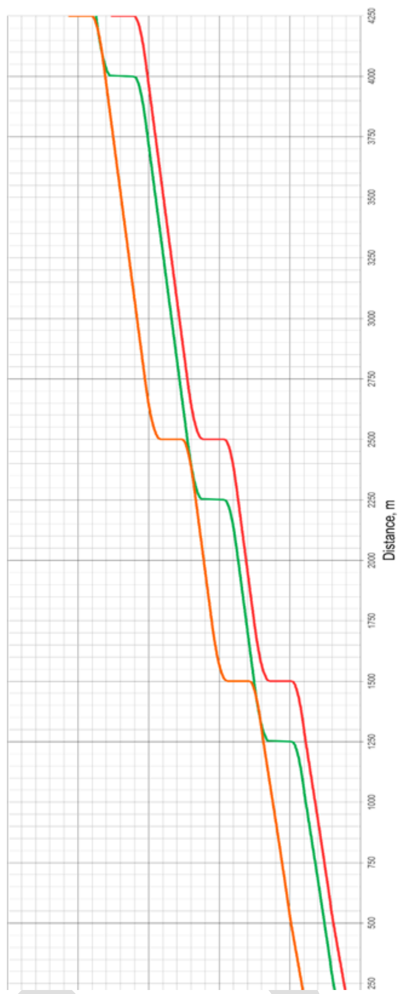
KEY:

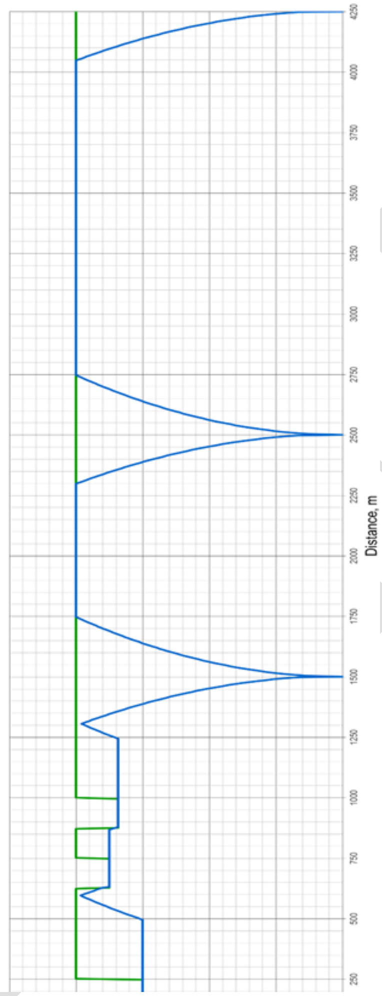
- Top Graph
  - Front of Train 1
  - Back of Train 1
  - Front of Train 2
- Bottom Graph
  - Train’s speed
  - Speed limit

Case 1:

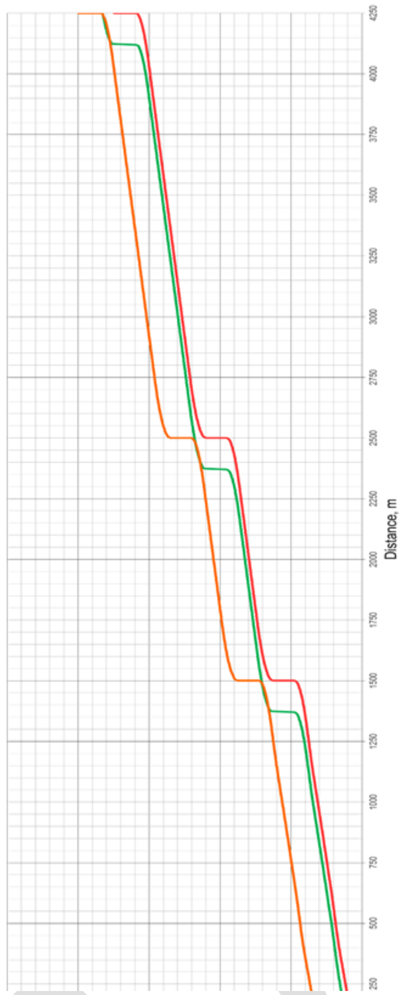


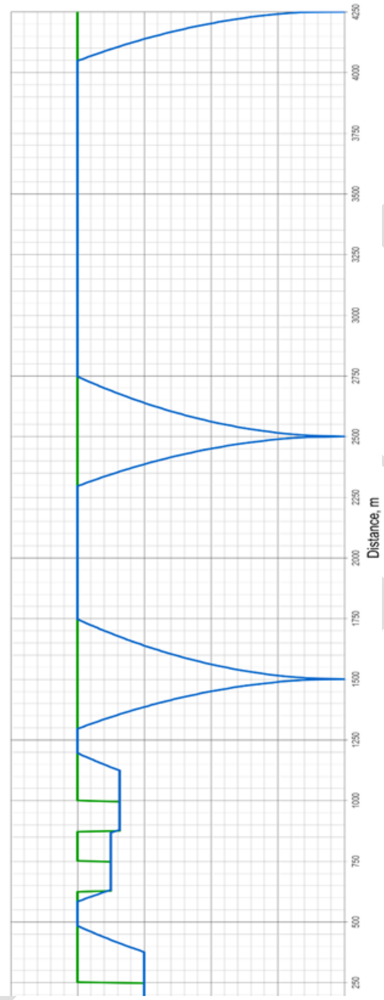
Case 2:





Case 3:





Recap/Discussion

Communicating complex ideas to people without a science background is one of the many challenges engineers face each day. Write a clear, concise report of the calculations you completed, but keep your audience in mind. Remember, the Mayor probably will not want too much detail on how you generated your solutions (although other engineers certainly will), but will only be concerned with your final results. Include an explanation of the features shown on the train graphs (~250-500 words).

Session 9: Show Time

Task: Present your proposal to the Mayor and competitors.

The Skills Room at the London Transport Museum (LTM) is used for professional presentations

You have worked hard to create what you did, be it a tunnel or a full rail line. You have learned a lot, considered many different ideas, and tested and improved your design. Now is the time to show what you have achieved!

Present your model to the Mayor and your competitors. This is your chance to explain everything you have learned, and by extension why your design is the best. You can focus on many different and important aspects of your design (i.e. - strength, safety, longevity, cost, appearance, etc.) in your presentation as long as you remember to make your business stand out.

Ultimately the Mayor will decide how they want proposals, but consider: a persuasive written justification; a slide-based presentation, a demonstration, submitting a technical report of theorized performance and actual testing data, and/or a cost analysis. The ability to explain your ideas to people, especially those without a background in science, is an absolutely crucial part of the team-based world of engineering!

Session 10: A Journey Back in Time

Task: Trip to the London Transport Museum.

A view from the mezzanine at the London Transport Museum (LTM)

Suggested exhibits to visit that correlate to the sessions studied in the program are listed in the table below. Feel free to explore the museum!

Time Period	Exhibit
1800s	• First railway • Carriage wheels versus railway wheels • River transport/bridges • Important People: , Elizabeth Birch (Westminster Omnibus Association)

1900s	• **Business as Usual**
	  o Posters
	  o Edward Johnston's roundel and font
	  o Important People: Frank Pick, Albert Stanley (or Lord Ashfield), Robert Hope Selbie, Harry Beck
	• **Train of Thought**
	  o Interactive monitors/tablets
	  o Steam vs. electric propulsion
	  o Steam/Smoke ventilation display
	  o First through Third class coaches
	• **Tunnel Vision**
	  o Brinell reinforcements
	  o Greathead Shield model
	  o Steam vent diorama
	  o Cut-and-Cover diorama
	• **Station Fixation**
	  o Architecture plans
	  o Escalators/Lift design
	  o Waterloo Station
	  o Important People: Charles Holden

Present-day London	• Train driving simulator • Crossrail* • Future Designs*

(Please note that these exhibits are temporary and may change in the future)*

Jot down some ideas below as you explore the museum:

Full Speed Ahead!

{Resource Handbook}

Table of Contents

Session 1: Business as Usual
Additional Context: Frank Pick, a Marketing Genius

Drawing of proportions for Johnston's roundel, c1925.
Taken from the London Transport Museum's Online Collection (Reference number: 2000/9202)

A Transportation Champion

One of the undeniable champions of public transportation in London was Frank Pick (1878-1941). For much of his career, Pick was the marketing director for the London Underground, and under his careful watch the network grew into the worldwide brand recognized today. Instrumental to Pick's success was his masterful use of marketing to rebrand the London Underground; one could go so far as to say Pick literally transformed the way the public perceived, and ultimately used, London's transportation infrastructure.

Pick's use of Posters

To ensure the Underground got its message across, Pick relied heavily on posters. He revolutionized station design, restricting the spaces companies could use for advertisements and putting official posters in illuminated, prominent cases in all stations. Eventually these posters became so popular and recognizable some of the most famous artists of the day contributed their talents to the endeavor; such professionals included Fred Taylor, Laura Knight, CRW Nevinson and Edward McKnight. By instructing artists to focus on specific destinations in their work and not on the vehicle used to reach them, Pick managed to convince daily train and bus commuters that the same company that brought them into work could also take them on leisurely trips to relaxing spots throughout the city or to the country for holiday.

Roundels, Architecture, and Maps

Pick's legacy is present in several other crucial elements of London's transportation infrastructure. The classic typeface seen on roundels was developed by Edward Johnston and commissioned by Pick. In fact, Pick was so impressed with Johnston's work the pair continued to collaborate and eventually unified all of the Underground with a redesigned roundel, the emblematic red and blue roundel still used today. Other icons that came into fame under Pick's watch were the station designs of Charles Holden, showcased on the then brand-new Jubilee extension line, and electronics-inspired tube map of Harry Beck. The later has actually been imitated by transportation networks all around the world, including those of New York City, Sydney, and Stockholm.

Advertising Done Well

And so Frank Pick ushered in an era of prominence which London's public transportation industry still enjoys today. Pick's marketing techniques were so successful that they actually shaped the future of the London Underground and became a permanent part of the company's culture and image. That is the power of advertising done well.

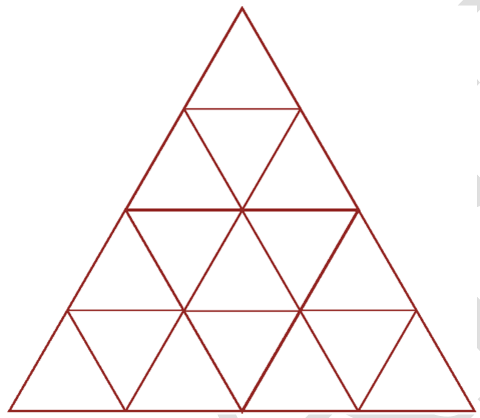
Creative Problems

1. **Electric Bulbs**

   There are three switches outside a closed room. There are three lamps inside the room. You can flip the switches as much as you want while the door is closed, but then you must enter just once and determine which switch is connected to which lamp. How can you do it?

2. **Counting Triangles**

   How many triangles do you see?

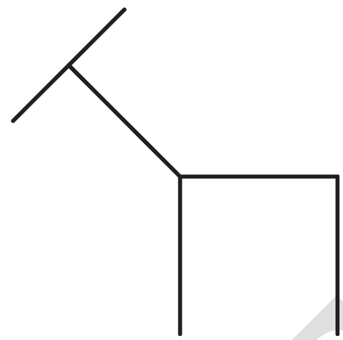


3. **The Candle Problem**

   You are given a candle, a box of thumbtacks, and a box of matches, and asked to fix the lit candle to the wall so that it will not drip wax onto the table below.

4. **Giraffe Problem**

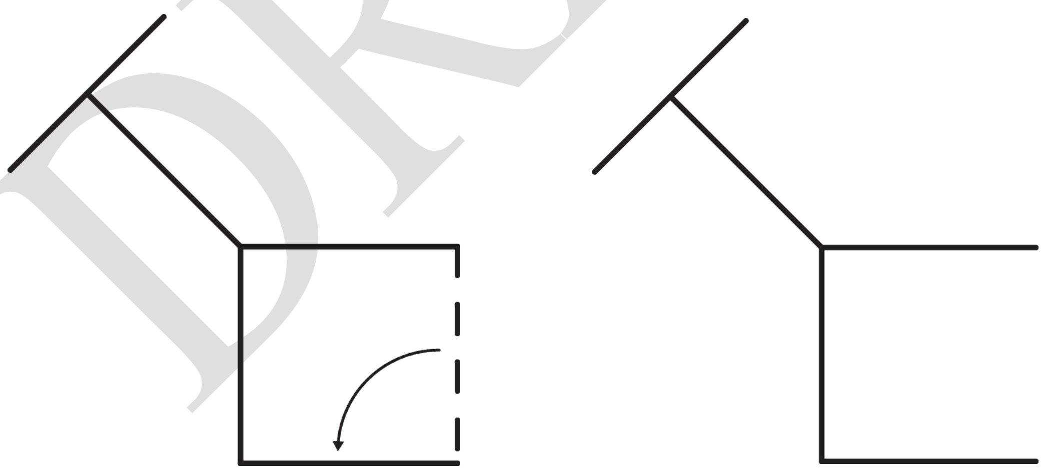
Five matchsticks were placed so as to form the figure of a giraffe as is shown in the diagram below. Can you move just one matchstick so that the shape of the giraffe is retained intact but is rotated or reflected?



Solutions to the Creative Problems

1. Switch the first one on for a minute, then turn it off and turn the second one on. Enter the room and feel the two bulbs are off. The warm one was turned on by the first switch, the light that is on is connected to the second, and the other to the third.
2. 27 triangles
3. See image

4. See image



Transport Transaction Game

Student Worksheet

Player breakdown: Minimum of 4 companies

Time Estimate: 30 minutes

Goal: The company with the most completed contracts wins!

Roles:

1. Teacher:
    - Transport for London Official
    - Keeps track of transactions between the companies on the whiteboard, chalkboard, or Excel File
2. Student teams:
    - Specialized companies that all have resources

Set Up:

Prep (needs 5-10 minutes)

Photocopy the tracking sheet so each company has one. Cut out the resources, contracts, and company specializations from the back of this packet. Put them in a hat or a bowl.

How to Play:

Choose several different cards equal to the number of companies for each category: resources, contracts, and company specializations. Each company will randomly draw for a card from each of the categories.

Company specializations will be put into a hat. A representative from each team will pull out a specialization, then a starting resource, and a contract. Each company begins the game with £ 1000. Then they will form a company name and begin strategizing the best way to complete their contracts. The company with the most contracts completed wins. However, if two companies have the same amount of contracts, then the company with the most money wins. All deals struck are final.

To complete a deal, a company must gather the right amount of resources to produce a commodity. Similarly a company needs to collect all of the commodities to complete a contract. An example: Company A specializes in biofuels. They have a contract to build an oyster card system. The oyster card system needs composites and computers. Composites need one textile and one biodegradable plastic. Computers need one metal and one biodegradable plastic. Therefore Company A needs to get three biodegradable plastics, two metals, and one textile to complete their oyster card system contract. To do this, they will have to negotiate with other companies to gain these resources.

Company Specializations:

- Metals
- Biodegradable Plastic
- Biofuels
- Textiles

Resources:

- Biofuels
- Biodegradable Plastics
- Metal
- Textiles

Commodities:

- Engines
- Composites
- Computers
- Tyres/Tires

Contracts:

BUS

- Tyres
  - Biodegradable Plastics
  - Metal
- Engine
  - Metal
  - Biofuels

TRAIN

- Engine
  - Biofuels
  - Metal
- Composites
  - Textiles
  - Biodegradable Plastics

BICYCLE

- Composites
  - Textiles
  - Biodegradable Plastics
- Tyres/Tires
  - Biodegradable Plastics
  - Metal

FERRY

- Engine
  - Metal
  - Biofuels
- Computer
  - Metal
  - Biodegradable Plastics

OYSTER CARD SYSTEM

- Computer
  - Metal
  - Biodegradable Plastics
- Composites
  - Textiles
  - Biodegradable Plastics

Company Specializations

Metals

Biodegradable Plastics

Biofuels

Textiles

Contracts

BUS CONTRACT: (£ 1000)

You have been tasked to build a **Bus**. The following commodities are needed to build this contract: Tyres and Engine. Tyres are made from biodegradable plastics and metal. Engines are made from biofuels and metal.

Train Contract: (£ 1000)

You have been tasked to build a **Train**. The following commodities are needed to build this contract: Engine and Composites. Engines are made from biofuels and metal. Composites are made from textiles and biodegradable plastics.

Bicycle Contract: (£ 1000)

You have been tasked to build a **Bicycle**. The following commodities are needed to build this contract: Tyres and Composites. Tyres are made from biodegradable plastics and metal. Composites are made from textiles and biodegradable plastics.

Ferry Contract: (£ 1000)

You have been tasked to build a **Ferry**. The following commodities are needed to build this contract: Engine and Computer. Engines are made from biofuels and metal. Computer are made from metal and biodegradable plastics.

Oyster Card System Contract: (£ 1000)

You have been tasked to build an **Oyster Card System**. The following commodities are needed to build this contract: Computer and Composites. Computer are made from metal and biodegradable plastics. Composites are made from textiles and biodegradable plastics.

Transport Transaction

Tracking sheet

Our company name is:

Our slogan is:

Our goal is to:

Monetary Funds include:

Our resources:

Our commodity:

Contracts Completed:

1)

2)

3)

4)

5)

6)

7)

8)

Final Resources:

Final Monetary Funds:

RESOURCES

1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC
1 TEXTILE	1 METAL	1 BIOFUELS	1 BIODEGRADABLE PLASTIC

Commodities

1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER
1 TYRES	1 COMPOSITES	1 ENGINE	1 COMPUTER

Citation(s)

"Frank Pick, a Marketing Genius" copyrighted images courtesy of the London Transport Museum.

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Session 2: Train of Thought

Additional Context: The Early Underground

Construction of the Metropolitan Railway, or what we call the London Underground, began in 1860. When construction was completed, it became the world's first underground railway. The line quickly served its intended purpose, to relieve traffic in the streets of London as well as transport passengers from London's mainline stations to the city.

Completing tunnelling along Praed street, Paddington for the Metropolitan Railway's Kensington extension, c1866. Taken from the London Transport Museum's Online Collection (Reference: 1981/535)

More than 2,000 navvies built the railway by hand with what is known as the 'cut and cover' method. Essentially, the track was laid in shallow cuttings dug along streets, which were then covered with a roof to make a tunnel. Despite the inherent danger of this technique, only a few accidents occurred. In 1863, the first section of the railway opened and ran from Paddington to Farringdon. The railway was an engineering success and extremely popular.

Metropolitan Railway A class 4-4-0T steam locomotive No. 23, 1866.
Taken from the London Transport Museum’s Online Collection (Reference: 1998/37950)

The Metropolitan Railway company made many efforts to reduce the steam and smoke from underground trains. They tested multiple different methods, such as a fireless train that ran on hot bricks. In the end, the company decided to use conventional steam engines, but with some special modifications. These engines had special pipes that could condense exhaust into side tanks of cold water. They also avoided using coal to limit the amount of smoke produced. Instead, they used coke. With the help of ‘blow holes’ (holes in the tunnel to let steam escape) in the Circle line, they were able to slightly limit the steam in tunnels. However, the final solution to the problem of smoke in the rail lines was the trains’ electrification in 1905. To learn more about the London Underground, please view the London Transport Museum’s Online Gallery.

Additional Context: Aerodynamics

Aerodynamics is the study of the way gases interact with bodies traveling through them. When we observe the effects of aerodynamics such as a plane flying in the sky or a flag waving in the wind we are seeing the effects of several different types of flow. There are three types of flow: laminar, turbulent, and transitional. Each are outlined below, but there is a lot more to them than is discussed here.

Laminar Flow

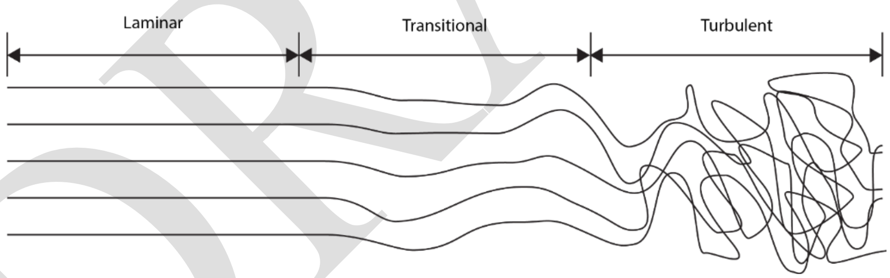
Laminar flow generally occurs at low speeds. It can be thought of conceptually as sheets which stack upon each other and are compressed or stretched towards and away from another depending on the shape of the object passing through them.

Turbulent Flow

Turbulent flow occurs most often at high speeds. In this type, flow becomes unpredictable as the molecules in the fluid take on erratic motions and form vortices comprised of eddies and wakes. This can contribute to the overall drag the object experiences as it passes through the fluid.

Transitional Flow

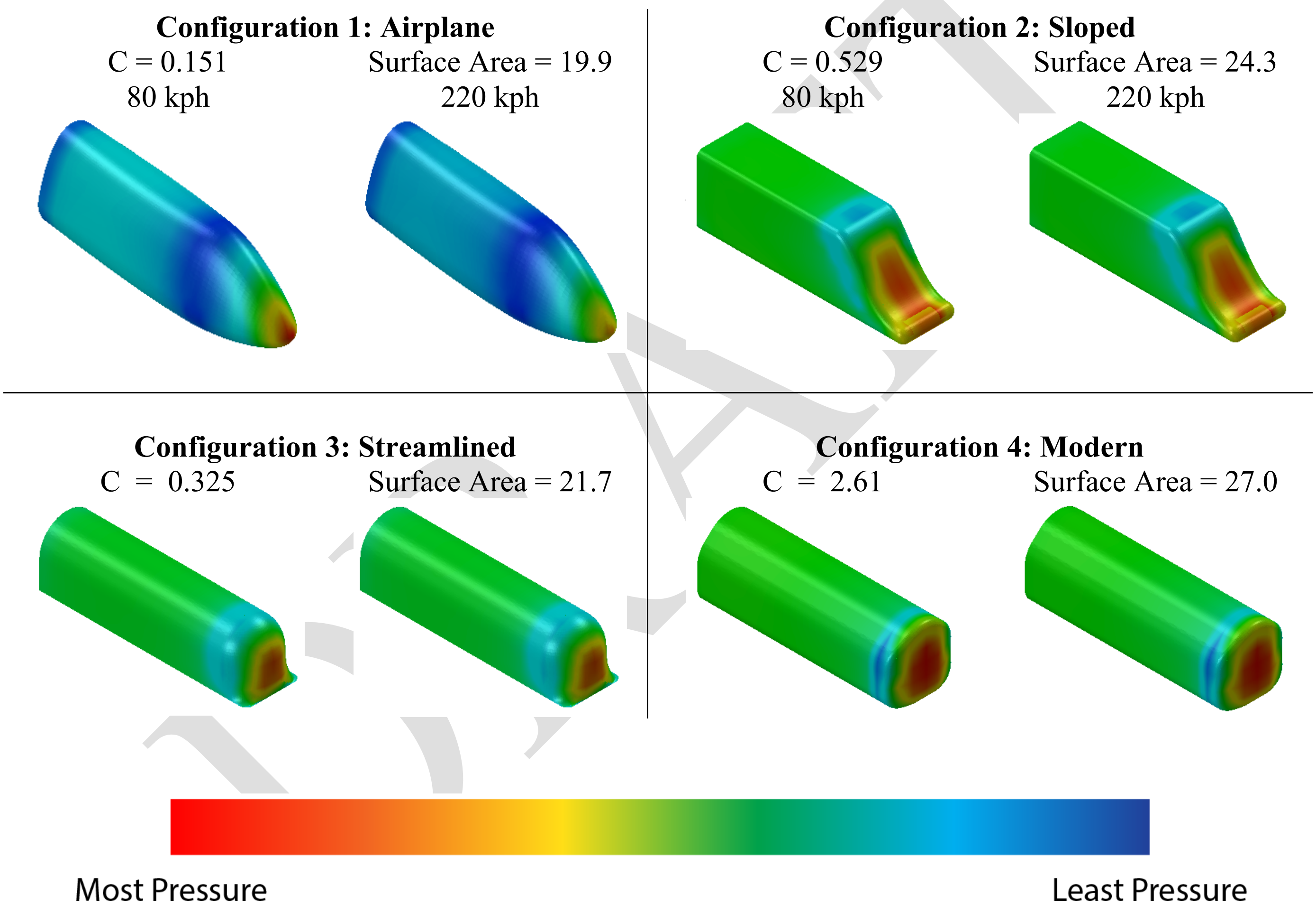
Transitional flow is a combination of turbulent and laminar flow and occurs at the transition between them.



Engineers use wind tunnels and sophisticated computer models to simulate how real trains will function. An important part of this process is optimizing the design of the head and tail of the trains to reduce drag, thus saving energy and improving the train's performance. The drag force can be determined using the following equation where C is the drag coefficient, ρ is the density of the fluid the object travels through, v is the velocity of the object or the fluid, and A is the surface area.

$$F_{drag} = -\frac{1}{2} C\rho A v^2$$

The force is multiplied by a minus sign because the drag force always opposes the direction of travel just as friction does. The drag coefficient is determined experimentally because it is almost impossible to predict how complex geometries will behave in fluids. Below are various designs simulated traveling at 80 kph and 220 kph. Notice that the larger the surface area is, the larger the drag coefficient becomes. Each simulation is scaled to show where the most and least pressure is on the model; therefore, the colors correspond to different pressures in each simulation. The units have been left off since the size of each design is relative.



In underground subways, the trains do not travel fast enough for the drag to have a considerable effect on the train's performance. However, in the 1930s, engineers around the world were designing streamlined vehicles with this in mind. In fact, one London tube prototype train, shown below on the left, from 1935 was designed with a rounded front and rear to make the train more aerodynamic. Configuration 3 is inspired by that design. Engineers soon realized this had little effect on the train's performance at subway speeds and opted to use a simpler train design, shown below on the right, to reduce manufacturing costs. Though your train will be a tube train as well, remember force is proportional to mass and acceleration. If you have a very light train, as yours may be, drag will have a greater effect.

Additional Context: Propulsion and Braking

Most modern subway trains are powered by electricity. The rails are connected to a power source along the track and the train's wheels complete a circuit which drives the motors on board each train. This prevents trains from having to burn fuels in traditional combustion engines which exhaust fumes harmful to passengers. Though this is the primary method used by underground trains around the world, be creative and consider normally implausible methods, such as fans, balloons, railguns, rubber bands, torsion springs, or cable systems.

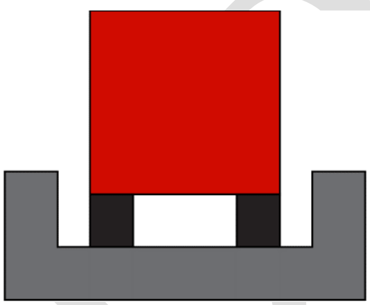
Similarly, make sure your train can stop. A runaway train is a recipe for disaster. Think about possible methods to slow your train down, such as magnetic braking or high friction surfaces. Modern trains use either air brakes or vacuum brakes, but both work on similar principles. Shown in the diagrams below are the different states an air brake system may be in. When the driver applies the brakes, the air flows out the brake pipe line allowing air from the reservoir to fill the brake cylinder applying the brake. On the other hand to release the brakes, air pumped into the brake pipe moves the valve to allow air from the brake cylinder to flow out the exhaust and extending the spring. An intermediate state is possible when pressure in the brake pipe is equalized with that in the valve preventing air from flowing in or out of the brake cylinder. These systems allow compartments which become detached from one another to automatically brake by severing the brake pipe. Vacuum brakes work identically, but operate on a lack of pressure, as opposed to air brakes.

Additional Context: Track Design

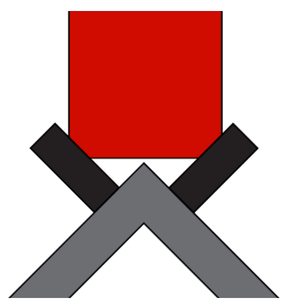
Your track design will largely influence the type of train you plan to design. Most trains, especially in the tube, use two rails which the train rides atop. However, many high speed trains are maglevs, meaning they use magnets to suspend the trains for ultra-low friction. One particular train in Germany, called the Wuppertal Suspension Railway, has the train hanging underneath the track. You can see a picture of this train below.

Below are some possible track designs, but be creative and see if you can design a better one or maybe a hybrid of two.

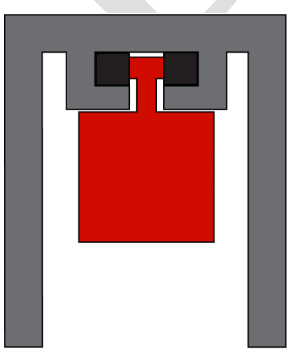
Traditional Track



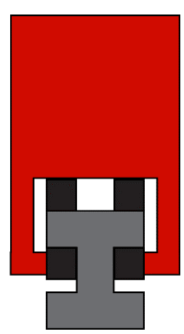
Angled Track



Hanging Track



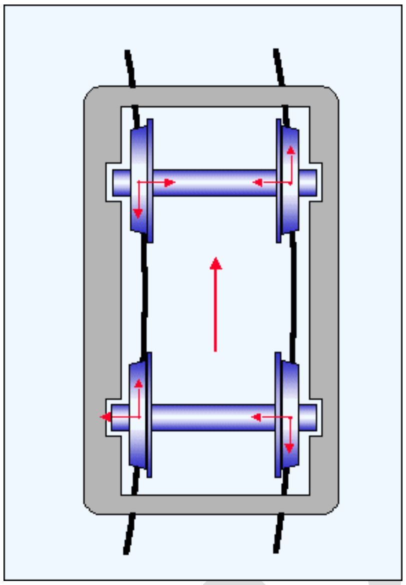
I-Beam Track



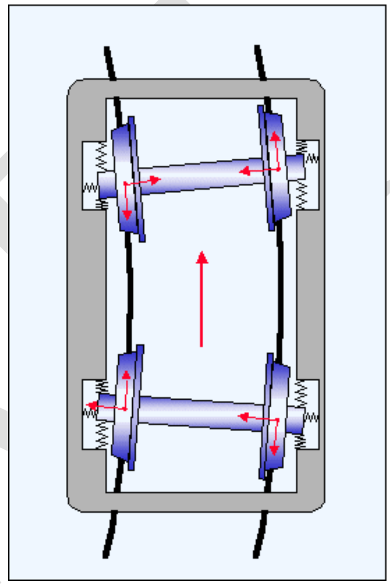
Additional Context: Bogies

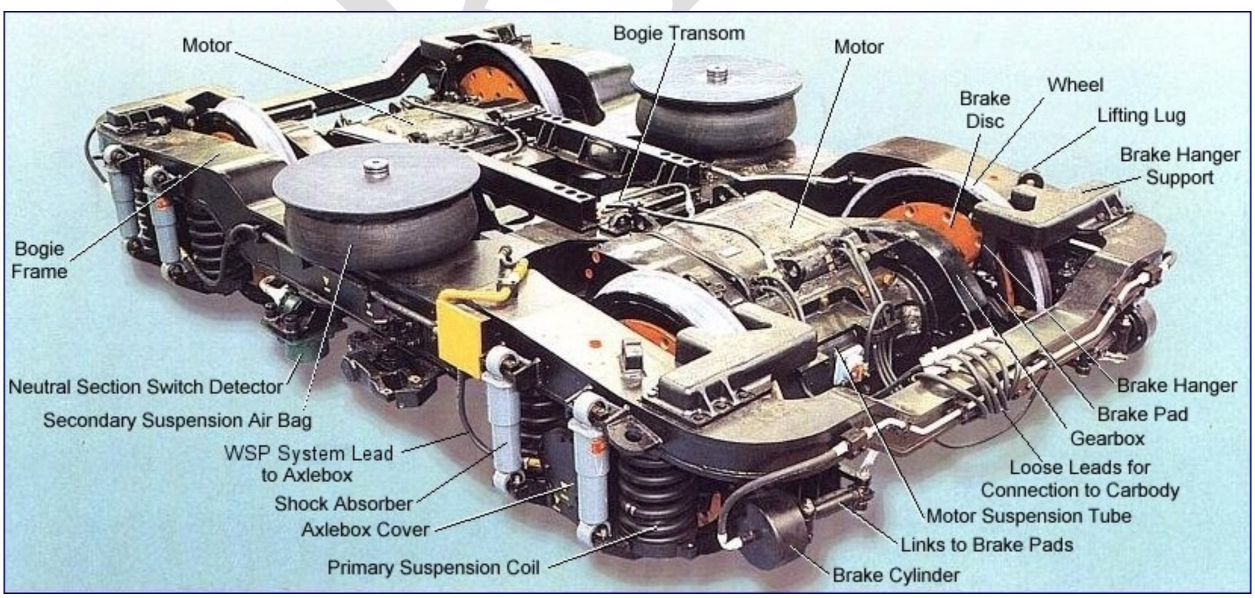
Bogies, also called trucks, are the part of the train which connect the body to the wheels. Bogies are highly engineered to include the wheels, suspension, sensing equipment, brakes, and motors. The image below shows a typical bogie and the various components inside. They generally have four wheels and steerable bogies, seen to the right of traditional bogies, allow the wheels to angle slightly for easier travel across curved track.

Non-Steerable Bogies



Steerable Bogies





Citation(s)

"The Early Underground" copyrighted images courtesy of the London Transport Museum.

- August 1, 2013, The Kaiserwagen, Retrieved from: https://en.wikipedia.org/wiki/Wuppertal_Suspension_Railway#/media/File:Wuppertal_kaiserwagen.jpg

- November 13, 1936, Retrieved from: http://www.ltmcollection.org/photos/photo/photo.html?_IXSR_=8LTLoXQoRgf&_IXMAXHITS_=1&IXinv=1998/89338&IXsummary=results/results&IXsearch=1935&_IXFIRST_=70

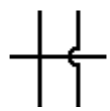
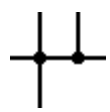
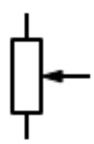
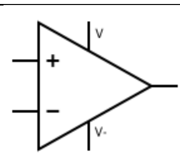
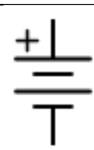
- April 19, 2012, Farrindon Station MMB 22 S-Stock, Retrieved from: http://upload.wikimedia.org/wikipedia/commons/c/c5/Farringdon_station_MMB_22_S-Stock.jpg

Session 3: Mixed Signals

Reference Material: Circuit Elements

One of the most important parts of a railway system is signaling. Train safety and management depends on it. In order to understand how signaling works, it is important to first understand how a circuit works.

Components in the Circuit

Name	Symbol	Description
Wire		Conducts electrical current.
Unconnected Wire		Wires are not connected.
Connected Wire		Connected wires are distinguished by black dots or nodes.
Resistor		Restricts current flow.
Potentiometer		Changes voltage output of wiper depending on position of knob
Photoresistor/Light Dependent Resistor(LDR)		Changes resistance based on light exposure.
Light Emitting Diode (LED)		Form of diode which emits light when current is passed through it.
Operational Amplifier (Op Amp)		Has two inputs, an inverting (-) and non-inverting (+), and an output. Must be connected to power and ground as well.
Battery		Provides power to the circuit with constant voltage.

Circuits

A circuit can be described as a cyclical path around which electricity flows from the positive terminal of a battery to the negative terminal of a battery. It is accustom to denote the positive terminal of the battery with a plus sign, +, and a red wire while the negative terminal is denoted by the negative sign, -, and a black wire. In order for a current to flow through a circuit, it must be closed (i.e. the path between the batteries terminals must be connected). If the path between terminals is not connected then the circuit is called open. A short circuit occurs when the resistance in an open circuit is zero (be sure to avoid this).

An especially important concept is power and ground. Power is generally very intuitive for people to grasp because it is the highest voltage in the circuit. However ground is a little more complex. Ground doesn't have to be 0 volts. Simply put, it can be anything so long as it is the lowest voltage in the circuit. The various notations for power and ground are noted below.

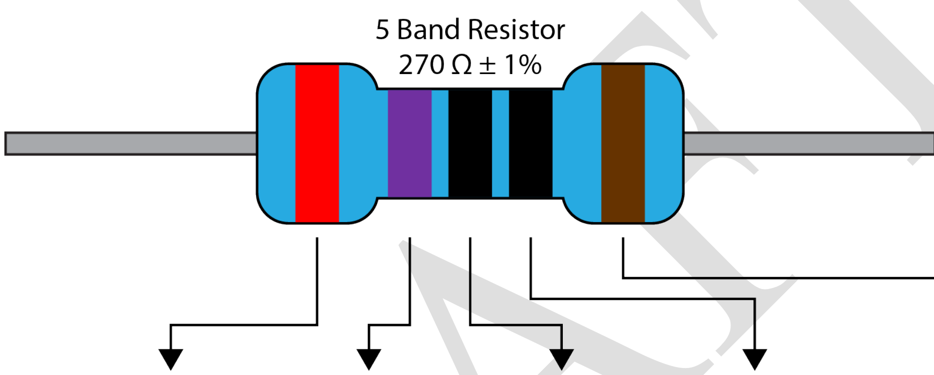
Power supply voltage	PWR	V_{CC}	V_{DD}	V+	V_{S+}	V_{cc+}
Negative supply voltage	GND	V_{EE}	V_{SS}	V-	V_{S-}	V_{cc-}

Resistors

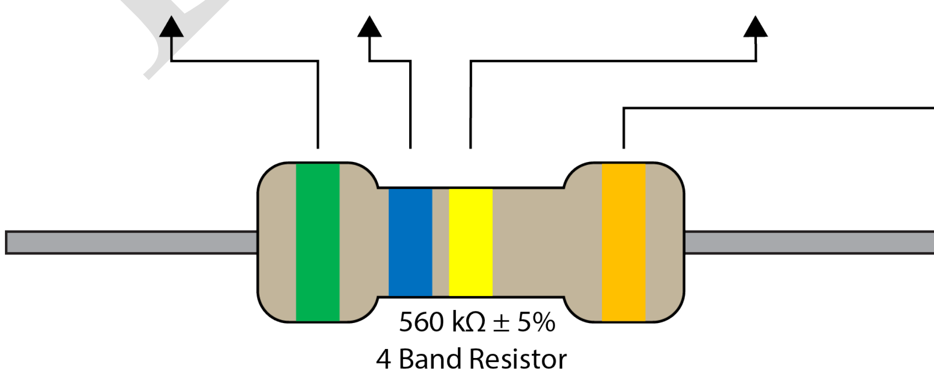
Resistors restrict the current flow through circuits. When a resistor is connected to a circuit and electricity is passed through it, there will be a voltage drop across the circuit. This can be found using the relation between resistance (R), current (i), and voltage (V) in Ohm's Law.

$$V = iR$$

Resistors are measured in Ohms. The higher the resistors value in Ohms, that the less current will flow through it (assuming you have a fixed voltage source). They can be anywhere from a couple of Ohms to millions of Ohms or even greater. You can determine the resistance of resistors using the chart of band colors below.

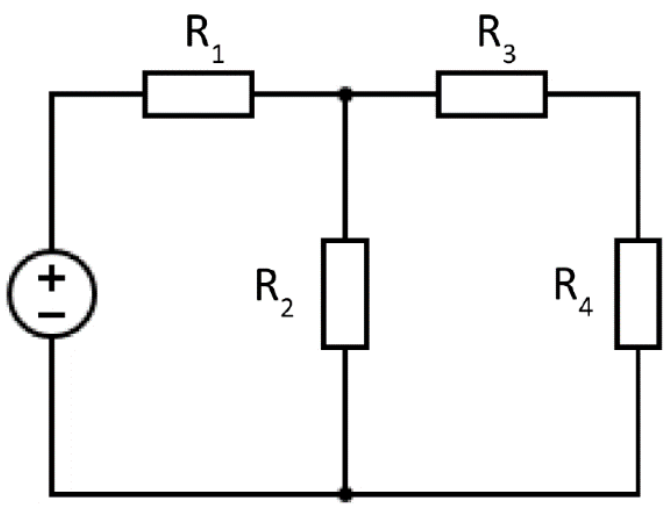


Color	1st Band	2nd Band	3rd Band	Multiplier	Tolerance
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1%
Red	2	2	2	100Ω	± 2%
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5%
Blue	6	6	6	1MΩ	± 0.25%
Violet	7	7	7	10MΩ	± 0.10%
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5%
Silver					± 10%



Parallel and Series

As can be seen in the diagram of the circuit there are both series and parallel combinations of resistors. The resistors R_2 is in parallel with R_3 and R_4. R_3 is in series with R_4, and R_1 is in series with all other resistors. Though this example uses resistors, the concept of parallel and series applies to any component though the equations below are specific to resistors. You will not be asked to calculate their equivalent resistance, but it can be found for any combination of resistors using the equations. The symbol □ denotes a summation. If for example, you have three resistors in parallel, your sum would be $\sum \frac{1}{R_n} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$. Likewise, for three resistors in series it would be $\sum R_n = R_1 + R_2 + R_3$.



Equivalent Parallel Resistance

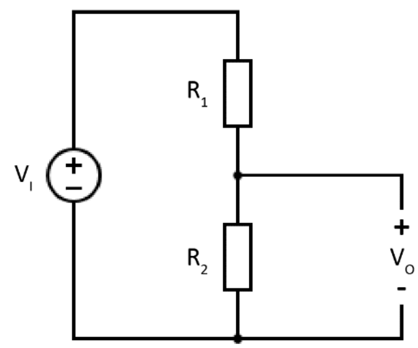
$$R_{eq} = \frac{1}{\sum \frac{1}{R_n}}$$

Equivalent Series Resistance

$$R_{eq} = \sum R_n$$

Voltage Dividers

Voltage Dividers are one of the simplest and most important circuits to learn. Theses circuits can take a large voltage and turn it into a smaller voltage. In this activity, the voltage divider allows us to convert the change in resistance of the photoresistor to a change in voltage for the input to the operational amplifier. The equation below relates the output voltage to the input voltage. You will not have to do any calculations for this activity but note that R_1 will be the photoresistor and R_2 a regular resistor.



$$V_O = V_I \frac{R_2}{R_1 + R_2}$$

Potentiometers

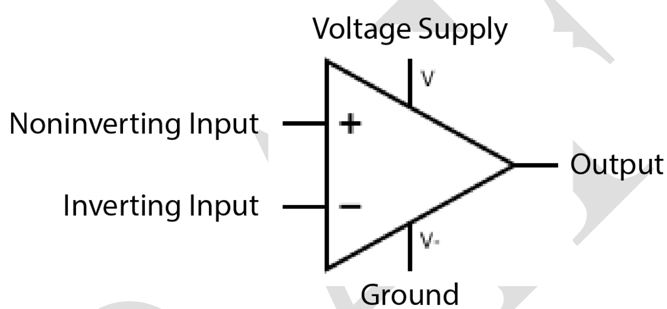
Potentiometers are extremely useful and common electrical components. By turning the knob, the voltage will change on the middle pin called the wiper. Potentiometers work on the concept of voltage dividers. However, for a potentiometer $R_1 + R_2 = R_{Potentiometer}$. Potentiometers like resistors have no direction, but remember to connect the left and right pins to power and ground.

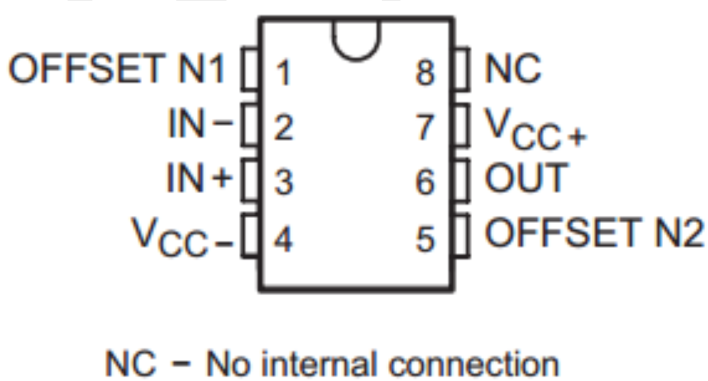
Photoresistors

Photoresistors are one component which can be used to detect light in a circuit. When in darkness, its resistance will be highest. When illuminated, its resistance will be lowest. Its change in resistance coupled with a voltage divider will allow you to change the voltage to the operational amplifier's noninverting input.

Operational Amplifiers

Operational amplifiers, op amps for short, are used in many manors. In this activity, it is used to compare the difference in voltage between two inputs and output a HIGH (on) or LOW (off) depending on which voltage is greater. An op amp requires the connection of at minimum five pins. Here you will connect the power and ground to provide electricity to the chip via V_{CC+} and V_{CC-}. In the final circuit, the wiper pin of the potentiometer should be connected to the inverting input (IN-) and the voltage divider wire from the photoresistor section should be connected to the non-inverting input (IN+). In the example chip below, you may ignore the OFFSET N1 and N2 pins as they are not important for your activity. You will need to look up the datasheet for you particular chip by doing an internet search for the text written on the top of it. Then find a picture similar to the example one below for information on each pin.

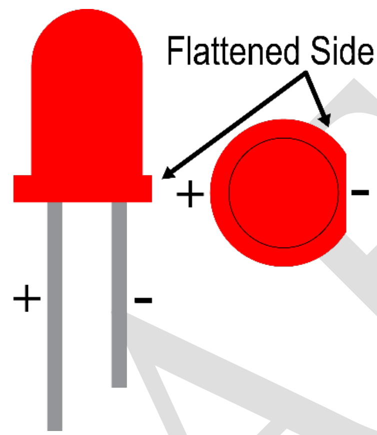




Chip Diagram for TL081CP

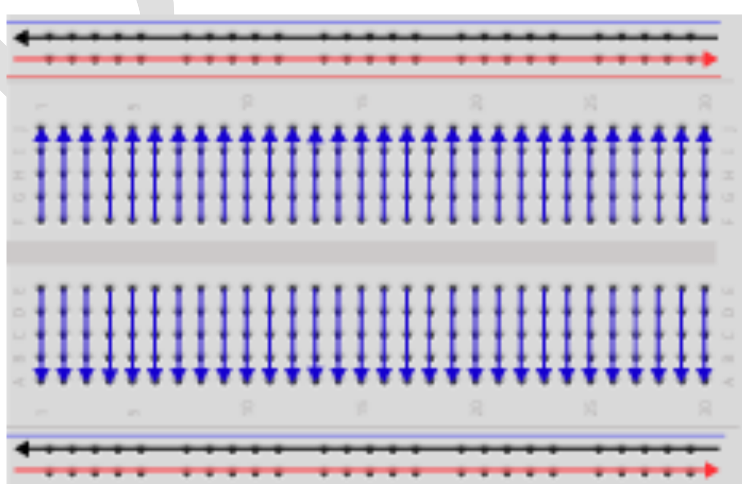
LEDs

Light emitting diodes, or LEDs, are a special type of diode which emit light when current is passed through them. Diodes unlike many common electrical components have a specific direction and burn out if they are placed incorrectly. On the circuit diagram symbol the flat line denotes the side which goes to ground. When looking at the actual component the side with the shorter wire is ground and the longer is power. This ground side of the LED will also be flattened.



Breadboards

Breadboards are extremely useful for rapid prototyping of electrical circuits. They come in various sizes but they all work the same. The vertical strips of holes on either side, sometimes only one side, are connected together as power and ground rails. Connecting any of these pins will result in all of the other inline pins being connected to the same source. In the middle of the board there are of rows. Each row on each side are connected together. Refer to the diagram below for a clearer picture of the connections on a breadboard.



Session 4: Rail Lines and Line Graphs

Additional Context: Signaling

In the early days of railways (in the 1830s and 1840s), there was no fixed signaling. Train drivers had to keep their eyes open for another train so they could stop before colliding with it. However, several accidents illustrated that this was not the best method for signaling trains as it was (and is) quite difficult to stop a train within the driver's sight distance.

Time Interval System

In order to counteract this problem, London Underground attempted the Time Interval System which was a system where the trains were only allowed to run at full speed for ten minutes, or a ten-minute headway, after the previous one had left the station. Policemen used red, yellow, and green flags to inform drivers when to proceed. A red flag was shown for the first five minutes after a train had departed. If a train arrived after five minutes, a yellow flag was shown to the driver. The green flag was given after a full ten minutes had passed. What do you think were some potential issues with this system? How dangerous was it? Think about this for a moment.

As you probably had already guessed, the Time Interval System was incredibly dangerous! Early trains were unreliable and would often break down between stations. The speed at which trains were running could not be guaranteed which resulted in many rear-end collisions. Another problem was line capacity. Even if all trains could be relied upon to travel at perfect conditions (no fluctuations in speed or unexpected stops), signal engineers still needed to run more trains on the line. Increasing the amount of trains on the line made the number of accidents increase in response. Eventually, they came up with fixed signaling which they hoped would finally fix the system.

The Golden Rule of Signaling

The basic rule of signaling is to divide the tracks into sections to ensure that only one train was allowed in one block at a time. Each block is protected by a fixed signal placed at its entrance so that a driver of an approaching train could see it. If the section is clear, the signal will show a "Proceed" indication. This indication used to be a raised semaphore arm; however, now it is a green light or green "aspect". If the block was occupied, then the signal will show a "Stop" indication, which is usually a red aspect. The next train will wait until the train in front has left the section.

The first mechanical signals in the UK appeared in 1841. In 1860, a signal box with levers controlling remote signals and points replaced these mechanical signals. Originally, the passage of each train was visually tracked by the signalman. When the train had cleared his section, the signalman would inform the signal box on the approach side that his block was free so that another train could go through. These messages were transmitted using an electric telegraph. The use of the electric "block telegraph" to pass messages and signal interlocking, which will be discussed further in depth later on, was introduced in the UK by the Regulation of Railways Act of 1889.

Distant Signals

Distant signals were introduced so that the driver could stop in time if the next stop signal was at danger. Positioning of these signals depended on visibility, curvature, maximum permitted speed, and a calculation of the train's ability to stop. Like the stop signals, distant signals were semaphores originally. They showed a green light at night if their stop signal was also green and yellow if the stop signal was red.

Additional Context: Track Circuits

Today, trains are monitored by track circuits. The London Underground was the first large-scale user of this system, applying it from 1904 to 1906. Low voltage currents are applied to the rails to cause a signal to show a "proceed" aspect. The current flow will be interrupted by the wheels of the train. This will cause the signal protecting the section to show a "stop" command (a red aspect or a stop signal). A "proceed" signal will only be displayed if the current does flow. Diagrams of Unoccupied and Occupied Blocks are provided below in Figures 1 and 2 respectively. A block section is separated electronically from neighboring sections by insulated joints in the rails. However, nowadays, more recent installations are electronics which allow jointless track circuits. In fact, some areas of the circuit allow signals, known as semi-automatic signals, to be held manually at red from a control center even if the section is clear.

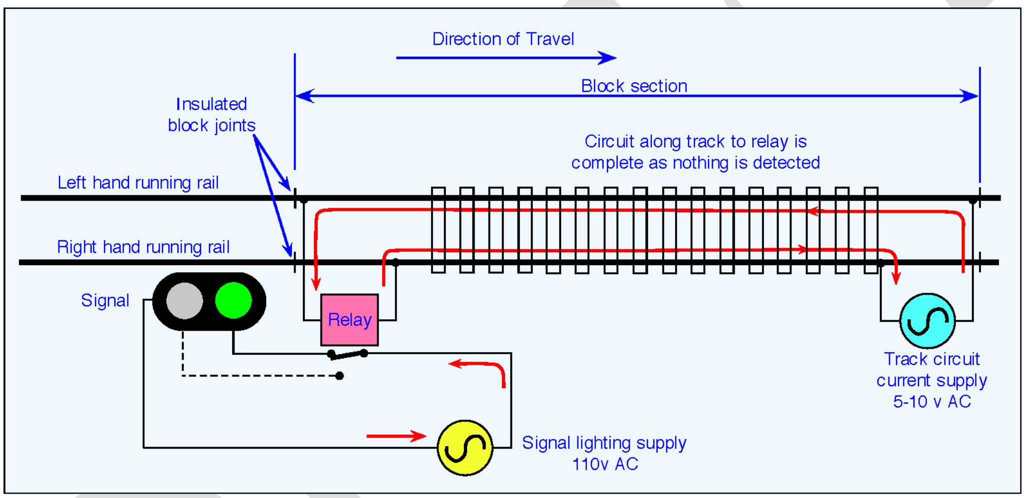


Figure 1: Unoccupied Block

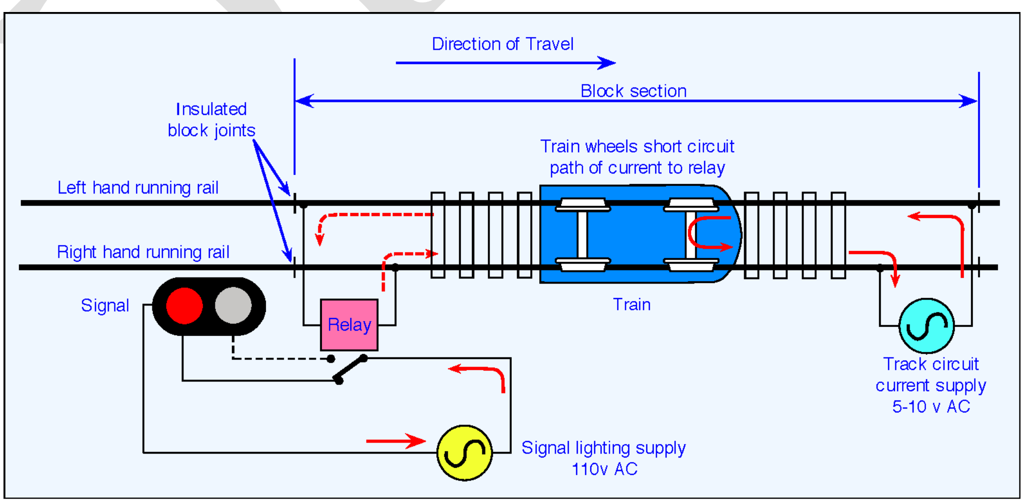


Figure 2: Occupied Block

Blocks

Railway tracks are divided into sections, or blocks, to ensure there is always enough space between trains and to avoid possible collisions. Each block is protected by a signal placed at its entrance. If the section is occupied by a train, the signal will be red. If the section is clear, the signal will be green. See Figure 3 to view this concept pictorially.

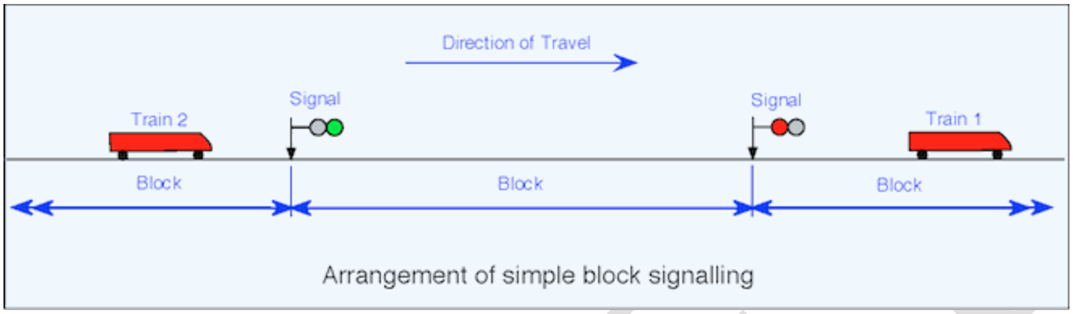


Figure 3: Simplified Block Diagram

Multi-Aspect Signals

There needed to be a new signals system for a train driving over 50 km/h because the driver needs a sufficient amount of time before he can stop. This led to distant signals, or caution signals, which were placed far enough back from the signal protecting the entrance to the block to give the driver a warning and a safe braking distance. Each signal was a multi-aspect signal and would show a red, yellow, or green aspect. Examples of multi-aspect signals includes a three-aspect signal and a four-aspect signal.

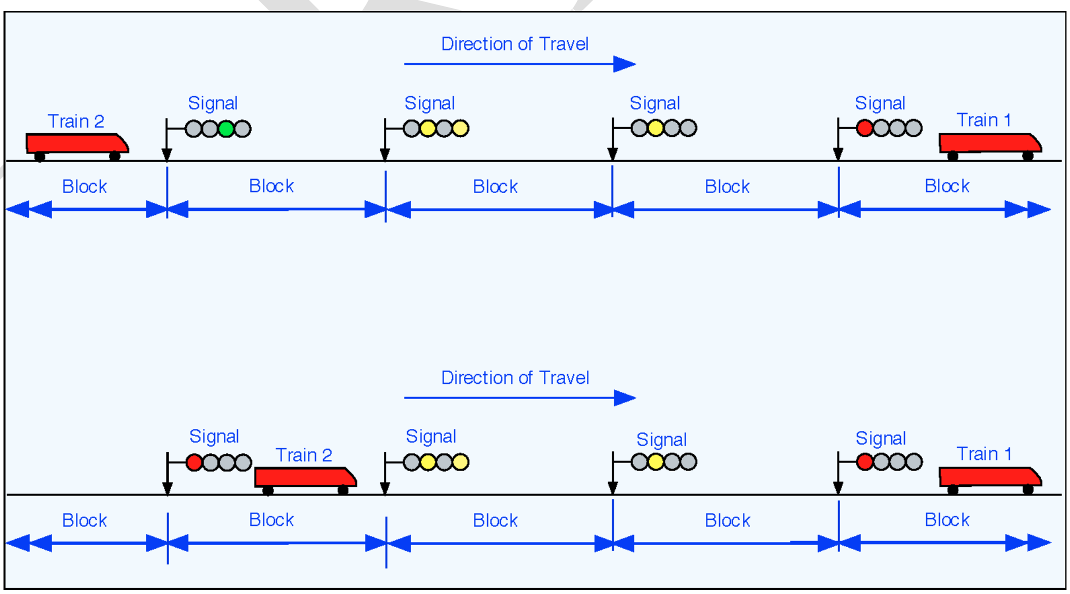


Figure 4: Four Aspect Block Signaling

Four-Aspect Signaling

The most commonly used multi-aspect signaling in the UK is a four-aspect system. It works similarly to the 3-aspect system, except they include two warnings (a double yellow and then a single yellow) before a red signal. This provides an early warning to higher speed trains so that they can prepare to stop. Figure 4 shows four-aspect signals with a high speed train with three clear blocks ahead (in the upper diagram) and a slower train with two clear blocks ahead of it (in the lower diagram). Lower speed trains can run closer together so more trains can be operated over a given section of line.

Reference Material: Fundamental Physics Equations

Included here are some of the fundamental equations of physics. Students should be familiar with these relationships, but this sheet may serve as a useful reminder of some of their details. Note that some of these same equations are behind the complex train graphs shown in this problem.

Table of Prefixes

Prefix and Abbreviation	Meaning	Example
giga- (G-)	1*10^9	1 Gg = 1,000,000,000 g
mega- (M-)	1*10^6	1 Mg = 1,000,000 g
kilo- (k-)	1*10^3	1 kg = 1,000 g
-	1	1 g
mili- (m-)	1*10^-3	1 mg = .001 g
micro- (-)	1*10^-6	1 g = .000 001 g
nano- (n-)	1*10^-9	1 ng = .000 000 001 g

Basic Kinematic Equations

- Let
    - x = displacement
    - v = velocity
    - a = acceleration
    - t = time

Assume acceleration is constant.

$$x = x_o + v_o * t + \frac{1}{2} a * t^2$$

$$x = x_o + v_{avg} * t = \frac{1}{2}(v + v_o) * t$$

$$x = x_o + v * t - \frac{1}{2} a * t^2$$

$$v = v_o + a * t$$

$$v^2 = {v_o}^2 + 2a(x - x_o)$$

Basic Energy Equations

- Let
  - m = mass
  - v = velocity
  - g = gravity
  - h = height
  - k = spring constant
  - x = displacement

$$Kinetic\ Energy = KE = \frac{1}{2} * m * v^2$$

$$Potential\ Spring\ Energy = SE = \frac{1}{2} * k * x^2$$

$$Potential\ Gravitational\ Energy = GE = m * g * h$$

Basic Momentum Equation

- Let
  - m = mass
  - v = velocity
  - p = momentum

$$p = m * v$$

Newton's Second Law of Motion

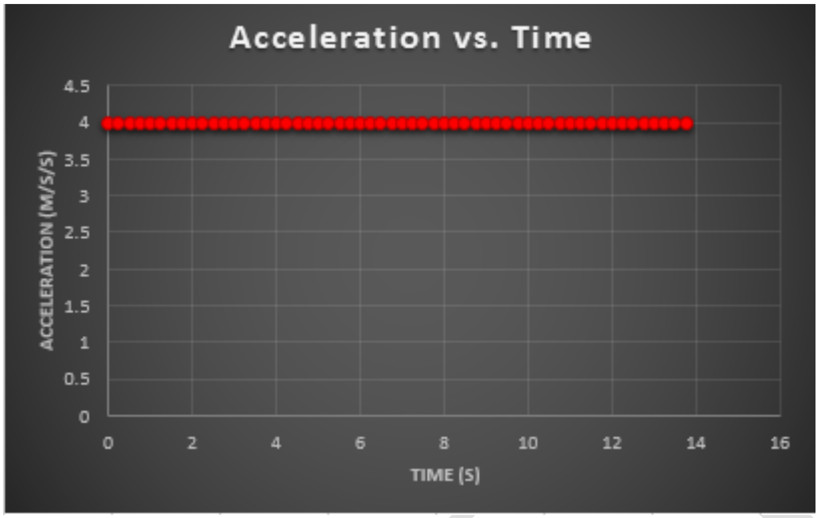
- Let
  - m = mass
  - a = acceleration
  - F = force

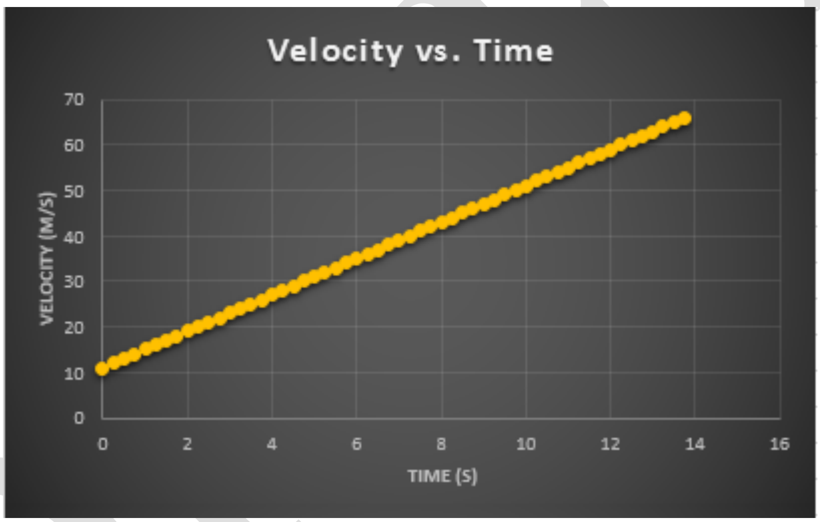
$$F = m * a$$

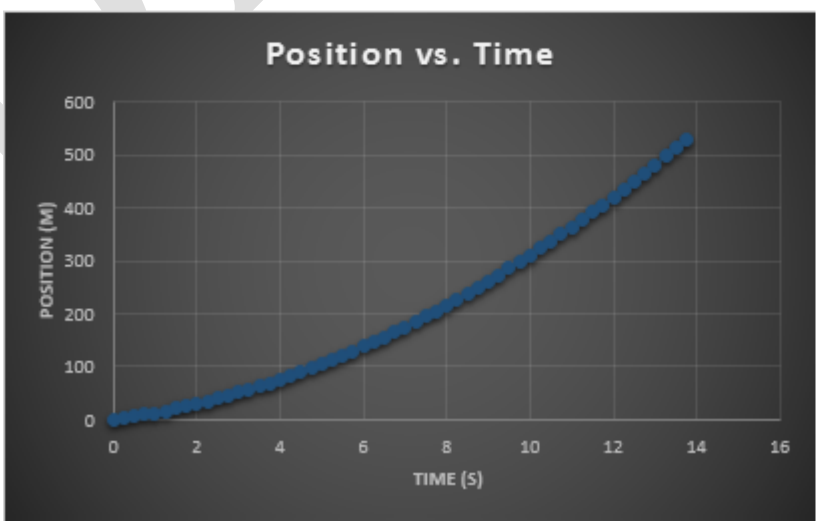
Reference Material: Fundamental Physics Relationships

Note that position vs. time, velocity vs. time, and acceleration vs. time graphs are all related. If acceleration is constant and positive at a given time, the velocity vs. time graph will have a constant positive slope and the position vs. time graph will be a parabola (concave up). Conversely, if acceleration is constant and negative at a given time, the velocity vs. time graph will have a constant negative slope and the position vs. time graph will be a parabola (concave down). These concepts are illustrated below.

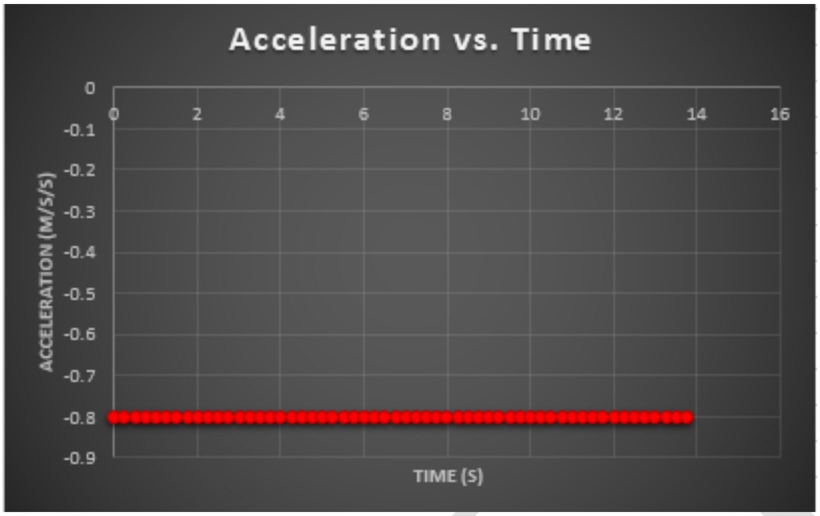
Example: Constant Positive Acceleration

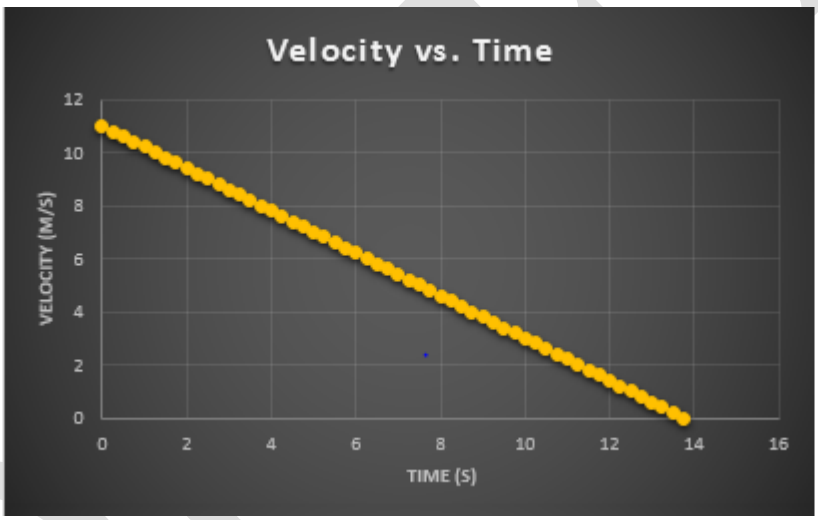


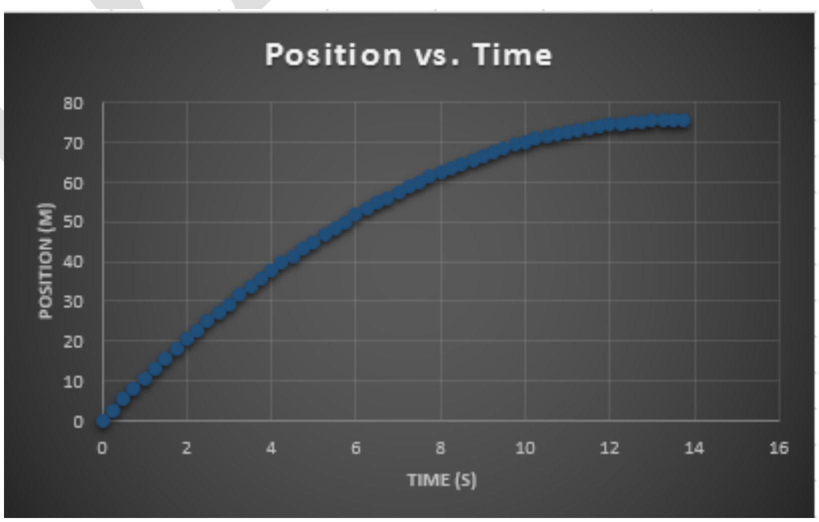




Example: Constant Negative Acceleration







Citation(s)

"Signaling" copyrighted images courtesy of Railway Technical Web Pages

- Railway Technical. (2014, December 9). Railway Technical Web Pages. Retrieved June 4, 2015, from http://railway-technical.com/stations.shtml#Station-Design

Session 5: Mind the Gap

Additional Context: Bridges

Used since ancient times, bridges are structures that provide passage over an obstacle, such as a valley or river. Some of the greatest bridges still standing today were built by Roman engineers. Pont du Gard (pictured above), spanning 272 metres, is an example of a Roman bridge. With the introduction of arches, the Romans revolutionized bridge building. Arched bridges allowed a downward force to be directed through the bridge's supports. Human civilizations employed this engineering feat for the next thousand years.

When designing a bridge, experts say that it's important to have a good understanding of BATS. BATS, is an acronym for the key structural components of bridges, **beams**, **arches**, **trusses**, and **suspensions**. Combinations of these four elements allow for various bridge designs from arch bridges and suspension bridges to side-spar cable-stayed bridges. The difference between these bridges is the length they can cross in a single span, which is defined as the distance between two bridge supports (physical braces that connect the bridge to the surface below).

Definitions

- **Stress** is the pressure or tension exerted on a material object.

$$\sigma = \frac{Force}{Area\ of\ the\ Cross\ Section}$$

Stress is measured in newtons per square meter, or pascals. This formula explains why thin objects break so easily: they have an extremely low cross-sectional area, so stress in the body is very high. Of course, the opposite is true for very large objects. So, ultimately stress causes an element to fail, not necessarily the force it experiences; engineers must consider both the forces present in bridge beams as well as their size and shape in order to create safe infrastructure. Examples of stress are **compressive, tensile, torsional** and **shear stress**; they are caused by compressive forces, tensile forces, moments, and sliding forces (forces acting parallel to a cross section) respectively.

- **Tension** is the state of being stretched. For example: What happens to a rope when you play a game of tug-of-war?

- **Compression** is the action of reducing an object in volume. For example: What happens when you push down on a spring? It becomes smaller and more compressed. You will even feel a force pushing back on you.

- **Moments** form as an element is bent or twisted. If you hold a heavy weight in your hand, your wrist will bend downwards; this is because a moment, or bending force, has formed in your wrist. Bridges usually cannot bend as well as your joints, so engineers must perform very precise calculations of moments to ensure no excessive stresses form as a result of these reactions. Note that moments and torque are very similar, and, for the purposes of this program, can be considered synonymous.
- **Dead load** is the result of the forces present in a structure by virtue of its own mass and geometry.
- **Live load** is the result of the forces present on a structure as it is in use. For example, on a bridge, this might be cars, pedestrians, snow, wind, etc.
- **Buckling** occurs when compression overcomes an object's ability to endure that force.
- **Snapping** occurs when tension overcomes an object's ability to handle the lengthening of the force. Let us go back to the game of tug of war. If both teams pull too hard, the rope will snap!

- **Trusses** are structures made of elements supported at two points. The ability of engineers to design trusses to support compressive and tensile loads as well as moments has made them critical to bridge design. Usually trusses are arranged into triangular shapes as triangles are easy to form out of metal beams and distribute loads evenly and predictably among their members.

Table of Bridge Designs

Bridge	Description
Beam/Girder	• The simplest bridge design. These bridges need a rigid horizontal structure and two supports for the bridge to rest on at each end. o These components directly support the downward weight of the bridge and any traffic travelling over it. o Generally made out of concrete or steel o Height and size are controlled by the distance the beam can span • Example: The Waterloo bridge
Truss	• Product of the Industrial Revolution • Adapted the beam bridge by adding more trusses. Can have a thorough truss (above the bridge) or a deck truss (beneath the bridge) • Example: The Millennium (Wobbly) bridge
Arch	• Distributes compression throughout its entire form. • Tension is negligible thanks to the arch (dissipates force outwards) • The greater degree of curvature, the greater the effects of tension on the underside of bridges. • Example: The Pont du Gard
Suspension	• A beam bridge with two towers, anchorages, supporting cables, and a deck truss. o Towers support the weight and dissipate the compression o Supporting cables receive the bridge's tension forces. o Deck truss is a supporting truss system beneath the bridge. Helps to stiffen the deck and keeps the roadway from snapping. • Can cross distances between 610 and 2,134 meters • Example: The Golden Gate Bridge in San Francisco
Cable Stayed	• Adapted from suspension bridge. First built in Europe after the end of World War II. • These bridges have a bridge with a tower, deck, and supporting cables. • Tower absorbs compressional forces • Example: The Dartford Crossing bridge

Citation(s)

- Introduction to Simple Truss Analysis. (n.d.). Retrieved June 4, 2015, from http://www.aboutcivil.org/simpl-truss-analysis-methods.html

- Lamb, R., & Morrissey, M. (n.d.). How Bridges Work. Retrieved June 2, 2015, from http://science.howstuffworks.com/engineering/civil/bridge.htm

Session 6: Tunnel Vision

Definitions

- **Shafts** - Vertical openings. They are often dug by hand or with boring equipment
- **Ventilation shaft** - Vertical passages used in mines and tunnels to replace stale underground air with fresh air
- **Portal** - The opening of a tunnel
- **Crown** - The top half and "roof" of a tunnel
- **Invert** - The bottom half and "floor" of a tunnel
- **Statics** - The branch of mechanics concerned with bodies at rest and forces in equilibrium.
- **Driving** - Engineers refer to advancing a tunnel as driving
- **Stand-up time** - The amount of time a tunnel will support itself without any additional structures. Knowing this time enables engineers to determine how much material they can excavate before they must add supports

Classification	Description	Example
Mining tunnels	These tunnels are cheap, temporary structures built to let miners access valuable resources. They are usually dark, cramped, and can use wooden supports.	Coal mines of West Virginia, USA
Public works tunnels	These tunnels are used to transport water, gas, sewage, electrical lines, etc. to and from urban areas.	The Romans included tunnels in their aqueducts, transporting water from mountain springs into the heart of Rome.
Transportation tunnels	Every day millions, if not billions, of people travel through tunnels, either on trains, on foot, or in cars.	The Chunnel, also known as the Channel Tunnel, links Britain with Continental Europe via several parallel rail lines.

Method	Description	Example
Fire-Setting	Inducing thermal stresses in rock can cause is to become brittle and shatter. By rapidly heating and cooling a rock face it becomes relatively easy to advance, or drive, a tunnel.	Romans used this technique to construct the aqueducts mentioned above.
Cut-and-cover	Here workers literally dig a trench, construct or install a section of the tunnel, then convert the completed structure. Obviously, this method has a huge impact on areas along the path of the tunnel.	The first few lines of the London Underground were constructed using this method; some 2,000 workers dug the necessarily trench by hand. Today, this technique is used on many underwater lines, where silt can be easily dredged. In these scenarios sections of tunnel are floated above the trench, filled with water, sent into the trench, joined by underwater workers, and finally drained of excess water. This technique was used during the construction of the Ted Williams Tunnel in Boston's "Big Dig".
Shielding (for soft ground)	When tunneling through soft ground, engineers must cope with a short stand-up time; cave-ins are a constant concern. Therefore, diggers must constantly reinforce areas as they dig. They remove a small amount of earth before covering the affected area with a board. Once the entire face of the tunnel has been excavated and covered large machines then push the protecting boards forward, and the process is repeated.	Marc Isambard Brunel first introduced this method in 1825 with a rectangular pedestrian tunnel beneath the Thames. Peter M. Barlow and James Henry Greathead applied the Brunel method to cylindrical tunnels in 1874 as part of the construction of the London Underground. Since then the method spread throughout the world, ultimately returning to London as the tunnel boring machines used in the Crossrail lines shield the tunnel as they dig.
Jumbos (for hard rock)	A jumbo is scaffolding placed at the cutting face of the tunnel. Workers use the platform to drill deep holes into the rock, stuff them with explosive charges, then blast away the rock, excavating the broken rock only after clearing the noxious smoke.	This process is also used for mining and making roads through mountains.
Full face method (for	This technique is reserved for either tunnels with a small diameter or tunnels	This technique is used heavily with Tunnel Boring Machines as these

hard rock)	going through strong materials. Here excavation is simultaneously being done on the entire rock face, not just a small section which is later reinforced. The material must be firm enough to support itself for this to be a viable option.	machines excavate all the way across their massive diameter.
Top-heading-and-bench (for soft ground and rock)	A smaller tunnel is dug first, known as a heading, along the crown of the tunnel, then a lower part of the tunnel is dug, called a bench. This repeats until the tunnel's full diameter has been excavated. Many benches can be created, depending on the desired size of the tunnel. A clear benefit of this technique is that it lets engineers test the quality of the ground ahead of the tunnel.	Perhaps this method was utilized during the historically sensitive phases of the Crossrail initiative. Slowing the digging to allow for archaeologists to examine individual layers of rock may have preserved many different types of artifacts.
Tunnel boring machines (for soft rock)	Tunnel boring machines, or TBMs, are massive devices that cut full cylindrical shafts through rock. They have disk cutters at their rotating front ends, conveyor belts to remove muck from the active end, and a massive mechanism to install shielding as the machine advances. Thus these machines can literally create a nearly finished tunnel in one pass.	The effectiveness and speed of TBMs has made them incredibly popular in recent years. The Crossrail project uses eight TBMs which can generate 100 m of new tunnel in a week. The Chunnel project used as many as 11 TBMs; French teams competed with English teams to see who could reach the middle of the English Channel first.
Tunnel jacking (for soft ground)	Powerful jacks advance a hollow metal box through the earth almost like a cookie cutter. The enclosed dirt is carted away and the exposed faces are reinforced.	This technique was used Boston's "Big Dig" as a way to drive the tunnel without damaging surrounding infrastructure.
Future	Advancements in tunnel-boring machines, research into ultrasonic imaging, and developments in waterjet cutting and concrete composition all have the potential to make tunnels larger, easier to produce, and safer.	

Additional Context: The Crossrail Initiative

Crossrail, Europe's current largest infrastructure project, will reduce traveler's journey time, ease congestion, and improve connections between Heathrow and Paddington. It is projected to open in 2018 and is predicted to increase the miles of tunnels in London's rail-based transport network by 10 percent- the largest increase since World War II. It is estimated that the Crossrail endeavor will add 42 billion pounds to the UK economy and create thousands of jobs and training opportunities throughout London.

The Tracks

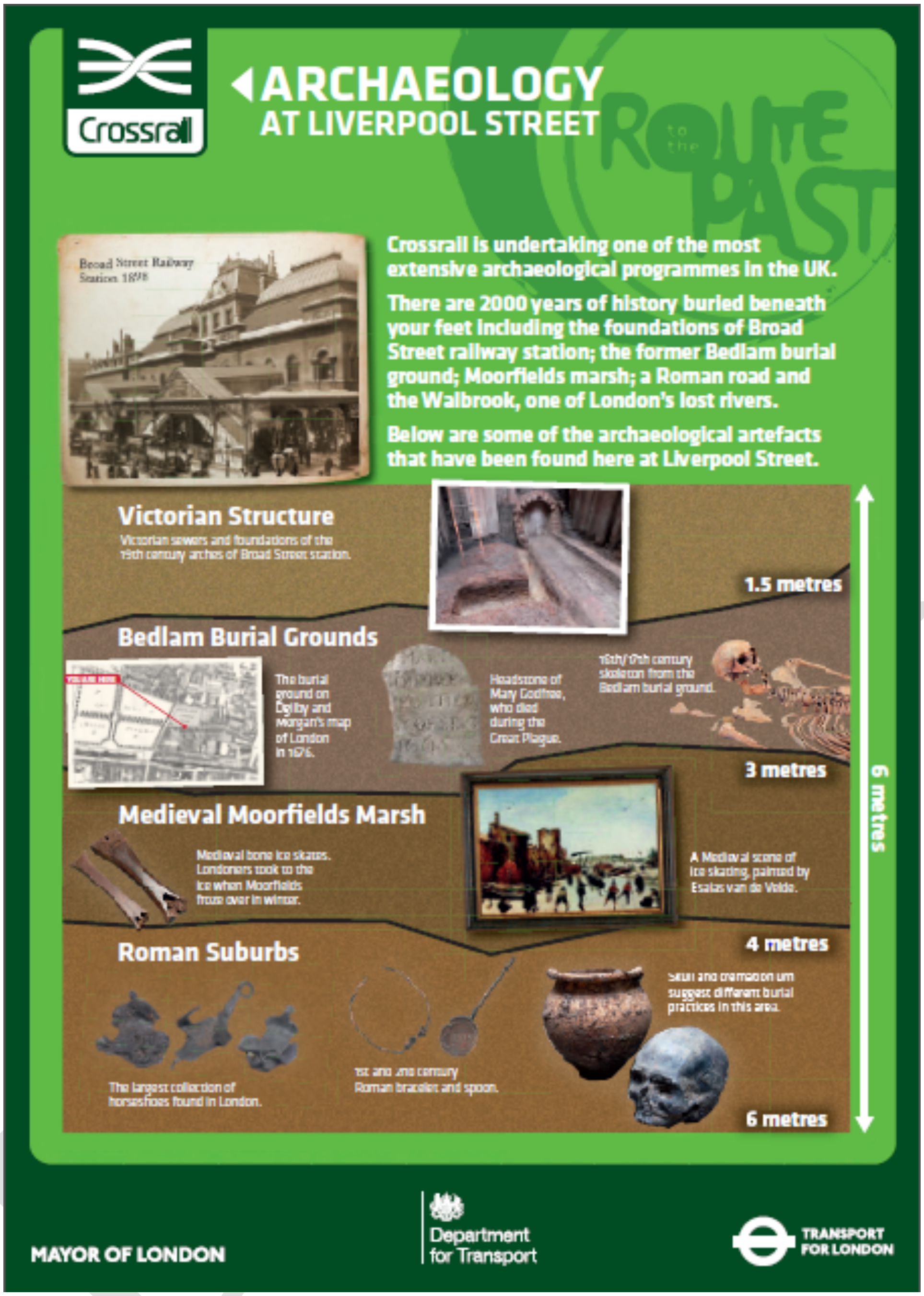
- 10 new Crossrail stations will be built at Paddington, Bond Street, Tottenham Court Road, Farringdon, Liverpool Street, Whitechapel, Canary Wharf, Custom House, Woolwich, and Abbey Wood.
- The new stations will be connected by 21 km of twin bore tunnels under central London to the 30 existing Network rail stations from Reading to Abbey Wood.
- As of June 2nd, 2015, the train tunnels are 90% complete. Tunneling should finish in spring of 2016.

The Trains

- Each train will be around 200 meters long
- Each train will accommodate roughly 1,500 passengers
- It is estimated that roughly 200 million passengers will use Crossrail each year

Crossrail's Archaeological Finds

In March 2015, Crossrail found a new archaeological site at Liverpool Street which reveals about 2,000 years of London's past ranging from the Roman Times to the Victorian Era. This site is now known as the Bedlam Burial Ground. Crossrail has sixty archaeologists working on the site. The archaeologists have found a Roman road running through the site as well as over 3,000 skeletons. To dig deeper into Crossrail's archaeological exploration, please view the informative pages provided by Crossrail shown below.



Crossrail
ARCHAEOLOGY
AT LIVERPOOL STREET
Route to the Past
Broad Street Railway Station 1898
Crossrail is undertaking one of the most extensive archaeological programmes in the UK.
There are 2000 years of history buried beneath your feet including the foundations of Broad Street railway station; the former Bedlam burial ground; Moorfields marsh; a Roman road and the Walbrook, one of London's lost rivers.
Below are some of the archaeological artefacts that have been found here at Liverpool Street.
Victorian Structure
Victorian sewers and foundations of the 19th century arches of Broad Street station.
1.5 metres
Bedlam Burial Grounds
YOU ARE HERE
The burial ground on Ogilby and Morgan's map of London in 1676.
Headstone of Mary Godfree, who died during the Great Plague.
16th/17th century skeleton from the Bedlam burial ground.
3 metres
Medieval Moorfields Marsh
Medieval bone ice skates. Londoners took to the ice when Moorfields froze over in winter.
A Medieval scene of ice skating, painted by Esaias van de Velde.
4 metres
Roman Suburbs
The largest collection of horseshoes found in London.
1st and 2nd century Roman bracelet and spoon.
Skull and cremation urn suggest different burial practices in this area.
6 metres
6 metres
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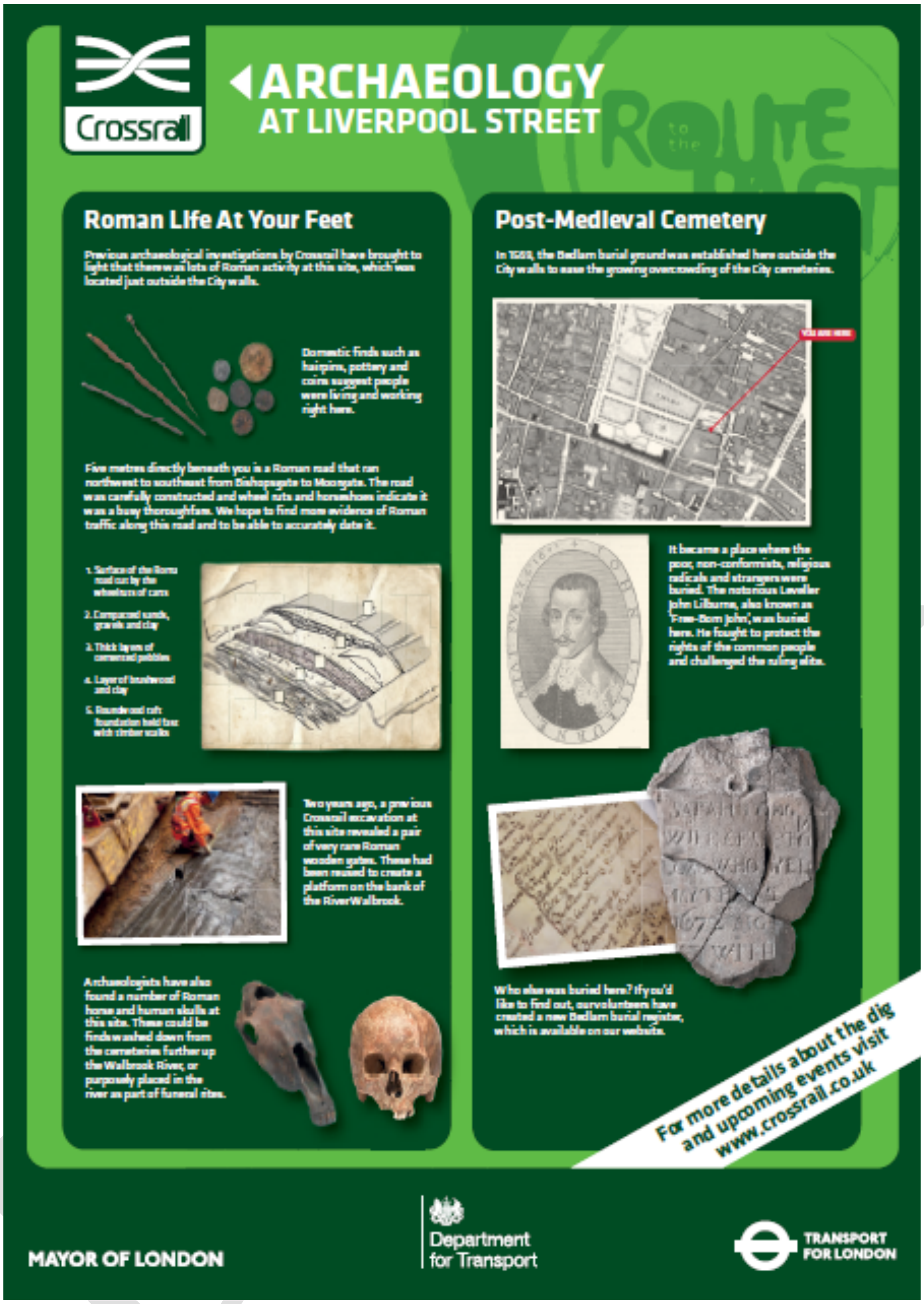
Crossrail
ARCHAEOLOGY
AT LIVERPOOL STREET
Route to the Past
Roman Life At Your Feet
Previous archaeological investigations by Crossrail have brought to light that there was lots of Roman activity at this site, which was located just outside the City walls.
Domestic finds such as hairpins, pottery and coins suggest people were living and working right here.
Five metres directly beneath you is a Roman road that ran northwest to southeast from Bishopsgate to Moorgate. The road was carefully constructed and wheel ruts and horseshoes indicate it was a busy thoroughfare. We hope to find more evidence of Roman traffic along this road and to be able to accurately date it.
1. Surface of the Roman road cut by the wheelruts of carts
2. Compacted sands, gravels and clay
3. Thick layers of cemented pebbles
4. Layer of brushwood and clay
5. Roundwood raft foundation held fast with timber stakes
Two years ago, a previous Crossrail excavation at this site revealed a pair of very rare Roman wooden gates. These had been reused to create a platform on the bank of the River Walbrook.
Archaeologists have also found a number of Roman horse and human skulls at this site. These could be finds washed down from the cemeteries further up the Walbrook River, or purposely placed in the river as part of funeral rites.
Post-Medieval Cemetery
In 1569, the Bedlam burial ground was established here outside the City walls to ease the growing overcrowding of the City cemeteries.
YOU ARE HERE
It became a place where the poor, non-conformists, religious radicals and strangers were buried. The notorious Leveller John Lilburne, also known as 'Free-Born John', was buried here. He fought to protect the rights of the common people and challenged the ruling elite.
Who else was buried here? If you'd like to find out, our volunteers have created a new Bedlam burial register, which is available on our website.
For more details about the dig and upcoming events visit www.crossrail.co.uk
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Crossrail

ARCHAEOLOGY AT LIVERPOOL STREET

Route to the Past

Bedlam Burial Ground

Historic research tells us that the 'New Churchyard' later known as the Bedlam Burial Ground was established in 1569. "The plot, about an acre in all, was walled in and the level raised by dumping earth and rubbish from cellar and well diggings in the City." The considerable cost of the walling and making up was paid by Alderman Sir Thomas Rowe.

Excavation of the burial ground. The cemetery wall is visible at rear

Evidence for these ancient works show a dense pattern of timber (elm) piles was driven into clays and silts on the edge of the Walbrook River. This formed the foundation for the brick cemetery wall that survived to a height of several brick courses. Within the area of the burial ground a thick layer of imported soil was placed to raise the land level. The earliest burials are found to cut through this soil. Finds were diverse and included a rare 16th century Venetian Gold Ducat.

Elm timber piles from the 16th century cemetery wall foundation at Bedlam Burial Ground being recorded

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Crossrail

ARCHAEOLOGY AT LIVERPOOL STREET

ROUTE to the PAST

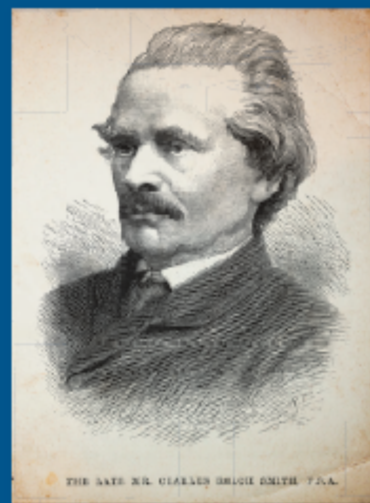
Bedlam Burial Ground

More than 10,000 people were buried in the new cemetery. As it was not attached to a particular parish church, no single burial register exists. Instead, entries like 'buried at Bedlam', or 'New Churchyard', are spread across different parish records.

Biographic detail rarely survives in the archaeology at this site. However, partial gravestones have been found re-used in the foundations of the cemetery wall'.

Charles Roach Smith (1807-1890) was a pioneering London archaeologist and founder of the British Archaeological Association. He lived at No. 5 Liverpool Street where he made the following curious observation.

"Opposite my house on the other side of the street was a long dead wall, which separated the street from a long piece of garden ground. When my man buried in it a deceased favourite cat, he said he came upon the remains of human skeletons. A few years later the cat's coffin and epitaph were bought before the directors of the North London and Great Eastern Railway as a very puzzling discovery!"



©Illustrated London News Ltd/Mary Evans

We now know that apart from Roach's cat, construction works for the building of Broad Street Station had encountered the Bedlam cemetery remains in the 1860s.

A rare Venetian gold ducat of Doge Leonardo Loredan, AD 1501-21 Obverse: the Doge kneels before St Mark Reverse: Christ 'ego sum lux mundi' (I am the light of the world)

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Citation(s)

- Crossrail. (2015). Welcome to Crossrail. Retrieved June 4, 2015, from http://www.crossrail.co.uk/

- Harris, W. (n.d.). How Tunnels Work. Retrieved June 2, 2015, from http://science.howstuffworks.com/engineering/structural/tunnel.htm

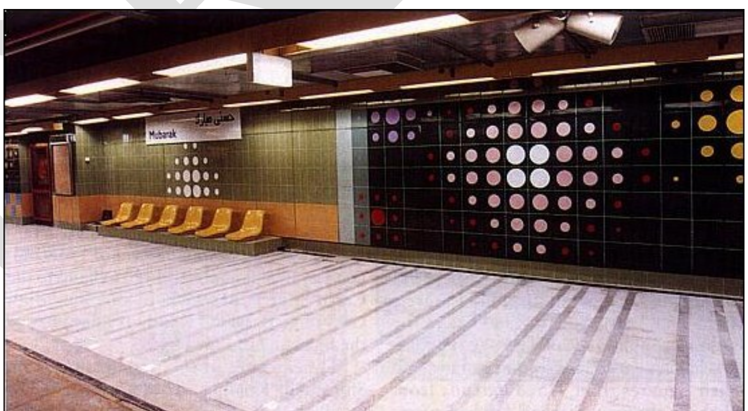
Session 7: Station Fixation

Additional Context: Station Artwork

The majority of the London Underground’s tube stations have their own unique personalities, oftentimes featuring famous artist's’ work or displaying an interesting architectural feature. Stations can also be set apart by an iconic image as well, such as the silhouette of Sherlock Holmes seen at the Baker Street station (Bakerloo line). However, London Underground is not the only tube system that showcases unique station architecture and design. Some examples of good station design are included below in Figures 1 to 3.

A new underground station on the metro system of Santiago, Chile. A combination of striking architecture and subdued lighting combine to give a pleasing overall finish. The use of upper level galleries, visible to the left and right, is unusual but adds to the feeling of accessibility.

Figure 1, Architecture: This photo is of an underground metro station in Santiago, Chile. The station is quite striking with its unique architecture and lighting. This station uses upper level galleries (which is unusual) to add to the feeling of accessibility.



An example of a wide station platform (Cairo Metro, Egypt) designed to accommodate large numbers of passengers boarding and alighting at the same time. Note that there are no supporting columns to limit circulation or visibility on the platform. There are a few seats for waiting passengers but these are arranged to prevent a person lying down on them. Vagrants sheltering in stations in a serious problem in some cities and has to be discouraged.

Figure 2, Platform: This photo was taken at a Cairo Metro station in Egypt. It is an example of a wide station platform which is designed to accommodate large numbers of passengers boarding and leaving at the same time. Note: there are no supporting columns to limit circulation or visibility on the platform. There some seats for waiting passengers but these are arranged to keep a person from lying down on them.

Madrid, Spain, offers an example of a light, airy station concourse with faregate lines dividing the "paid" and "unpaid" areas. The ticket office is located in the centre of the gate line so it can be used by passengers in both areas. The lightweight steel structure over the escalators in the foreground carries CCTV cameras and loudspeakers.

Figure 3, Concourse Design: The photo was taken in Madrid, Spain. It offers an example of a light, airy station concourse with fare gate lines dividing the “paid” and “unpaid” areas. The ticket office is located at the center of the gate line so it can be used by passengers in both areas. The lightweight steel structure over the escalators (bottom left of photo) allows CCTV (Closed Circuit Television) cameras and loudspeakers to be hung.

Citation(s)

"Station Artwork" and "Station Design" copyrighted images courtesy of Railway Technical Web Pages.

- Railway Technical. (2014, December 9). Railway Technical Web Pages. Retrieved June 4, 2015, from http://railway-technical.com/stations.shtml#Station-Design

Session 8: Time is of the Essence

There are many descriptions of the CPM (Critical Path Method) algorithm available online, from the original published paper onwards. Mosaic, a company working in project management, has a large list of scheduling-related papers. “Basic CPM Calculations” is a good resource to expand the given exercises to include more detail on the calculations and changes to the process. It provides modifications to the method that accommodate more complex scheduling scenarios. The Above and Beyond section in the Teacher Handbook for this session has some of these modifications. The basic calculations paper can be found here: http://www.mosaicprojects.com.au/pdf/schedule_calculations.pdf

Critical Path Information:

History and Summary

The Critical Path Method (CPM) is a method of mathematical analysis to shorten the completion time of large projects. It was developed in the 1950’s by Morgan Walker and James Kelly. Walker worked at DuPont, an American chemical company, where managers were looking for uses for their ‘UNIVAC1” computer, with an interest in planning, scheduling, and estimation. CPM has been used in engineering, software development, construction, and research projects, and for other projects with many components. A related method of project modeling was used to plan the 1968 Winter Olympics, from 1965 onwards.

The Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT) are related algorithms to schedule a large number of activities, some of which depend on a previous activity being finished.

Definitions

- **Project** - A large, complex goal that can be broken down into specific activities.
- **Activity** - A task in the project. Each activity has a duration, and a (possibly empty) set of activities that must be completed before it can begin.
- **Network diagram** - A way of representing the activities in a project to show the order they must be completed in, and the timings involved.
- **Path** - A sequence of activities in the networking diagram
- **Critical Path** - The path through the networking diagram from start to finish with the longest total time. This determines the project's duration.

Basic Steps to the Critical Path Method (CPM) are as follows:

1. Define the activities in the project, activities that must precede these activities, and the duration of each activity.
2. Create a network diagram to display the activities clearly and determine the project's duration.
3. Determine the duration of the project, and the critical path.

Theater Production

Student Worksheet

Definitions

Project - A large, complex goal that can be broken down into specific activities.

Activity - A task in the project. Each activity has a duration, and a (possibly empty) set of activities that must be completed before it can begin.

Network diagram - A way of representing the activities in a project to show the order they must be completed in, and the timings involved.

Basic Steps to the Critical Path Method (CPM) are as follows:

1. Define the activities in the project, activities that must precede these activities, and the duration of each activity.
2. Create a network diagram to display the activities clearly and determine the project's duration.
3. Determine the duration of the project, and the critical path.

This example determines the total time required to produce a theater performance.

Define the Activities, Dependencies, and Durations

The activities, their dependencies, and their durations are provided.

Activity Name	Activity identifier	Preceding activities	Duration (Days)
Choose designers	A	-	5
Choose crew	B	-	5
Choose cast	C	-	3
Rehearsals	D	C	19
Design set	E	A	10
Build set	F	B,E	9
Technical run-through	G	F	1
Actor run-through	H	D	2

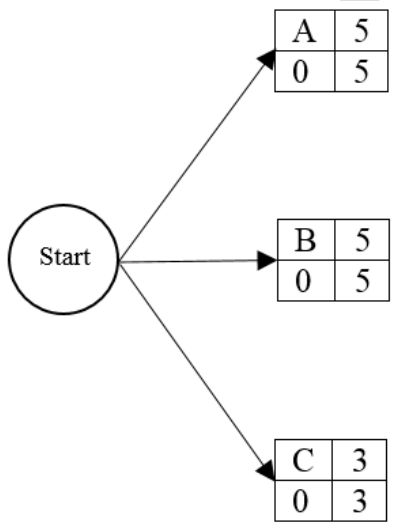
Create a Network Diagram

Each activity will be represented by its letter ID, the earliest time it can begin, the time it will finish, and its duration, in the following format:

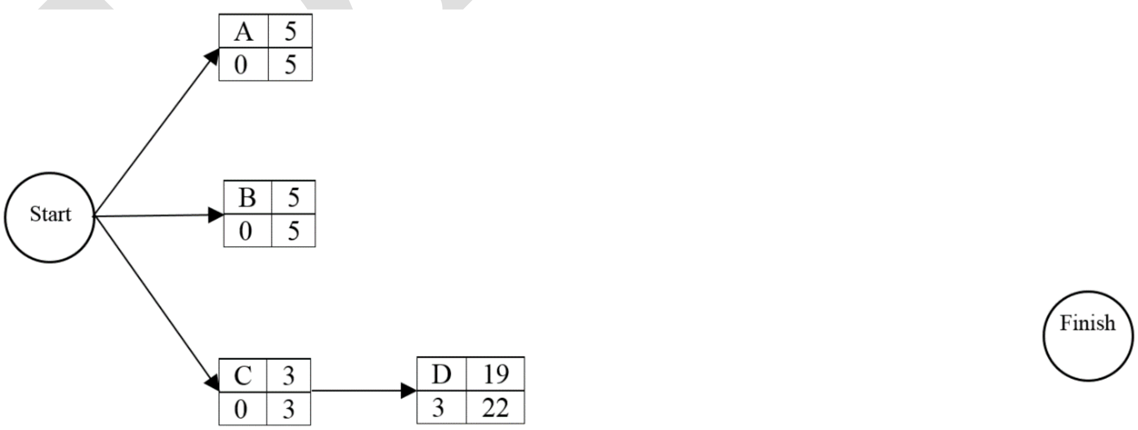
ID	Duration
Start	Finish

Formats will vary across different sources.

Network diagrams begin with the start node at the left edge. The next step is to add activities that do not depend on completion of a previous activity. This is completed in the diagram below.



Now, add in activities depending on a previous activity. The activity's start time will be the end time of the previous activity, and the end time can be determined from its duration.



Complete the diagram above by placing the remaining activities. What happens when an activity has multiple preceding activities?

After all activities are added, the activity or activities that have no activity depending on their completion are connected to the finish node. The finish time of the project should be written in the finish node. The project is complete when the last activity has ended.

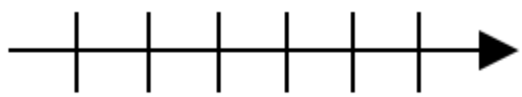
Determine the Critical Path

Definitions

Path - A sequence of activities in the networking diagram

Critical Path - The path through the networking diagram from start to finish with the longest total time. This determines the project's duration.

Determine the critical path by starting at the finish node and moving backwards to the start node. When there are two or more preceding activities to choose from, as there are at the finish node, choose the one with the latest finish time. Mark the arrows between activities you encounter as follows:



Identify the critical path on the diagram above.

Station Design

Student Worksheet

Consider the following table of activities to construct a railway station.

Activity	Activity identifier	Preceding activities	Duration (days)
Foundation	A	-	30
Core structure	B	A	16
Roofing and siding work	C	B	20
Install windows	D	C	5
Electricity	E	B	12
Plumbing	F	B	10
Insulation	G	E, F	4
Install interior walls	H	G	10
Finish flooring	I	G	14
Plumbing and electrical fixtures	J	H	7
Painting and décor	K	I, J	5
Shops set-up	L	D, K	4

Create a network diagram for this simplified building schedule of a station.

What is the total time estimate for the project? Which activities are on the critical path? Mark the critical path on your diagram.

Questions

Consider these questions independently of one another, working from the initial schedule. (When looking at the flooring strike, do not consider the safety violation in the electrical work.) Keep in mind how you arrive at your answers.

1. The inspection of the electrical work reveals a safety violation that takes three days to fix. How does this impact the total project time?

2. The workers hired for the flooring go on strike, causing a delay of four days. How does this impact the total project time?
3. Under pressure to finish the station, one of the managers brings in a larger and more efficient crew to install fixtures, reducing the time required from seven days to two. How much time is saved by this over the entire project?
4. There is a shortage on the materials used for siding on the station's exterior. How many days can the siding be delayed by without delaying the entire project?

Float Time

Student Worksheet

Delays are part of any large project. It is important to know how a delay will impact your project's schedule, and be able to find this information easily even in a project with many activities.

To expand the networking diagram to reflect how long an activity can be delayed without slowing the project, a new node format is needed:

EST	ID		EFT
LST	DUR	Float	LFT

Definitions

EST and **EFT** - Early start and finish time estimates for the activity. These are the start and finish time estimates calculated previously.

LST and **LFT** - Late start and finish time estimates for the activity. These are the latest time values for the activity to start and finish without delaying the project's finish time.

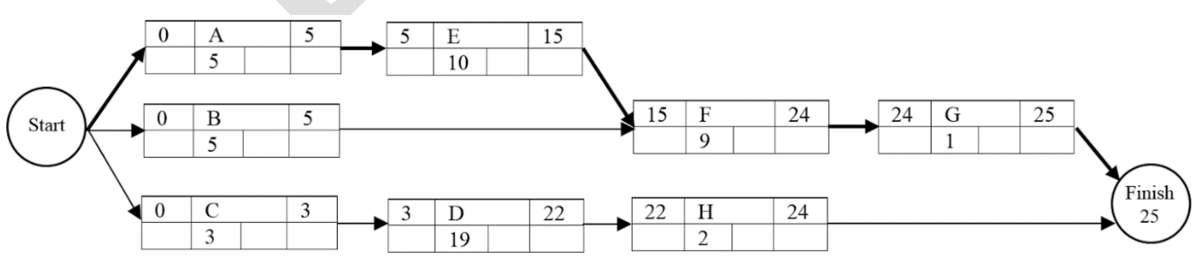
Float - The amount of time that an activity can be shifted by without delaying the project's finish time.

Theater Example, Revisited

Calculate the LFT and LST for each activity, then the float. Start with G and H, and work towards the start. The LFT for G and H is 25.

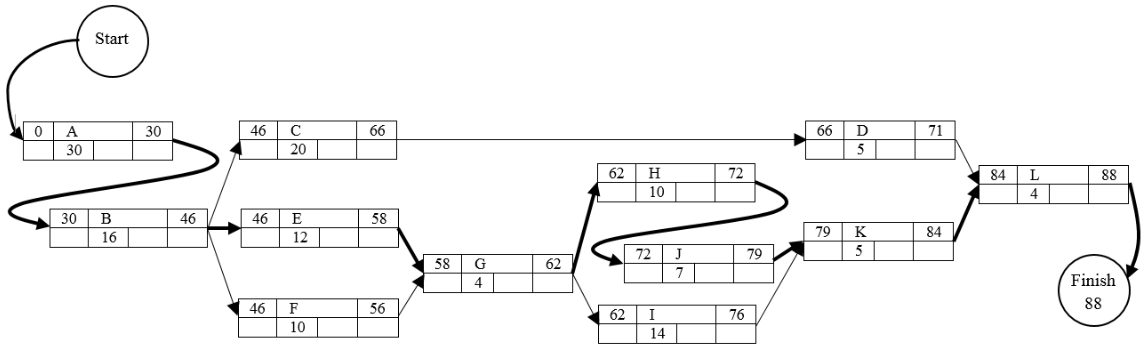
Find the LFT and LST for G and H. From the definition of float given above, what is the float time for G and H? What is the calculation you are using to determine float?

What happens when an activity has multiple activities depending on its completion, as in the start node?



Now Try On Your Own

Determine the LFT, LST, and float for each activity in the diagram below, which represents the station design project, in your company.



Critical Path Method Supplemental Explanation

Teacher Reference Sheet

This example determines the total time required to produce a theater performance.

Define the Activities, Dependencies, and Durations.

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Choose designers	A	-	5
Choose crew	B	-	5
Choose cast	C	-	3
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Technical run-through	G	F	1
Actor run-through	H	D	2

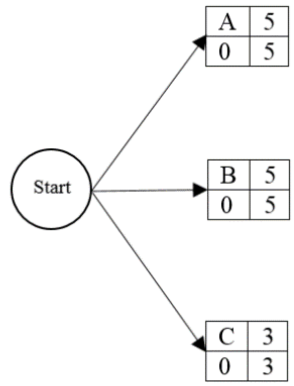
Create a Network Diagram

Each activity will be represented by its letter ID, the earliest time it can begin, the time it will finish, and its duration, in the following format:

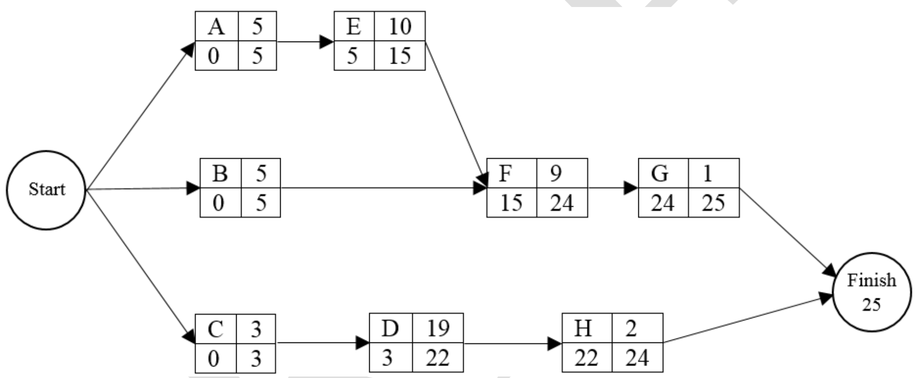
ID	Duration
Start	Finish

Formats will vary across different sources.

Place the start node at the left edge of the diagram. Add activities that do not depend on completion of a previous activity. The finish time for an activity is the sum of its start time and duration.

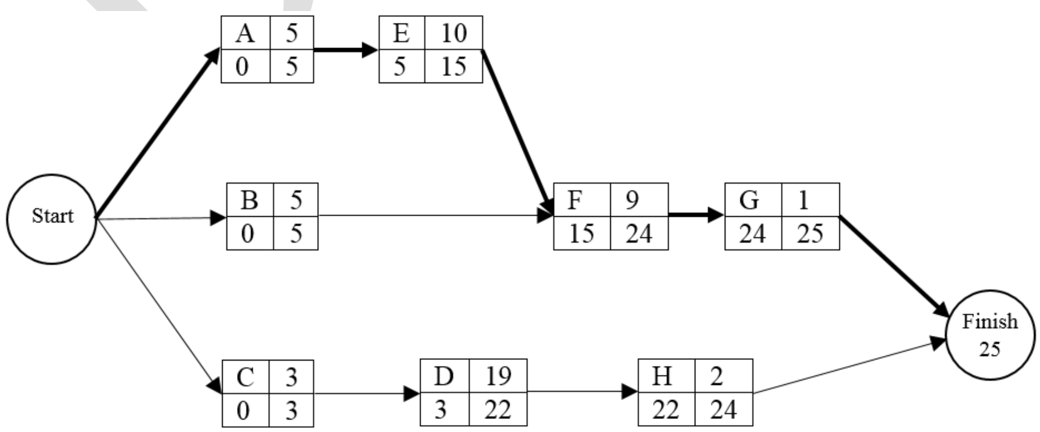


Add in activities depending on a previous activity. The activity's start time will be the end time of the previous activity. If an activity has more than one preceding activity, use the maximum of their end times. After all activities are added, the activity or activities that have no activity depending on their completion are connected to the finish node. The finish node has the finish time of the project, determined by the maximum end time of the activities leading to it.



Determine the Critical Path

Determine the critical path by working backwards from the finish node, to the start node. When there are two or more preceding activities, choose the one with the latest finish time. The critical path is marked in bold below.



Float Time Supplemental Explanation

Teacher Reference Sheet

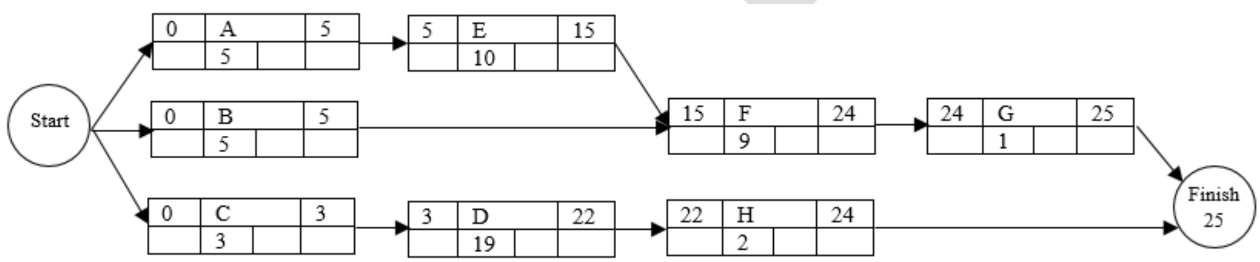
To expand the networking diagram to reflect how long an activity can be delayed without delaying the project, a new node format is needed:

EST	ID		EFT
LST	DUR	Float	LFT

EST and EFT are the early start and finish time estimates for the activity. These are the start and finish time estimates calculated previously.

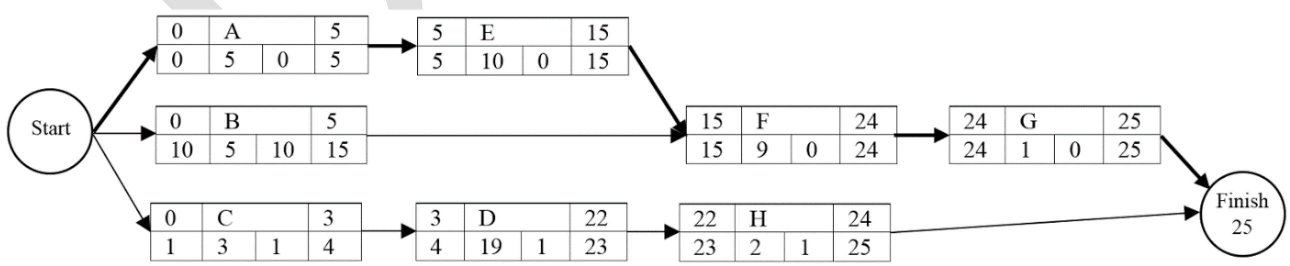
LST and LFT are the late start and finish time estimates for the activity. These are the latest time values for the activity to start and finish without delaying the project's finish time.

Float is the amount of time that an activity can be shifted by without delaying the project's finish time.



Working from the finish backwards, the LFT is determined by the LST of the activity directly after it, or the finish time if it has no subsequent activity. If an activity has multiple subsequent activities, use the one with the earliest LST. The LST is the difference between the LFT and the activity's duration, and the float is the difference between the EST and LST.

For reference: LST = LFT - duration; Float = LST - EST



Activities that are on the critical path will have a float time of zero. Any delay on the longest sequence of activities will cause a delay in the project's completion. If an activity does start late, the float for other activities may be affected. In this case, if C is delayed by one time unit, then D and H will be starting at their late start times, and have zero float.

Citation(s)

- A Brief History of Scheduling: Back to the Future. (2006, April 1). Retrieved May 20, 2015, from http://www.mosaicprojects.com.au/PDF_Papers/P042_History of Scheduing.pdf

- Basic CPM Calculations. (2014). Retrieved June 8, 2015, from http://www.mosaicprojects.com.au/pdf/schedule_calculations.pdf

- Michallon, A. (2005). Xth Winter Olympic Games Official Report. Retrieved June 4, 2015, from http://library.la84.org/6oic/OfficialReports/1968/or1968.pdf

Session 9: Show Time

There are no additional resources for this activity.

Session 10: A Journey Back in Time

There are no additional resources for this activity.

Full Speed Ahead!

{Letter to the London Transport Museum Program Coordinator}

To whom it may concern,

The Full Speed Ahead Program (FSAP) is designed to inspire year 10 and 11 students to pursue a career in engineering through hands-on activities and connections to the London Transport Museum's (LTM) rich collection. There are ten sessions, including a visit to the museum galleries. Teachers may choose to use any number of the sessions, which combined will have students create a train and a track with a bridge, tunnel, and station, among other tasks. We believe this curriculum will inspire students to pursue engineering, and empower them with the confidence to do so, as well as show them the breadth and depth of engineering as a field.

Our development of the program included input from educators, engineers, and students in a small-scale pilot of the most challenging sessions, as well as members of the LTM's Learning Office. We recommend that you meet with teachers who use the program to gather feedback on what went well and what should be improved; for example, you may hold a focus group, visit participating classrooms, or collect information via phone or email. These comments, paired with the recommendations included in our final report, could be used to improve the FSAP over time.

We have suggested handling objects for each session that can help enhance a student's experience in the FSAP. Engineering Ambassadors from Transport for London could bring one or two of these objects to classes using the program to further engage them in real-world engineering challenges. These suggested items should be set up in a box, which has an inventory sheet, the objects to be used, and a laminated sheet for each object with a picture and some notes for Engineering Ambassadors to invite a discussion with students on the features of the object. A list of the suggested handling objects and relevant exhibits at the LTM is included here:

Session	**Handling Object/Link to LTM**	**Sign in**	**Sign out**
Business As Usual	Frank Pick Metroland Exhibit Metroland Door Handle Johnston Woodblocks (T&E)	N/A	N/A
Train of Thought	Composite Conductor Rail Fact Sheet (T-06) Pandrol Clip Fact Sheet (T-02) (T-16) Pressure Switch Fact Sheet (T-11) (T-12) Rail Fastenings Fact Sheet (T-01) (T-13) (T-14)		
Mixed Signals	Capacitors (E-07) (E-08) T-Piece Fact Sheet (T-05) Hawkbox Tuning Unit Component Fact Sheet (S-17) Indication Contact Arrangement Fact Sheet (S-13) (S-14) Indicator Push Rods Fact Sheet (S-0.5.1) (S-0.5.2)		
Rail Lines and Line Graphs	Relay Fact Sheet (S-15) (S-16) Wiring Cables Fact Sheet (S-01) (S-02.1-2.9) (S-18.1) (S-18.2) Unicoder Communication System for London Bus Services		
Mind the Gap	Post Tensioning Cable Fact Sheet (C02)		
Tunnel Vision	Concrete Fact Sheet (C-01) Link to Tunneling Exhibit at LTM		
Station Fixation	Water Meter (C-07)		
Time is of the Essence	Microprocessors / Heatsinks (E-01) (E-06) Random Access Memory (RAM)		
Show Time	N/A	N/A	N/A
Journey through Time	Refer to Session 10 of the Teacher Handbook	N/A	N/A

LTM Handling Objects and Exhibits that match with the FSAP Sessions

The handling objects are used in the collection to help students not only understand the evolution of transportation technology but also understand how engineering solutions are changed over time. Please refer to the LTM's accompanying handouts for detailed descriptions about each of these objects.

Your role in keeping these objects available for use in the FSAP and gathering feedback for its improvement is appreciated.

Sincerely,

Lauren Baker

Casey Broslawski

Cameron Crook

Shannon Healey

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