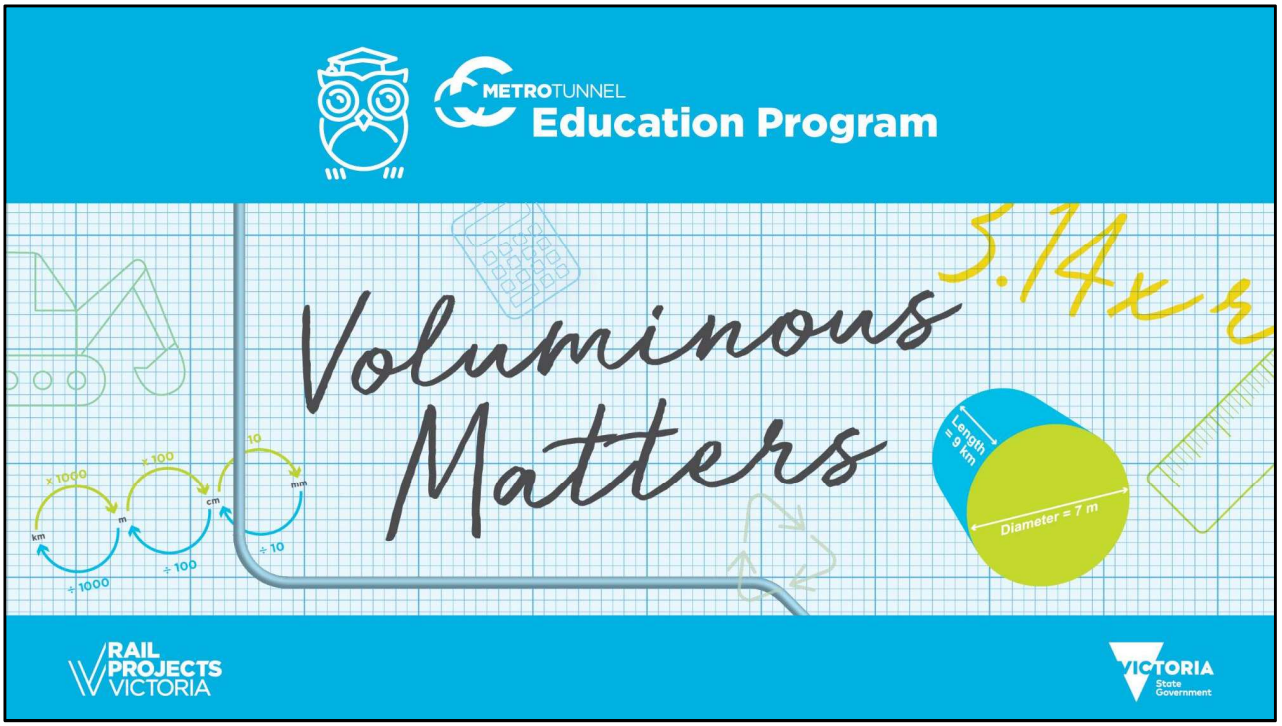


Welcome to Voluminous Matters!
A “real world” soil engineering workshop calculating the volume of spoil to be excavated and determining the logistics of removal, including “wicked” factors such as cost, environmental impact and local transport conditions. The maths is very straightforward, involving calculating the volume of cubes and cylinders, but students do need to have been exposed to the concept of Pi.

We have run it successfully with students in Years 7-10 but you do need to move about the room when they are doing the calculations to keep them on task – particularly when they calculate the volume of a cylinder to determine the amount of excavated material to be removed for each of the tunnels.

The activity takes around 60 minutes with time to discuss and demonstrate, but you could split it over two lessons, doing the volume calculations first and saving Part 2, the trucking logistics, for a follow up session.

Class Kit

- PPT slides
- PDF with slides and these teacher notes for your reference

- Enough copies of the Student Worksheets (note they are A3) – this lesson works well with students working in groups of 2 and 3
- Calculators - ideally one per student so they can check answers internally before sharing with the class
- Pens

Optional: create you own bulking factor demonstration model. We used pompoms in a food storage container, but something like cotton wool balls in a poster mail cylinder would work just as well (scrunched up newspaper even). All you need is something that can be compacted into a container which then gets a whole lot bigger (fluffier!) when removed.

THE METRO TUNNEL PROJECT

Set the context

1) Establish the context for the exercise by introducing the Metro Tunnel Project.

You may have seen and heard a few things about Metro Tunnel – this huge project is building a new train network underground for the future.
THE METRO TUNNEL WILL FREE UP SPACE IN THE CITY LOOP TO RUN MORE TRAINS TO AND FROM THE SUBURBS, BY TAKING OUR BUSIEST TRAIN LINES THROUGH A NEW TUNNEL UNDER THE CITY.
That means more trains, more often across Victoria, with a less crowded and more reliable train network.
Work to build the massive 9km twin rail tunnels and five new underground stations is underway.
The Sunbury and Cranbourne/Pakenham lines will be upgraded with next-generation High Capacity Signalling to allow more trains to run more often and more reliably.

There are a couple of short videos on our Education webpages that will help

contextualise the exercise:

- **Introducing the Metro Tunnel** (this one even comes with a quiz)
- **How are we building the Metro Tunnel?** Explains how road headers and tunnel boring machines work, including some great shots of our underground works

And our **9 stages of construction** puzzle is also a fun way to introduce students to the scale of the project. Note just how much work needs to be done before we even start tunneling!

In this lesson we are going to consider how an engineer might work out how much earth will be excavated for the project and then experience the problems a logistics manager would encounter with removing that material.

2) Pose the question: **Exactly how much earth will need to be excavated to create the twin 9 km tunnels and five new stations?**
This is something the engineers would need to know from the start, so they could plan, cost and create timelines for the project

Teacher insights
Actually we prefer the term “excavated material”. It’s not just earth or soil that comes out of the tunnels, at the depths we’re dealing with our machinery encounters solid rock which it crushes into rubble.

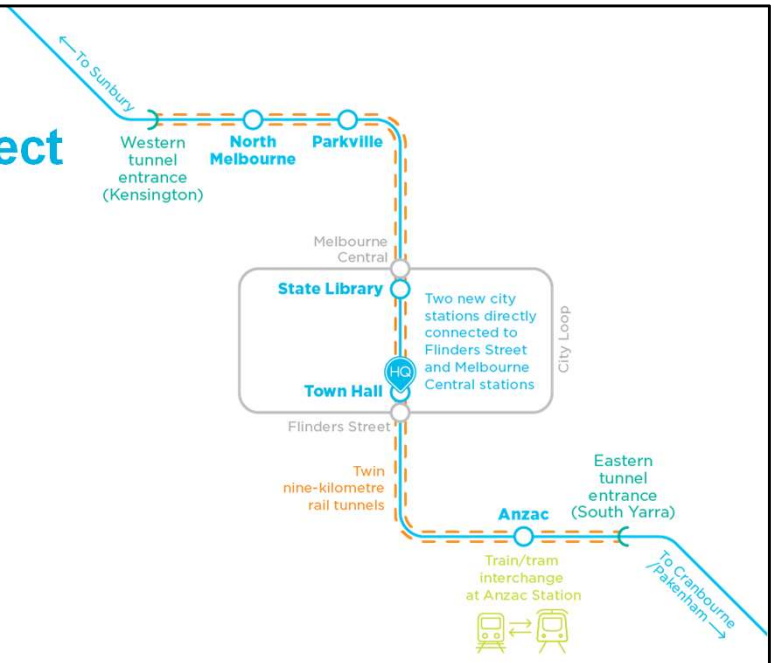
Another term you’ll hear used is “spoil” but that’s also a bit misleading.

At some point in this lesson at least one of your students is going to ask “Where does it all go?” And fair enough. It’s not just waste. Much of the excavated material from works such as this can be reused. It can be repurposed into bricks but chiefly it gets used in other large scale building projects such as freeways.

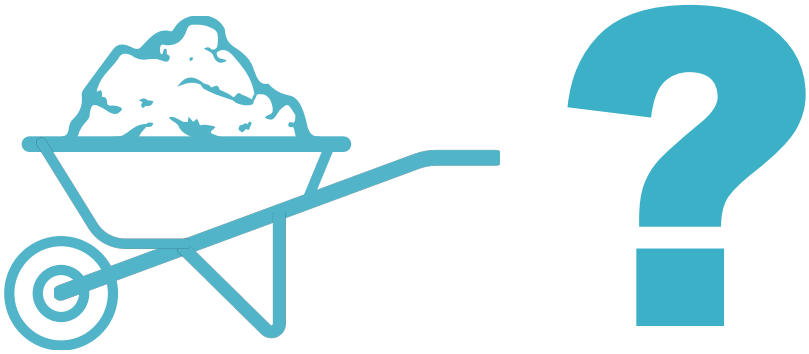
Imagine you’re building a freeway but the route encounters some steep terrain. That’s not good. Vehicles need to slow down and change gears to travel up and down hills and that defeats the purpose of a road designed for smooth travel at speed. It’s also not efficient in terms of petrol use (emissions) and vehicle wear and tear. Excavated material from projects like the Metro Tunnel can be used to back fill a sharp incline, turning it into a gentle slope or fill out a sharp bend so that it becomes a wide curve. That takes a lot of excavated material but your students are about to calculate some very big numbers!

About the Metro Tunnel Project

1. • 9 km twin tunnels
2. • 5 new stations
3. • 7,000 jobs



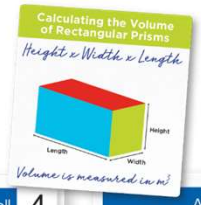
How much material will be excavated to build the tunnels and stations?

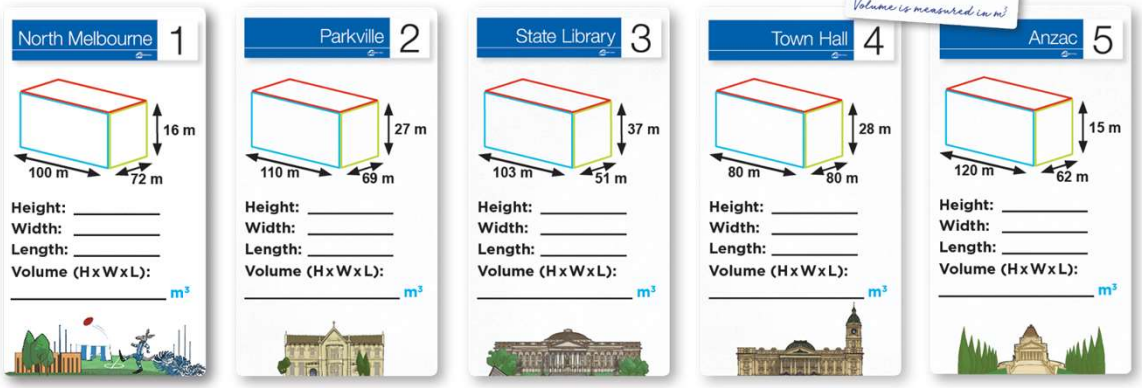


Part 1- How much dirt?

- Distribute the two **How much soil needs to be excavated worksheets**
- Your class are soil engineers estimating the total amount of excavated material to be removed
- Working in 2 or 3's, students calculate the totally amount of soil to be removed
- So that we all get the same answers use 3.14 for Pi (not your calculator function, even if it has one!)
- Allow 15 minutes for this activity

How much will be excavated for the stations?





Now work out the volume of the tunnels.

Teacher insights

Most students find it relatively easy to calculate the volume of the 5 station cubes. The figures used here are approximate to the actual scale of excavation for the Metro Tunnel - although our “station boxes” (that’s what we call the underground caverns that will hold the new stations), are not perfect cubes.

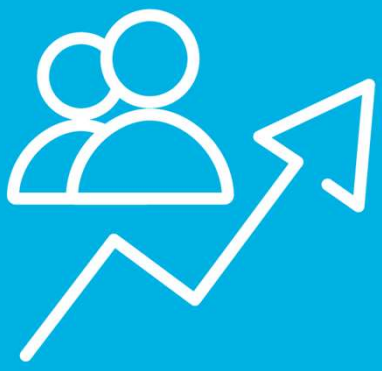
Teacher insights

This worksheet is a little trickier and you may need to work the room reminding students how to calculate the volume of a cylinder.

We've included a couple of deliberate "traps" in this part of the exercise – although there are prompts on the worksheet to call them out.

- **Remember to use 3.14 for Pi so everyone gets the same answer**
- Students will need to *halve* the diameter of the tunnel to get its radius in order to calculate the Area of the TBM face
- The length of the tunnels is stated in *kilometres* - they'll need to translate this into *metres* (x 1000) to get the volume of one tunnel
- Have they calculated the **Total volume of both tunnels** - *or just one*?

VOLUME ANSWERS



Volume answers

Volume of stations:

North Melbourne 1	Parkville 2	State Library 3	Town Hall 4	Anzac 5
16 x 72 x 100 =	27 x 69 x 110 =	37 x 51 x 103 =	28 x 80 x 80 =	15 x 62 x 120 =
115,200 m^3	204,930 m^3	194,361 m^3	179,200 m^3	111,600 m^3

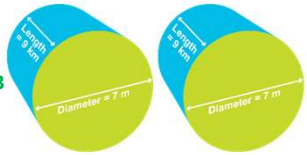
Volume of tunnels:

Diameter of the TBM head is 7 m, so radius of TBM head is: **7 ÷ 2 =** 3.5 m

Area of the TBM head is: **3.5 x 3.14 =** 38,465 m^2

Volume of one tunnel is: **38,465 x 9,000 =** 346,185 m^3

Volume of two tunnels is: **346,185 x 2 =** 692,370 m^3



Add it all up: **115,200 + 204,930 + 194,361 + 179,200 + 111,600 + 692,370 =** 1,497,661 m^3

Students share their answers and agree on a final figure

Teacher insight

Most tables/desks are around 70 cm high, so it's relatively easy to demonstrate in the classroom what 1m3 looks like. This can be a useful way to get students to understand the scale of what we are dealing with here!

Total Volume Answer

1,497,661 m^3

but …

Here's where you do the big reveal!
Guess what- you're all wrong!

… the engineers are working with a figure of:

1,800,000m^3

Cue groans and outrage. You made us do maths and then we got it all wrong!

But wait a minute… **we all got it the same wrong**… something else is going on here.

Why are the soil engineers on the Metro Tunnel Project working with a figure of 1,800,000m3?

LET'S PLAY!

Use the images in the following slides or your own demo model to show how the volume of the tunnels and stations themselves is different to the volume of the excavated material to be removed in order to create them.

Student's initial estimate of the number of truck loads required will often be under 15 and well short of the mark!

Once they see the impact of three truck loads and how the extracted material takes up more room in the container, they'll quickly adjust their estimates.

Teacher insight
When the **COMPACTED** material is broken up into rubble and mixes with air, it takes up more space. Soil engineers typically calculate a "**BULKING FACTOR**" to get a better estimate of just how much excavated material will need to be removed from a site. The bulking factor adjustment they make depends on the nature of the ground conditions they're dealing with.

So what we have learned here is that there can be a difference between maths in the

“real world” and the calculations we do in the classroom (or in an exam- please students do not get smart and add a bulking factor to your calculations in an exam! The marker just won’t get where you’re coming from!)

Guess how many truck loads to empty the tunnel?

1 truck load…

3 truck loads… hmmm…wanna change your estimate?

1,800,000m^3 is roughly equal to…

Coffee Cups

7,000,000,000

Olympic–size Swimming Pools

80

MCG

1

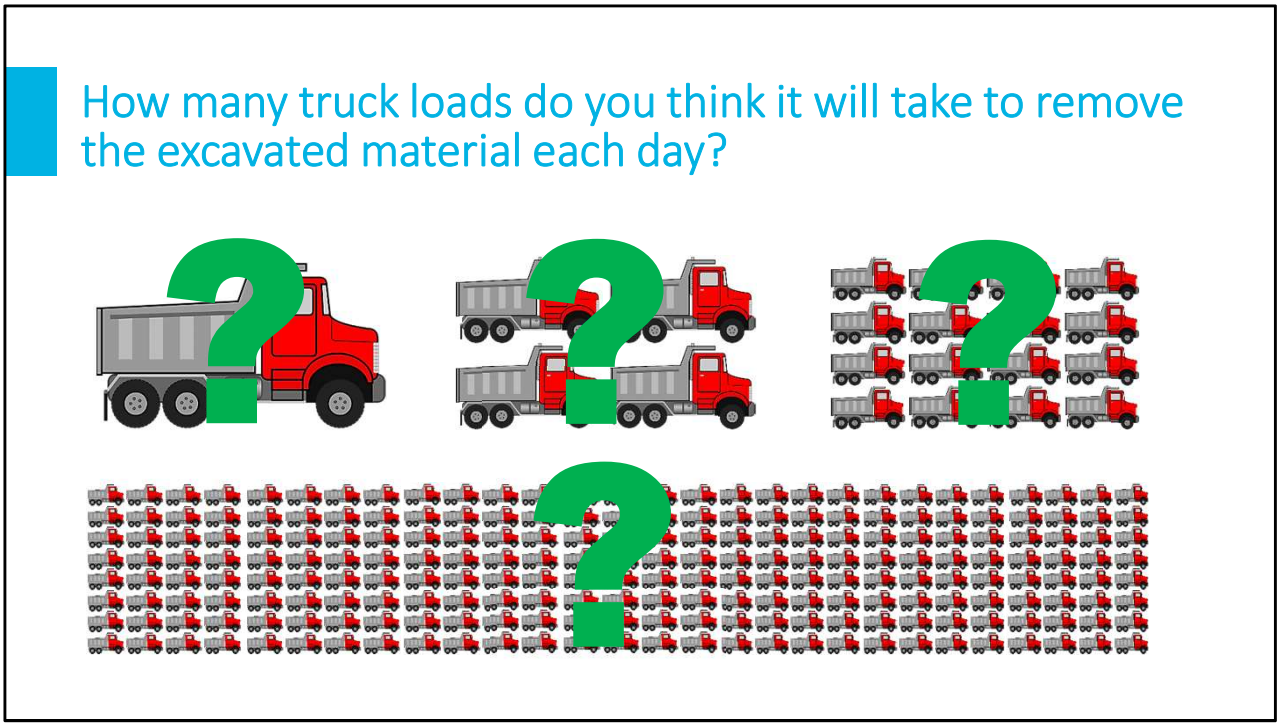
Teacher insight
You can get your students to try and guess these .

It's quite fun to realise that the amount of excavated material removed for the Metro Tunnel Project would be enough to fill one regular sized coffee cup for **everyone on the planet!**
(although that would be a lot of recycle waste!)

It's actually 1 MCG filled right to the top with a bit overflowing- imagine a gigantic dirt Dixie Cup!

That's not only a lot to dig out, it's a huge amount to dispose of too!

PART 2



Part 2: Logistics

This part of the exercise could be saved for follow up lesson.

Now we move to the part of the exercise where we calculate how many trucks we'd need to remove the excavated material each day.
It can't just all pile up on site!

- Distribute the 3 truck worksheets (how we love that the huge double one is known as "a truck and a dog"!)
- **The class is now a haulage company working out the cost of removing 3000m3 of excavated material per day** (that's about how much we will be excavating each day when the tunnel boring machines are in full swing)
- Students can do one sheet each - the mathematics here is straightforward
- Allow 10 minutes for this exercise

Logistics answers

Truck 1:
10 Metre Tipper

Number of Trucks:
32

Cost of the Truck:
$915

Total Cost per Day:
$29,280

Truck 2:
Semi Tipper

Number of Trucks:
25

Cost of the Truck:
$1,168

Total Cost per Day:
$29,200

Truck 3:
Truck with Dog Trailer

Number of Trucks:
17

Cost of the Truck:
$1,743

Total Cost per Day:
$29,631

Teacher insights

The Semi-Tipper is cheapest but what else might the company need to factor in to a decision about which truck to use?
The notes on each truck worksheet will help you identify the strengths and weaknesses of each choice

Extension activity
If you have time (or some students finish early) it can be fun to calculate how many days work it would to remove all the excavated material

1,800,000 / 3000 = 600 days (that's about two years work – and incidentally that's about as long as the tunnelling component of the project will take)

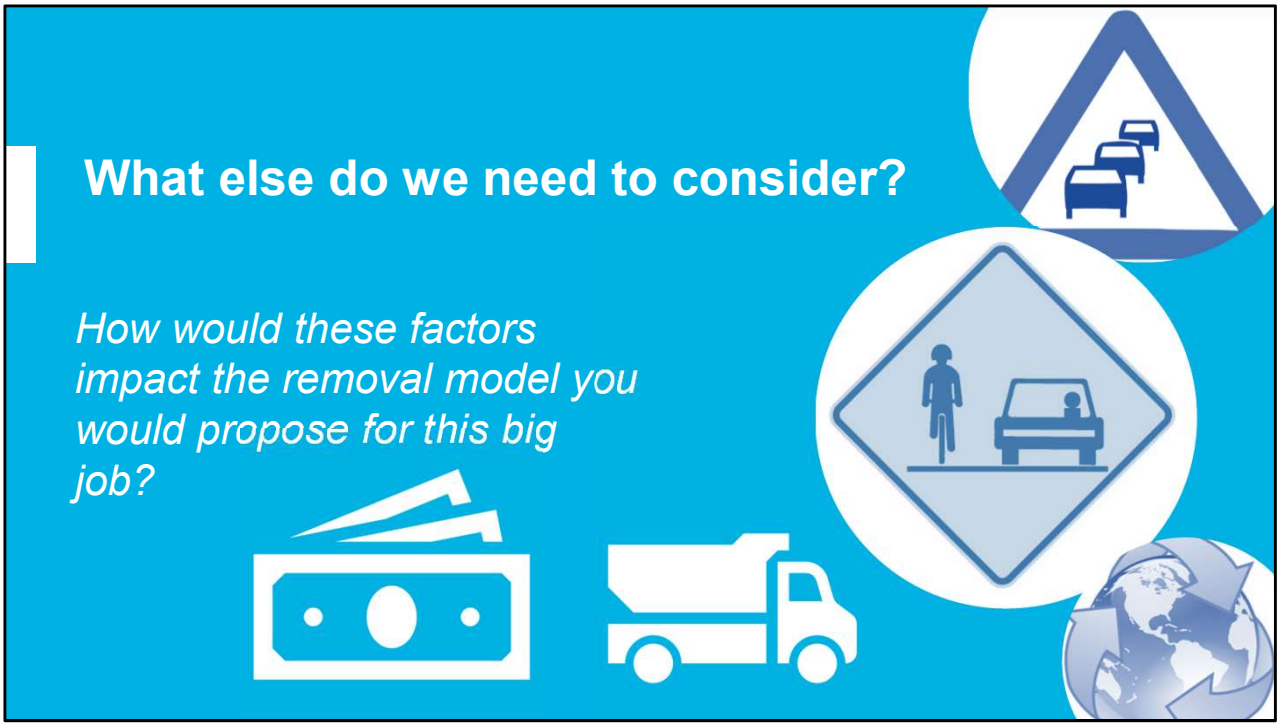
So how much would that cost?
Let's go for round figure of $29,500 per day
WOW!

That’s $17,700,000

But wait … that’s what it’s costing you as a logistics and haulage company to do the job!
What are you going to charge the Metro Tunnel Project for this work?
You want to make a profit don’t you?
You’re not a charity!

And that’s when the lights come on and at least one student in the class doubles the amount and starts thinking they’re Lindsay Fox.

Which we love - because logistics is a fascinating career which doesn’t necessarily get a lot of attention in a classroom setting ;)



This is an open discussion – direct student back to the information about each vehicle on their worksheet. Students should debate the best truck option taking into consideration factors such as:

- Cost
- Congestion – and what if your company was restricted to only certain hours of the day to restrict this?
- Safety
- Environmental factors
- Labour supply
- Where is the excavated material being moved to? Did anyone ask that?

What we are learning here is that although the maths to calculate cost of an can be quite straight forward, there may be additional factors to consider and cheapest may not be best (or even stay cheapest) in the long run.

Logistics is about solving the “wicked” problems of doing business.

It doesn’t just take maths skills – and sometimes the maths parts are relatively

straightforward - you need to be able to balance 'cost' against the impact of other considerations to find the best way forward.

Teacher insights

The difference in cost per day to remove the dirt is fairly similar no matter what truck you use.

So which one would you pick?

The Semi-Tipper is cheapest but could it get into tight spaces or deal with narrow city streets
The 10 Meter Tipper is the most nimble but you'd need a lot more of them:

- More drivers to manage
- More congestion
- Statistically a greater chance of more accidents
- And these trucks have higher emissions ☹

The Truck and Dog is the most efficient over long distances but no way it could get into the centre of the city either

Maybe you need took look at using more than one type of truck?

Extension activity
If you have time (or some students finish early) it can be fun to calculate how many days work it would to remove all the excavated material
1,800,000 / 3000 = 600 days (that's about two years work)

So how much would that cost?
Let's go for an average cost of $29,500 per day
WOW!
That's $17,700,000

But wait … that's what it's costing you as a logistics and haulage company to do the job.
What are you going to charge the Metro Tunnel Project for this work?
You want to make a profit don't you?
You're not a charity!

And that's when the lights come on and at least one student in the class doubles the amount and starts thinking they're Lindsay Fox
Which we love- because where else would they learn about logistics as a career?