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PROJECT CAPITAL CONNECT

BLOTT-MATTHEWS CHALLENGE 2017

REBECCA GALBRAITH, DAVID VAHEY, WILL UDY,
MAX BIRMINGHAM, GUY MULLINS

OAKLANDS CATHOLIC SIXTH FORM COLLEGE

Contents

A Note on Reading this Report

We hope you find this report informative, well-detailed, organised and easy to follow. As an aid to ensure the latter, given below are some pointers as to how we have presented our proposal for solving the problem of the five London airports, as per the brief.

Layout

The report is subdivided per section:

> # AaBbCc
>
> Denotes the title of the section.
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> ## AABBCC
>
> Denotes a major subheading or subsection.
>
> ### *AaBbCc*
>
> Denotes a division with subsections or a minor title for shorter sections.
>
> **AaBbCc**
>
> Denotes key information and table headers.

Navigating sections

In addition to page numbers at the bottom of each page, sections are coded in the top-right margin along with their section title. The codes are identical to those laid out in the contents.

Research sources

Footnotes within the text as superscript numbers link information and researched data to their respective sources. Footnote numbers can be used to navigate all of the collated sources in the 11.1 Bibliography section.

With regards to supporting images and diagrams from external sources, if these are themselves apparently unsourced, you will find them as part of the webpages sourced via footnotes and weblinks in the bibliography.

Introduction

Transport between the 5 major London airports of Gatwick, Heathrow, Luton, Stansted and London City is both time consuming and very expensive using current transport methods such as the London Underground or National Express. Therefore, the brief of our project was to introduce a new method of transport that would reduce both the time and cost of travelling around London whilst linking all five airports together in a 'super-hub'.

In this document, we will outline all the different transport methods we researched, before deciding on a transport method that will best suit the brief - Hyperloop. We will show how the transportation system works, as well as considering human factors including land cost, safety and security surrounding the Hyperloop system, before finally creating detailed costing models to show overall profits at the end of the 20-year project.

About Us

Rebecca Galbraith

I have been both the team's report writer and geologist. Therefore, I have been responsible for all research surrounding geological complications with building a high-capacity transport system in a city short for land space, as well as piecing together all our findings.

I currently study A Level Chemistry, Physics, Geography and Maths. On leaving Sixth Form at the end of next year, I will be going to university to study Geology. Then, following on from my undergraduate degree, I want to go into Volcanology. This will involve a Masters and likely a PhD too. Geophysics within this is particularly interesting because it truly explores how the Earth physically works: seismic waves, palaeomagnetism, geomorphological processes... etc.

David Vahey

I am a student in the first year of A-level studying Maths, Further Maths, Physics and Chemistry with the hope of pursuing a Chemistry masters in higher education. In this project, I have been focusing on the logistics and costing of the project which played to my strengths as it relied on solving logic problems and other calculations. Outside of the classroom I play clarinet, saxophone and piano and I am in a range of bands both in and out of school.

Will Udy

I am a Year 12 student studying Maths, Physics and Chemistry at A Level. Throughout the project, I have been particularly interested in researching the various technical options within mechanical and civil engineering and the associated costings - I am currently investigating future career paths in engineering. Apart from study, I am a keen cricketer and musician – playing the piano and euphonium. It has been very enjoyable to work on a project as part of a team, with the ability to share and discuss different ideas.

Max Birmingham

Alongside Guy, I have tackled the task of understanding and explaining the mechanics of the Hyperloop project. Over time, I have conducted research into how every little contraption will come together to form a fully functional sonic-speed transport system. This has involved adopting and combining different mechanical ideas to come up with a final piece which is structured, and logical.

As for ambitions and future aspirations, civil engineering and things incredible to even think about being put into existence have taken my eye, hence my will to take up this interesting project, topic of transportation methods.

Everything so far along the journey of this project has been highly beneficial to myself, working well alongside great contribution and input from the team.

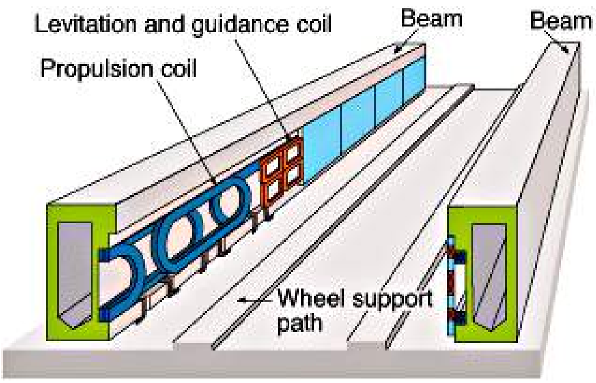
Guy Mullins

I am 16 years old studying Maths, Physics, Chemistry and Geography. In the future I am aiming to go to university in order to study mechanical or chemical engineering and then follow this in an engineering carrier. I also enjoy playing many sports including hockey, tennis and cricket.

In this project, I have helped with the cost of the land and the housing. I was particularly interested in the mechanical engineering part of this project. I really appreciate the opportunity to work with a team.

Advanced Modern Transportation Systems in Use

The pages in this section document our initial research into current but new (and therefore highly advanced) systems of public transportation, in order to help inform our decision for the Capital Connect proposal. Each of the researched options were compared until we came to that which we thought superior.



Maglev Trains

How Stuff Works: Maglev Trains [1]

The magnetized coil running along the track, the **guideway**, repels the large magnets on the train's undercarriage, allowing the train to levitate between 1 to 10 centimetres above the guideway. Once levitated, power is supplied to the coils within the guideway walls to create a unique system of magnetic fields that pull and push the train along the guideway. The electric current supplied to the coils in the guideway walls is constantly alternating to change the polarity of the magnetized coils. This change in polarity causes the magnetic field in front of the train to pull the vehicle forward, while the magnetic field behind the train adds more forward thrust.

Maglev trains float on a cushion of air, eliminating friction. This lack of friction and the trains' aerodynamic designs allow these trains to reach unprecedented ground transportation speeds of more than **310 mph**, or twice as fast as Amtrak's fastest commuter train.

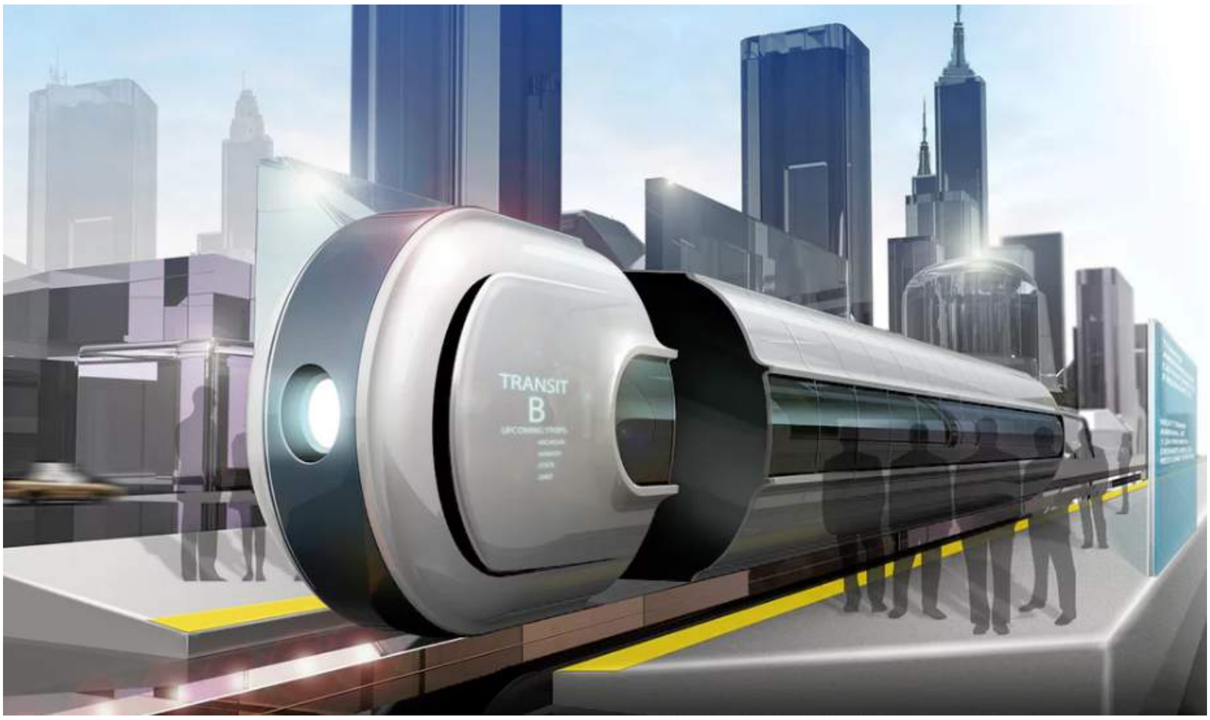
In comparison, a Boeing-777 commercial airplane used for long-range flights can reach a top speed of about 562 mph. Developers say that maglev trains will eventually link cities that are up to 1,000 miles apart. At 310 mph, you could travel from Paris to Rome in just over two hours.

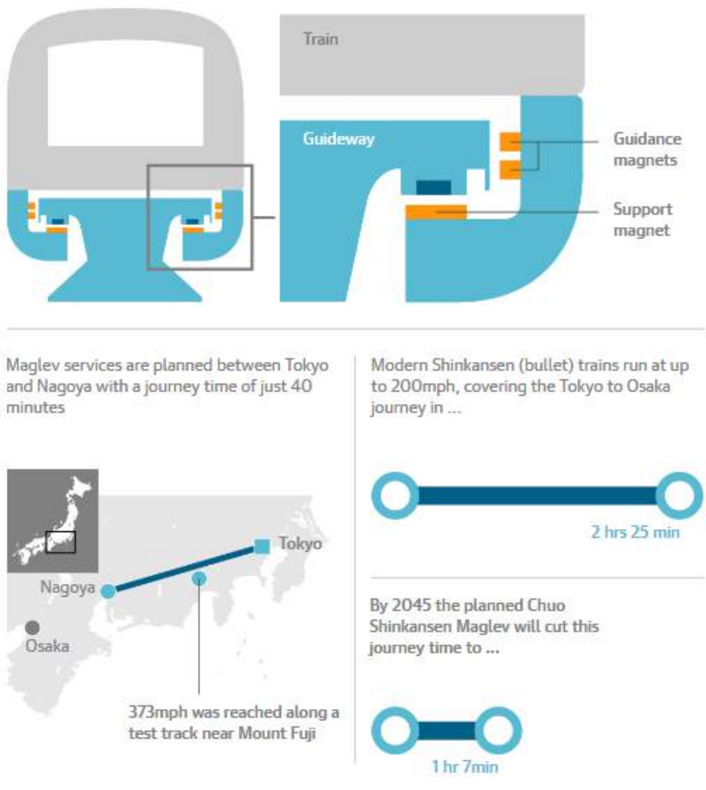
Wikipedia: Shanghai Maglev Train [2]

The train line connects Shanghai Pudong International Airport and the outskirts of central Pudong where passengers could interchange to the Shanghai Metro to continue to the city centre. It cost **$1.2 billion** to build. The Shanghai Maglev has length 153 metres, width 3.7 metres and height 4.2 metres. Its passenger configuration is 574.

The Guardian: Industrial Design Future Transport [3]

Magnetic Levitation technology will be standard in most major cities (within the next 50 years). Reduced friction allows for higher speed and lower power consumption. Thus, commuter distances increase. What appears to be a singular tram is individual partitioned units allowing for a more private form of public transport. The segmented aspect of Maglev cars allows for any private unit to have its own stop agenda, moving aside to allow the rest of the train to continue. Passengers disembark without inconveniencing other commuters.





The Guardian: Japanese Maglev Train Speed Record [4]

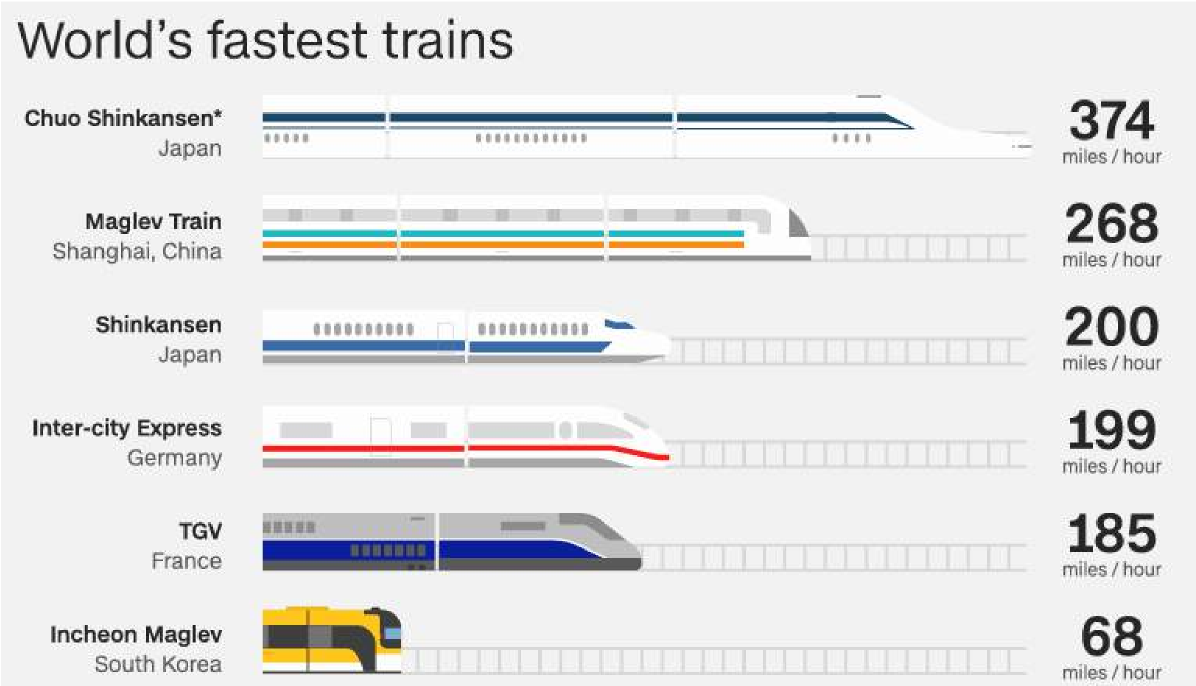
Japan has again demonstrated its prowess in high-speed rail travel with its state-of-the-art maglev train setting a world record of just over 600kph (373mph), just days after it broke its previous 12-year-old record.

The seven-car maglev – short for "magnetic levitation" – reached a top speed of **603kph** on Tuesday during what officials described as a "comfortable" zip along a test track near Mount Fuji. The Lo Series train, carrying 49 Central Japan Railway employees, covered **1.8km in just under 11 seconds at over 600kph**, the company said and "The ride was comfortable and stable."

By 2045 maglev trains are expected to cover the 410km between Tokyo and Osaka in one hour and seven minutes, cutting the journey time in half.

CNN: Japan Record-breaking Maglev Train [5]

The new Japanese maglev became the fastest train in the world after traveling at **374 mph** (603 kph) on a test run near Mount Fuji last year, breaking its own world record of **366 mph** (590 kph), set the previous week.



Source: CNN, November 2016

Hydrogen Trains

Wikipedia: Hydrail [6]

Hydrail is the generic term denoting all forms of rail vehicles, large or small, which use on-board hydrogen as a source of energy to power the traction motors, or the auxiliaries, or both. Hydrail vehicles convert the chemical energy of hydrogen to mechanical energy either by burning hydrogen in a hydrogen internal combustion engine vehicle or by reacting hydrogen with oxygen in a fuel cell to run electric motors. Widespread use of hydrogen for fuelling rail transportation is a basic element of the proposed hydrogen economy.

Hydrail vehicles are usually hybrid vehicles with renewable energy storage, such as batteries or super capacitors, for regenerative braking, improving efficiency and lowering the amount of hydrogen storage required. Potential hydrail applications include all types of rail transport.

CNN: Germany's Zero Emission Train [7]

The world's first hydrogen powered, emission-free train is set to go into service in Germany in 2017 -- a ground-breaking innovation that could signal the phasing out of heavily polluting, diesel-powered trains.

The first "hydrail", or hydrogen-powered train, will begin transporting passengers on the

Buxtehude-Bremervörde-Bremerhaven-Cuxhaven line in Lower Saxony, in northern Germany, in December 2017, German newspaper Die Welt reported.

Although the first train in operation will only run a short, 60 mile (96 km) route, four German states have signed an agreement with Alstom, the French company that builds the trains, for the purchase of up to 60 additional locomotives, if they are judged a success.

"Alstom is proud to launch a breakthrough innovation in the field of clean transportation," Alstom chairman and CEO, Henri Poupart-Lafarge, said in a statement. "It shows our ability to work in close collaboration with our customers and develop a train in only two years."

Engadget UK: Hydrogen Fuel Cell Train [8]

Hydrogen fuel cells aren't gaining a huge amount of traction in cars, where there's a steady move toward electric. But what about regional railways, where long ranges and a lack of powered rails makes electric trains impractical? Alstom thinks that makes plenty of sense -- the French firm has introduced one of the first hydrogen fuel cell trains, the Coradia iLint. The 300-passenger locomotive can travel up to 497 miles at a reasonably brisk **87mph**, all the while spewing nothing more than water. Hydrogen gives it the freedom to run on non-electrified rails, and it's considerably quieter than diesels -- helped in part by batteries that store unused energy.

There are plans to put it into service relatively quickly. The first Coradia iLint should reach a rail line in northern Germany in December 2017, and it won't be surprising if other customers follow suit. The biggest challenge is infrastructure. Train service operators must upgrade all their relevant garages and stations with hydrogen filling systems, which could be more than a little expensive when spread across an entire rail network.

Hyperloop [9]

This is an advancement to magnetic levitation using aluminium tracks (cheaper than current maglev copper coils) or air pods (cushioned on air) that hurtle through tubes at low air pressures. The lower air pressure results in less air resistance, which means higher speeds can be reached. The entire system is supposedly low energy and self-powering.

Speeds of over **700mph** are suggested for long straight journeys, but there are practical implications that must be considered on a short stop-start journey, such as the acceleration and deceleration sensation that passengers would go through.

At present, Elon Musk has merely announced the Hyperloop is going to be made. There is going to be a 1-mile track built by SpaceX adjacent to Hawthorne, its California headquarters. The plan is to have a competition for students with their various pod designs in the summer of 2016. Following this, if the project goes ahead, Musk will have a route that will connect Los Angeles and San Francisco.

Transportation System Case Studies

Presented below are some case study examples of where public transport is integrated in airport and city transportation systems with the intention of keeping steady flows of incoming and outgoing airport users.

SkyTrain [10]

Vancouver

- SkyTrain is the oldest and one of the longest automated driverless light rapid transit systems in the world connecting Vancouver with the cities of Burnaby, New Westminster, and Surrey. Another line connects downtown Vancouver to the Vancouver International Airport (YVR) and the city of Richmond. Trains run above the ground, easing congestion etc.
- The Expo Line and Millennium Line have a punctuality record of over 96%; passenger interference with train doors is a principal cause of delays.
- SkyTrain uses the world's longest bridge dedicated to transit services. Skybridge crosses the Fraser River between New Westminster and Surrey. It is a 616 m (2,021 ft) long cable-stayed bridge, with 123 m (404 ft) tall towers.
- 117.7 million Used the SkyTrain service in 2014.

H Bahn [13]

Dortmund University

- The H-Bahn ("Hängebahn", or "hanging railway") in Dortmund and Düsseldorf is a suspended, driverless passenger suspension railway system.
- The system can operate on a schedule or on-demand, whereby a passenger requests a carriage via the push of a button like with an elevator. The maximum speed is 50 km/h. Runs on a monorail.
- Carries more than 5,000 passengers a day at the University of Dortmund. Total length of tracks 3km – links to public transport too.

“L” [12]

Chicago

- It has a series of metro lines raised above the ground, with a total track length of 165 km, across 8 tracks.
- Top speed 55mph.
- O’ Hare airport (more info in ‘Current Airport and Inter-Airport Links) is a part of this system, and it is also linked to Midway International airport via the “L” system.
- 2015 passenger numbers = 241.96 million

Current World Airport and Inter-Airport Links

Many cities across the world have are very limited in terms of inter-airport links. Some cities have them but most just have shuttle buses and a select handful have metro trains e.g. New York uses shuttle buses between the two airports. For our purposes, this is too slow a service.

O' Hare International Airport [13]

Chicago, USA

- Internal transport
- Automated metro system

The Airport Transit System (ATS) is a quick and convenient way to get around O'Hare International Airport. The ATS is a free, 24-hour rail system that operates between the three domestic terminals (1, 2 and 3), the international terminal (5), all parking facilities, the Kiss 'n' Fly drop-off point, and the PACE Bus stop.

The ATS is fully automated and spans 2.7 miles, accommodating up to 2,400 passengers per hour. From beginning to end- Terminal 1 to Parking Lot E -the total travel time is just nine minutes. All points on the ATS route system are fully accessible to persons with disabilities, with elevators available at each of the stops.

Tokyo between Narita and Haneda Airports [14]

Located approximately 35 miles from central Tokyo, Narita International Airport is Japan's primary international gateway. Haneda Airport, located closer to the city centre, operates mainly domestic flights to and from the Japanese capital.

STEP 1

Take the **Narita Express train** from Narita Airport into central Tokyo (single ticket £23.27) and then **the Tokyo Monorail** to Haneda Airport (single ticket £1.94). Get off the train at Hama Matsucho station and transfer to the Tokyo monorail, which takes you directly to Haneda Airport. Allow at **least an hour to reach central Tokyo from Narita and then 15 to 20 more minutes to Haneda.**

STEP 2

Ride the Airport Limousine Bus nonstop from Narita to Haneda. Follow the signs in the terminal to one of the bus loading areas, which are in front of terminal 2 and both the north and south wings of terminal 1. Allow 65 to 85 minutes for the journey, keeping in mind that this may increase due to traffic.

Shanghai Airport [15]

China

- Shuttle bus to city centre (10 routes).
- Maglev: The speedy Maglev Train (SMT) Transfer to city get off the maglev in the city centre, where you can get on the subway line 2 – subway line goes to Hongqiao Airport.
- Subway line 2 goes between each airport (Pudong to Honqiao) but is slower than using the maglev train for part of the journey, but involves a change of trains.

Current Prices of Alternative Transport

As part of our research, we have compared the cost of travelling via National Rail [16] and National Express [17] to each of the five respective stations.

Line	Method of transport	Average Peak Fare Price (Adult Single)	Average Off-Peak Fare Price (Adult Single)	Average Travel Time
Gatwick – Heathrow	National Rail	£70.20	£70.20	1h 48mins
	National Express	£25.00	£20.00	1h 10mins
Gatwick – London City	National Rail	£25.80	£14.50	1h 17mins
Gatwick – Luton	National Rail	£30.30	£28.40	1h 42mins
	National Express	£25.90	£20.00	1h 30mins
Gatwick – Stansted	National Rail	£40.10	£39.40	1h 59mins
	National Express	£52.00	£37.50	3h 35mins
Heathrow – London City	Currently there are no direct rail or bus links	N/A	N/A	N/A
Heathrow – Luton	National Rail	£43.30	£43.30	1h 50mins
	National Express	£25.00	£20.00	55mins
Heathrow – Stansted	National Rail	£43.60	£43.60	2h 17mins
	National Express	£27.00	£20.00	1h 30mins
London City – Luton	National Rail	£30.80	£30.80	1h 43mins
London City – Stansted	National Rail	£19.00	£19.00	1h 31mins
Luton – Stansted	National Rail	£41.40	£41.40	2h 00mins
	National Express	£24.00	£16.00	2h 10mins

As you can see, all of the above are both costly and time-consuming journeys for the passenger. It is our aim as part of our transportation system to beat these costs and times, making London transport much more accessible.

London's Existing Transport Links

[18] [19] There are many ways of moving to, from and around London. The main methods for travelling to each of the five major airports include:

Buses and coaches - National Express [17] operates a regularly to and from Victoria Coach Station. Its services run country-wide and encompass major destinations such as Heathrow. Other companies such as Easybus offer regular services connecting the City of London to its airports.

Rail services

- *London Underground* – The tube connects most London-based destinations. However, use of the tube is time-consuming for the commuter as there are multiple stops and change-overs to get to any one place.
- *London Overground* – The London Overground serves a large part of Greater London and parts of Hertfordshire, with 112 stations on several routes. The network forms part of the National Rail network.
- *National Rail Links* [4] – National Rail has a variety of networks connecting major areas.
- *Roads* – Being a major city, London is well connected with roads accessible to the general public and independent transport companies alike.

Gatwick

Time summary from central London:

- Bus / coach = minimum **65 minutes**
- Underground = **55 minutes**
- Overground = **64 minutes**
- Road = **79 minutes**

Buses and coaches: Easybus **route EB4** operates a **regular service** to and from Earls Court/West Brompton. Journey time is **65 minutes**.

National Express operates a regular service, operating **24 hours a day**, to and from Victoria Coach Station, via Streatham. Journey time **65-95 minutes**.

Rail: Gatwick Express operates **4 trains per hour** to and from London Victoria. There is no service between 00:30 and 03:30 from London, and between 01:35 and 04:35 from Gatwick. Other rail operators run services through the night.

Southern Rail operates **3 trains per hour** to and from London Victoria. An **hourly service** operates through the night.

Thameslink operates **up to 4 trains per hour** to and from London Bridge, City Thameslink, Farringdon and St. Pancras International.

Heathrow

Time summary from central London:

- Coach = **35 - 60 minutes**
- Taxi = **30 - 45 minutes**
- Underground veer Piccadilly line = **50 minutes**

National Express offers a **regular service** from Victoria Coach Station.

London City [21]

Time summary from central London:

- Underground = **26 minutes**
- Road = **33 minutes**

Rail: The airport has a dedicated station on the Docklands Light Railway (DLR). Journey times are **18 minutes** to Canary Wharf and **22 minutes** to Bank. Trains run **every 10 minutes** departing Canary Wharf and Bank between 05:30 (07:00 on Sundays) and 00:38 and departing City Airport between 05:28 (07:00 on Sundays) and 00:20.

Luton

Luton Airport is located approximately **30 miles (48km)** to the north-west of London.

Time summary from central London:

- Bus / coach = approx. **80 minutes**
- Rail (combined services) = **68 minutes**
- Road = **74 minutes**

Coach: **National Express** route **A1** operates a regular service **24 hours a day** between Golders Green, Finchley Road, Baker Street (Gloucester Place), Marble Arch, Victoria, and Luton Airport. Journey time is upwards of **70 minutes**.

Green Line route **757** operates a **regular service**, operating 24 hours a day, to and from Luton via Finchley Road, Baker Street (Gloucester Place), Marble Arch and Victoria, for a connection to Luton Airport. Please note that this is not a direct service. Journey time from **90 minutes**.

Easybus route **EB7** operates a **regular service** to and from Baker Street (Gloucester Place) direct to Luton Airport. Journey time from **60 minutes**.

Rail: **Luton Airport Parkway** train station is close to the airport and a **regular shuttle bus** connects the two. Rail passengers can buy through tickets to the airport and other passengers can buy shuttle bus tickets for £1.

Thameslink operate up to **6 trains per hour** to and from St Pancras International, London Bridge, Farringdon, London City Thameslink, and Blackfriars stations. Journey time from **35 minutes**. An **hourly night service** operates to and from St Pancras International and Blackfriars. However, please note there are no trains between approximately 01:00 and 03:00.

East Midlands Trains (formerly Midland Mainline) operate a **frequent service** from St. Pancras to and from Luton Airport Parkway station. Journey time from **21 minutes** between 06:00 (09:00 Sundays) and 23:15.

STANSTED

Stansted Airport is approximately **39 miles (63 km)** NNE of central London.

Time summary from central London:

- Bus / coach = **50 – 90 minutes**
- Rail (combined services) = **61 minutes**
- Road = **63 minutes**

Coach: National Express operates **two separate coach services** between Stansted and central London:

- **A6** operates up to **every 15 minutes**, 24 hours a day to and from Victoria Coach Station via Marble Arch, Baker Street (Gloucester Place), Finchley Road and Golder's Green. Journey time is minimum of **90 minutes**.
- **A9** operates **every 30 minutes** to and from Liverpool Street station and Stratford, 24 hours per day. Journey time **50-80 minutes**.

Terravision operates **three separate coach services** between Stansted and central London, with journey times of **50-75 minutes**.

- **A50** operates **every 30 minutes** to and from Victoria Green Line Coach Station.
- **A51** operates **every 30 minutes** to and from Liverpool Street station.
- **A52** operates **every 30 minutes** to and from Stratford station.

Easybus route **EB2** operates a regular service from Baker Street (Gloucester Place). Journey time from **70 minutes**.

Rail: **Stansted Express** operates up to **4 trains per hour** to and from Liverpool Street station with a journey time from **45 minutes**. Trains from Liverpool Street station commence at 04:10 with the last train leaving at 23:25.

Trains from Stansted Airport commence at 06:00 (later at weekends). Connections from the Tube are also available at Tottenham Hale, which is **11 minutes** from Liverpool Street on the Stansted Express.

HS2 Details

The construction of the line is now forecast to cost **£55.7bn** at 2015 prices, up from the **£50.1bn** estimate that was made two years ago. A Department for Transport (DfT) spokesman said the 11.2pc increase was to account for inflation.

The government fully recognises that a scheme on the scale of HS2 will have impacts on the local environment and communities and we are committed to minimising these impacts and treating those affected fairly.

"We've listened to the views of local people and have made refinements to the route where possible and we are also working with environmental groups as we design the railway." [22]

"We will minimise the local environmental impact of the new railway wherever possible by using tunnels, deep cuttings and existing transport corridors where we can. We will also use noise barriers, landscaping, and other measures to help reduce the visual and noise impacts of the scheme."

Land usage from properties [23]

You can sell your property to the government through the Express Purchase Scheme if:

- Your house or 25% of the total area of your property is inside the area marked 'surface safeguarding' on the 'safeguarding maps'

If you qualify the government will:

- Buy your property at its open market value as if HS2 wasn't going to be being built (known as 'unblighted' value)
- Give you a 'home loss' payment equal to 10% of the property's open market value (up to £58,000).
- Pay reasonable expenses, e.g. stamp duty, surveyors' and legal fees, and removal costs.

Heathrow Expansion

It is well worth considering the potential for the third runway at London's busiest and most profitable airport. The expansion of Heathrow will have huge economic impacts on our network.

Expansion Plan Projections [24]

- A growth in passenger numbers of **5% p.a.**, from 2025 to 2030, once a **third runway** becomes operational in **2025** is expected. Thereafter we assume a central case **2.4% p.a**. growth in passengers. The five-year period of 5% p.a. growth is based on Heathrow's research of other previously constrained international airports.
- A fourth runway could be added in the longer term if it was ever required.
- The commission estimated the costs to be around **£18.6 billion**.

Current Transport Links

- Heathrow's surface access is unrivalled. It is extremely well located in relation to the strategic highway network with direct access from the M25 and M4, as well as being within ten miles of the M40 and M3. It is served by fast and frequent rail services into London, provided by Heathrow Express, Heathrow Connect and the Piccadilly Line, as well as operating as the busiest bus and coach hub in the UK.

Plans to Expand Transport Links

- *Crossrail* – a committed project.
  In 2019, Crossrail will provide **direct rail access** to the West End, the City, Canary Wharf, and east London. Crossrail will bring the heart of London's financial district and much of east London within a **60-minute catchment** area for Heathrow. Journey times from Whitechapel, Canary Wharf and Stratford to Heathrow will be **36, 40, and 41 minutes respectively**. In the longer term, an **increase in frequency** of services to the airport would be possible to support the growth in passenger and employee numbers.

- *Piccadilly Line upgrade* – a committed project.
  Transport for London's planned upgrade of the Piccadilly Line will see **tube frequency** and **journey time improvements** for all users, including those travelling to Heathrow. Even with the advent of Crossrail, it will remain a key mode of public transport access for connecting London to the UK's hub airport, particularly for catchments to the west of London.

- *Western Rail Access* – a committed project.
  By 2021, Western Rail Access will provide fast direct connections between Heathrow and Slough, Reading, and the wider Thames Valley, as well as improving journey times to the South West and South Wales.

- *High Speed Two* – Phase 1 is a committed project; Phase 2 has policy support, subject to the outcome of the Airports Commission.
  In 2026, HS2 Phase 1 will connect Heathrow to the **Midlands** via a new interchange at Old Oak Common which will be served by Heathrow Express and Crossrail services. In 2032, Phase 2 will provide direct connections to key cities in the Midlands, the **North** and **Scotland**

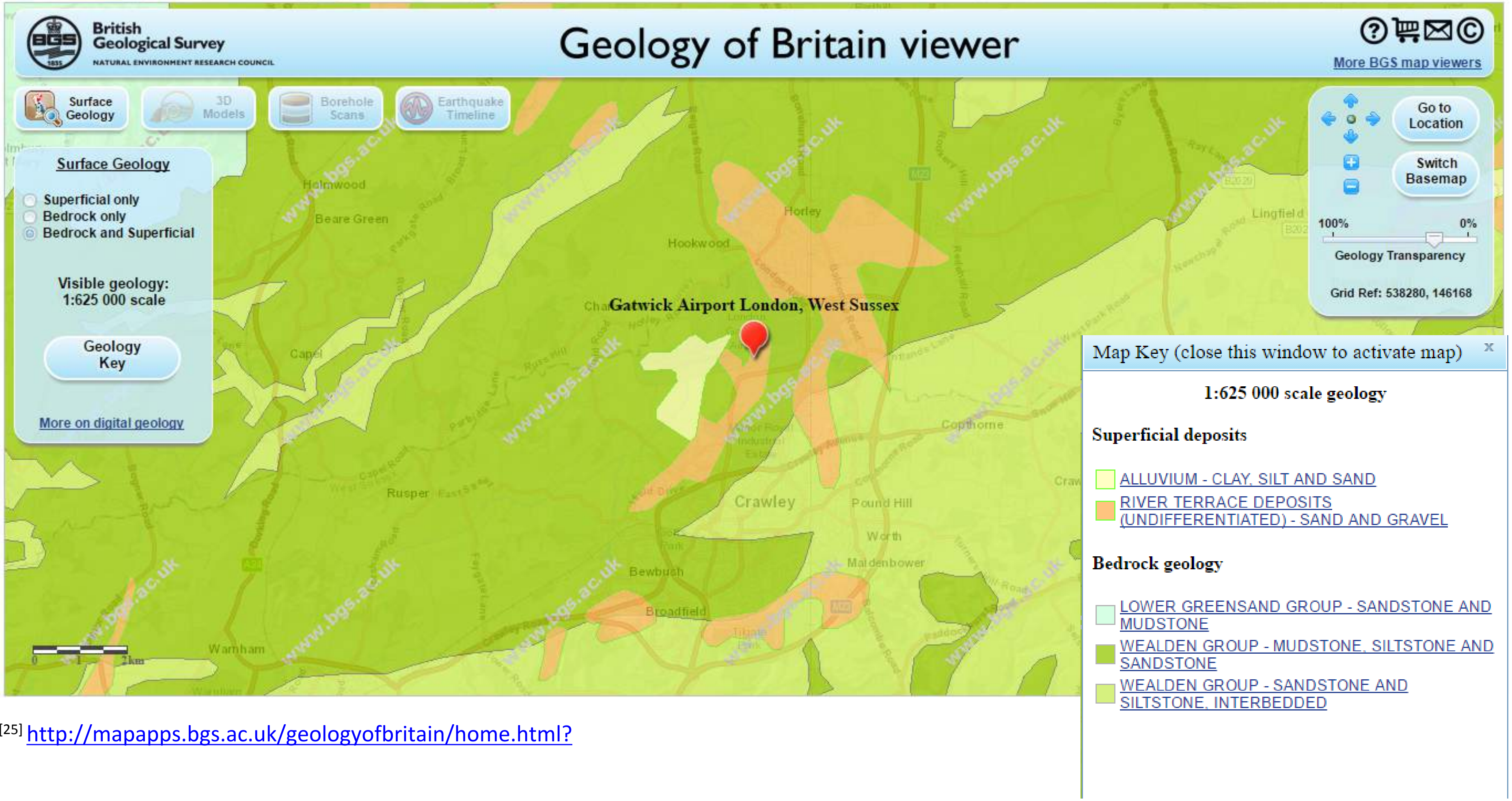
– dramatically **reducing journey times**. The Government anticipates that Heathrow would be served by an on-airport station at **Terminal 5**.

- *Southern Rail Access* – attracting strong policy support from Network Rail and stakeholders. A new southern rail link into the airport would provide rail access **to key catchments in South and South-West London, Surrey,** and the **South coast**. Heathrow is committed to working closely with Network Rail and other key local stakeholders to identify the **optimum route alignment** for connecting these important catchments to Heathrow.

- Expanding Heathrow's **car share** scheme (already the world's largest).
- We will also introduce new and **enhanced bus and coach services**, building on the **540,000 annual movements** today.

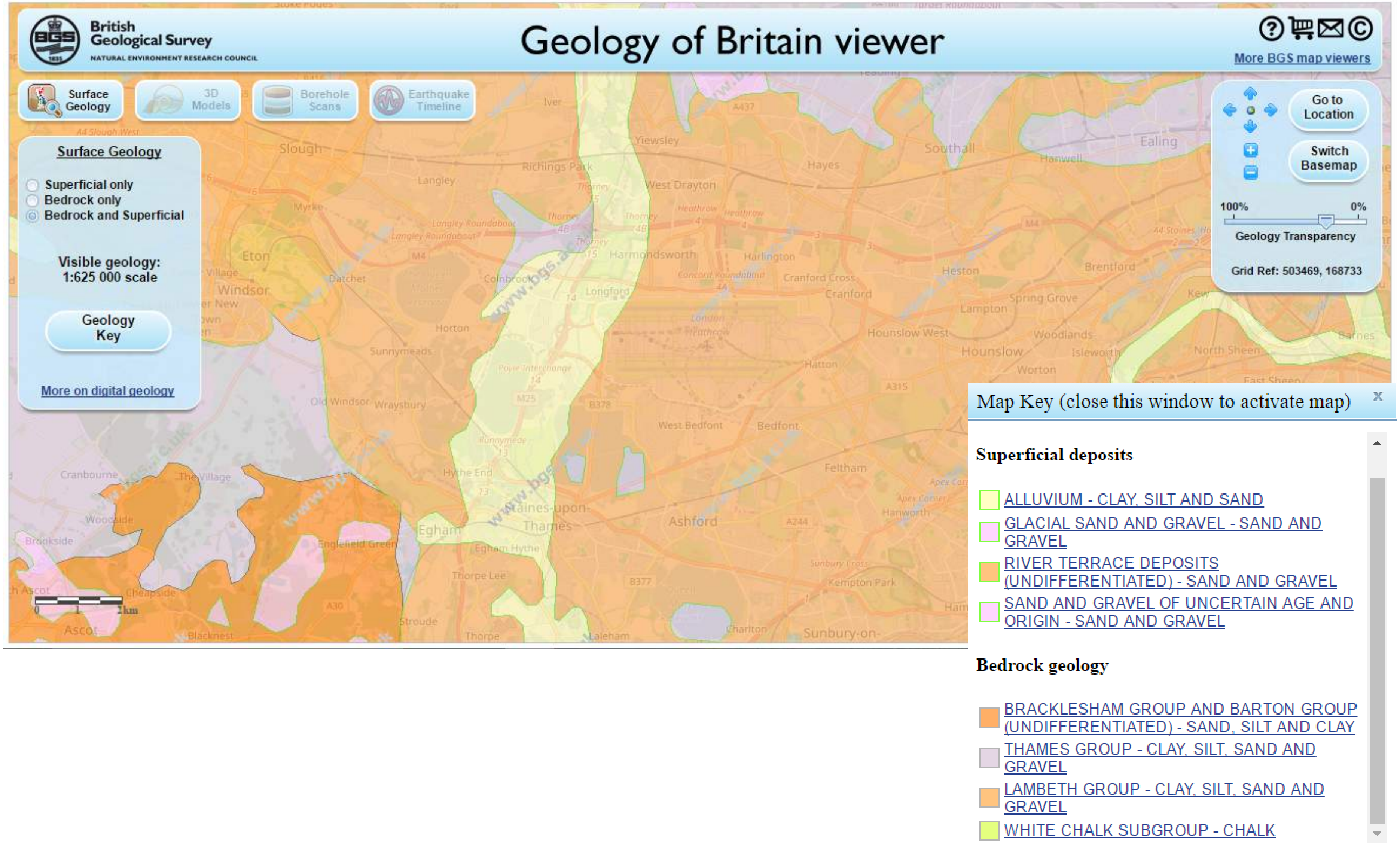
Superficial and Bedrock Geology Mapping

Gatwick

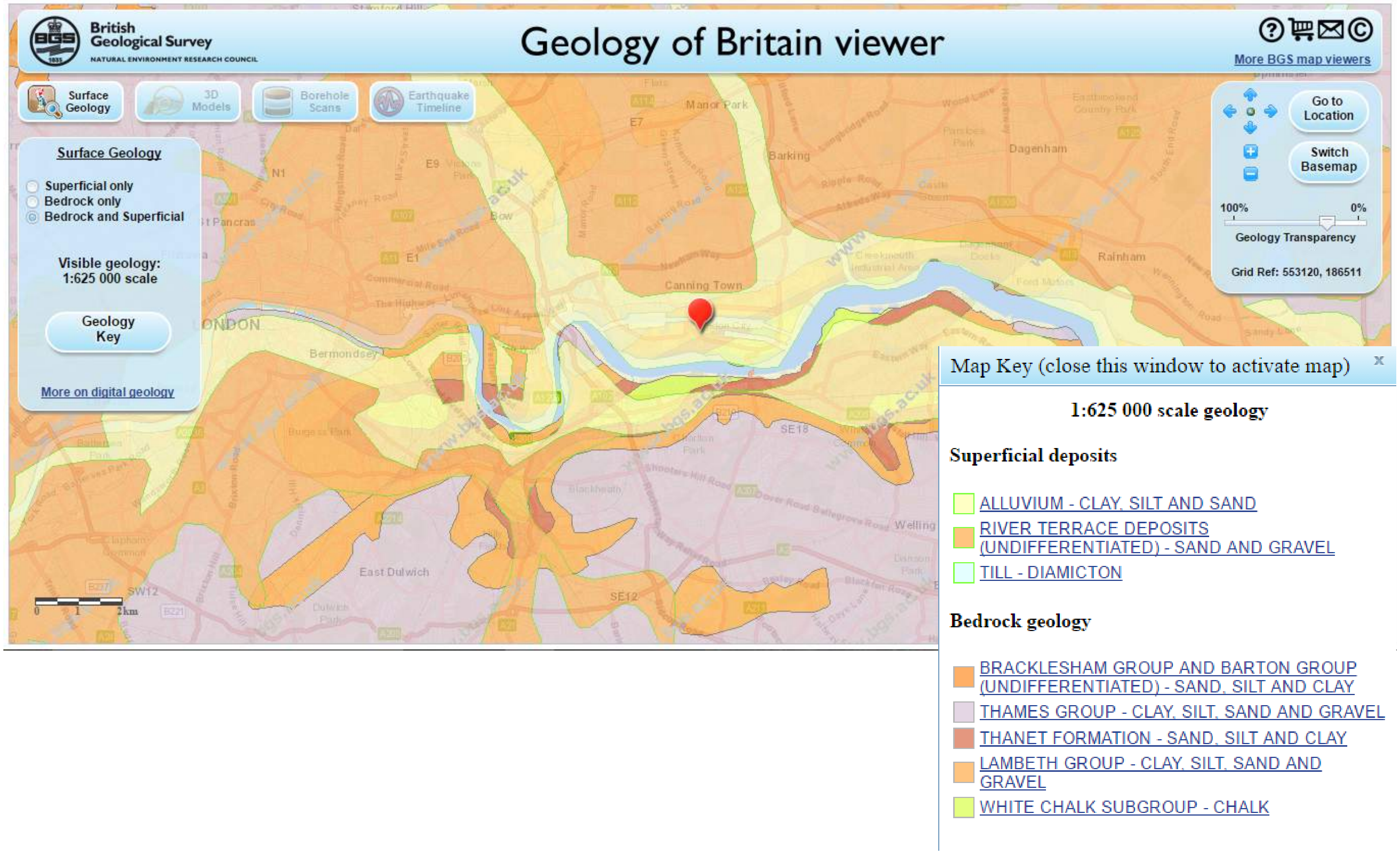


[25] http://mapapps.bgs.ac.uk/geologyofbritain/home.html?

Heathrow


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Geology of Britain viewer
More BGS map viewers
Surface Geology
3D Models
Borehole Scans
Earthquake Timeline
Surface Geology
Superficial only
Bedrock only
Bedrock and Superficial
Visible geology:
1:625 000 scale
Geology Key
More on digital geology
Go to Location
Switch Basemap
100%
0%
Geology Transparency
Grid Ref: 503469, 168733
Slough
Windsor
Eton
Datchet
Langley
Colnbrook
Harmondsworth
West Drayton
Yiewsley
Hayes
Southall
Ealing
Hanwell
Harlington
Cranford
Heston
Brentford
Hounslow
Hounslow West
Isleworth
Spring Grove
Woodlands
Lampton
Kew
Horton
Wraysbury
Old Windsor
Sunnymeads
West Bedfont
Bedfont
Feltham
Ashford
Egham
Staines-upon-Thames
Thorpe Lee
Thorpe
Laleham
Charlton
Sunbury-on-
Englefield Green
Ascot
Cranbourne
Map Key (close this window to activate map)
Superficial deposits
ALLUVIUM - CLAY, SILT AND SAND
GLACIAL SAND AND GRAVEL - SAND AND GRAVEL
RIVER TERRACE DEPOSITS (UNDIFFERENTIATED) - SAND AND GRAVEL
SAND AND GRAVEL OF UNCERTAIN AGE AND ORIGIN - SAND AND GRAVEL
Bedrock geology
BRACKLESHAM GROUP AND BARTON GROUP (UNDIFFERENTIATED) - SAND, SILT AND CLAY
THAMES GROUP - CLAY, SILT, SAND AND GRAVEL
LAMBETH GROUP - CLAY, SILT, SAND AND GRAVEL
WHITE CHALK SUBGROUP - CHALK

London City


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Geology of Britain viewer
More BGS map viewers
Surface Geology
3D Models
Borehole Scans
Earthquake Timeline
Surface Geology
Superficial only
Bedrock only
Bedrock and Superficial
Visible geology: 1:625 000 scale
Geology Key
More on digital geology
Go to Location
Switch Basemap
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Geology Transparency
Grid Ref: 553120, 186511
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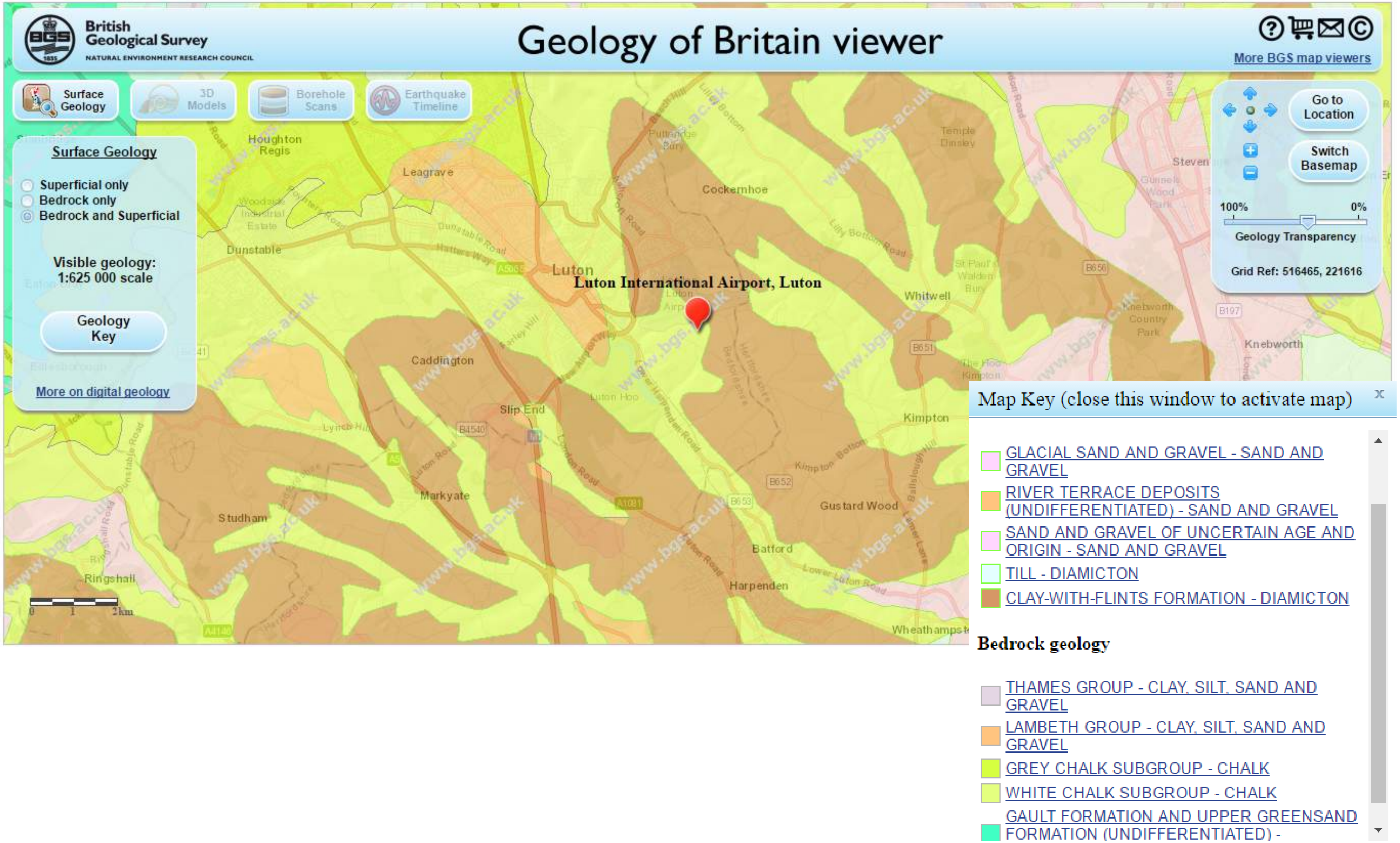
1:625 000 scale geology
Superficial deposits
ALLUVIUM - CLAY, SILT AND SAND
RIVER TERRACE DEPOSITS (UNDIFFERENTIATED) - SAND AND GRAVEL
TILL - DIAMICTON
Bedrock geology
BRACKLESHAM GROUP AND BARTON GROUP (UNDIFFERENTIATED) - SAND, SILT AND CLAY
THAMES GROUP - CLAY, SILT, SAND AND GRAVEL
THANET FORMATION - SAND, SILT AND CLAY
LAMBETH GROUP - CLAY, SILT, SAND AND GRAVEL
WHITE CHALK SUBGROUP - CHALK
LONDON
Canning Town
Barking
Dagenham
Rainham
Manor Park
Bermondsey
East Dulwich
Welling
0 1 2km

Luton


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Geology of Britain viewer
More BGS map viewers
Surface Geology
3D Models
Borehole Scans
Earthquake Timeline
Go to Location
Switch Basemap
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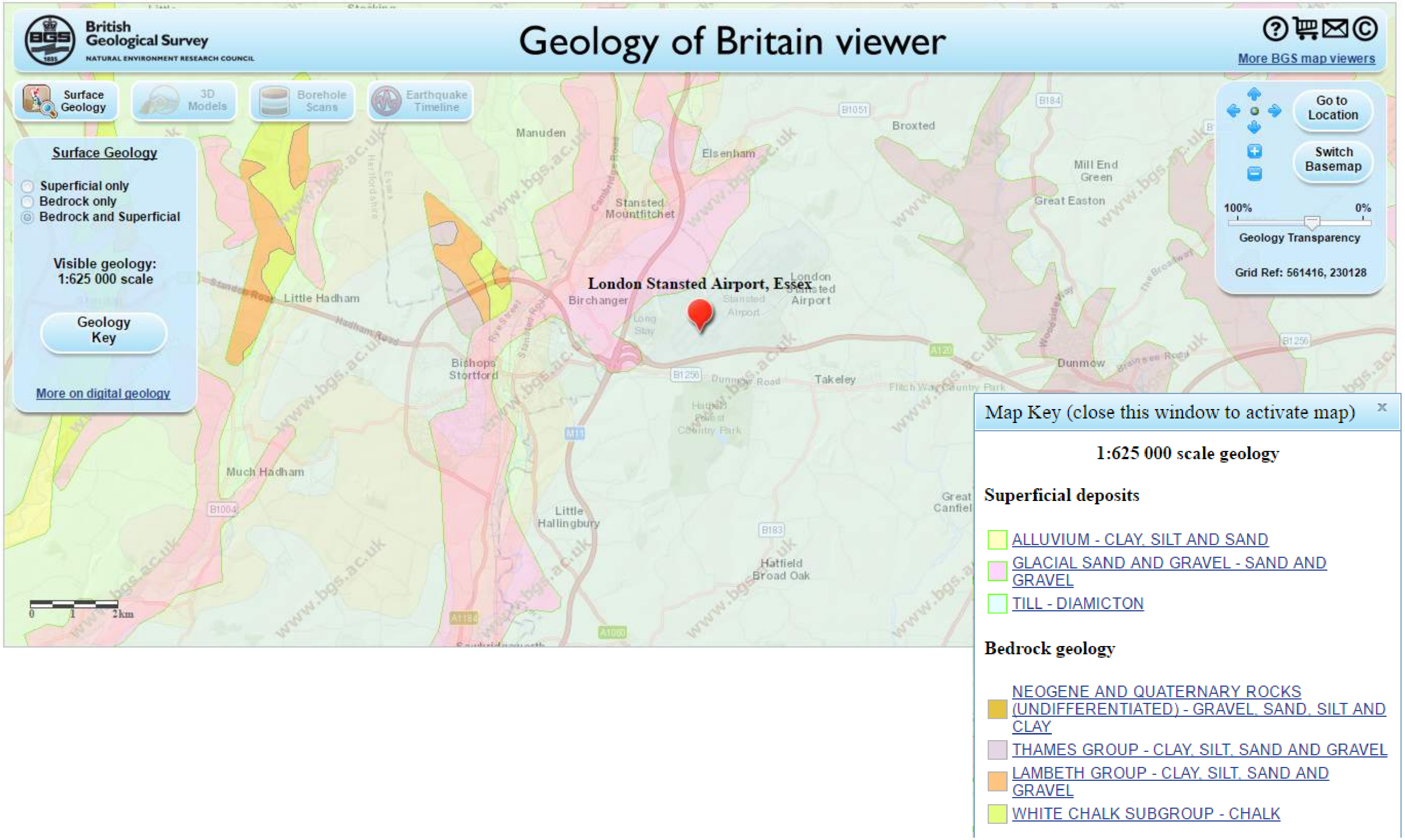
Geology Transparency
Grid Ref: 516465, 221616
Surface Geology
Superficial only
Bedrock only
Bedrock and Superficial
Visible geology: 1:625 000 scale
Geology Key
More on digital geology
Luton International Airport, Luton
Houghton Regis
Leagrave
Cockernhoe
Dunstable
Luton
Whitwell
Caddington
Slip End
Kimpton
Markyate
Studham
Gustard Wood
Batford
Harpenden
Ringshall
Knebworth
Wheathampstead
0 1 2km
Map Key (close this window to activate map)
GLACIAL SAND AND GRAVEL - SAND AND GRAVEL
RIVER TERRACE DEPOSITS (UNDIFFERENTIATED) - SAND AND GRAVEL
SAND AND GRAVEL OF UNCERTAIN AGE AND ORIGIN - SAND AND GRAVEL
TILL - DIAMICTON
CLAY-WITH-FLINTS FORMATION - DIAMICTON
Bedrock geology
THAMES GROUP - CLAY, SILT, SAND AND GRAVEL
LAMBETH GROUP - CLAY, SILT, SAND AND GRAVEL
GREY CHALK SUBGROUP - CHALK
WHITE CHALK SUBGROUP - CHALK
GAULT FORMATION AND UPPER GREENSAND FORMATION (UNDIFFERENTIATED) -

Stansted


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Geology of Britain viewer
More BGS map viewers
Surface Geology
3D Models
Borehole Scans
Earthquake Timeline
Surface Geology
Superficial only
Bedrock only
Bedrock and Superficial
Visible geology:
1:625 000 scale
Geology Key
More on digital geology
Go to Location
Switch Basemap
100%
0%
Geology Transparency
Grid Ref: 561416, 230128
London Stansted Airport, Essex
Manuden
Elsenham
Broxted
Mill End Green
Great Easton
Stansted Mountfitchet
Birchanger
Little Hadham
Bishops Stortford
Takeley
Dunmow
Much Hadham
Little Hallingbury
Hatfield Broad Oak
Map Key (close this window to activate map)
1:625 000 scale geology
Superficial deposits
ALLUVIUM - CLAY, SILT AND SAND
GLACIAL SAND AND GRAVEL - SAND AND GRAVEL
TILL - DIAMICTON
Bedrock geology
NEOGENE AND QUATERNARY ROCKS (UNDIFFERENTIATED) - GRAVEL, SAND, SILT AND CLAY
THAMES GROUP - CLAY, SILT, SAND AND GRAVEL
LAMBETH GROUP - CLAY, SILT, SAND AND GRAVEL
WHITE CHALK SUBGROUP - CHALK

Geological Complications

Superficial and Bedrock Geology and Soil Geochemistry [26]

Sands and gravels

In granular soils, there is often movement due to a condition whereby there are too many voids between particles, meaning foundations or other infrastructure built directly over them has the potential to collapse.

A good mixture of particle size normally will increase stability. An example of this is on tarmacked road surfaces where bitumen is strewn with large particles overlain by smaller particles to fill in the gaps and thus strengthening the road.

Clays

Clays can be potentially problematic as they are impermeable and non-porous, and more difficult to engineer with if they are 'expansive' clays. Their soils can undergo shrinking and swelling with regards to moisture content e.g. following heavy rain, making them unstable.

In cases where clays are prominent, any engineering-work on the surface (rather than overhead) may need to be built deeper, where more competent strata can be found. This is called underpinning.

Silts

Soil deposits containing silt can be subject to soil expansion due to 'frost heave', which is a result of ground freezing. This presents the unwanted possible outcome of lifting and manipulating heavy slabs and infrastructure foundations.

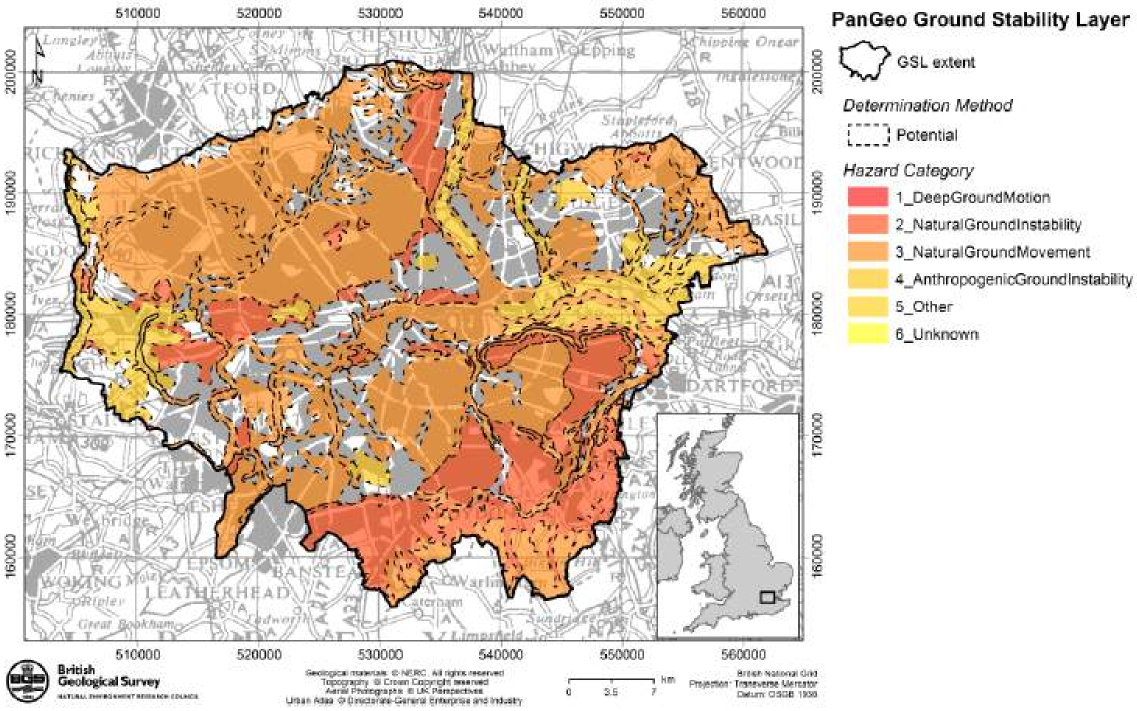
To avoid this, the technique of underpinning may be used, as with clays. Grouting may also be an option, whereby cement-like material is forced below the unstable geology to stabilise it and thus avoiding liquefaction.

White chalk [27]

There are few problems associated with building chalk: it is more durable and does not swell or shrink as the softer geology does. However, chalk – a very pure type of limestone – is susceptible to carbonation due to its solubility. This decreases its rock mass and creates fissures in its structure that make engineering a challenge.

In their article titled 'Planning for Problems with Soluble Rocks', [28] the British Geological Survey discussed how GIS (Geographic Information Systems) serve key roles in mapping areas such as these and then working around them, since tackling the problem head-on can be costly and perhaps unnecessary.

PHYSICAL GEOHAZARDS [29]



The geological composition of the Greater London area means that deep ground motion, ground instability and ground movement are all active factors that prove problematic when considering even any small-scale feats of infrastructural engineering.

Of the **1,240km² area** attributed to the referenced study by the British Geological Study, 1,133km2 is classed as being subject to geomorphology:

- **868km²** is classified as having shrink-swell potential, particularly areas where clay is the dominant rock material.
- **266km²** is compressible ground, (applies to alluvium and marine deposits).
- **566km²** has potential for natural ground instability, of which 190km2 could result in ground dissolution, which could lead to the development of cavities and therefore structural collapse above.
- **237km²** is the land space within this area of Greater London that has potential for sand liquefaction.

These geomorphological processes provide as hazards for engineering works, in connecting the airports Gatwick, Heathrow, London City, Luton and Stansted. Those features and processes such as cavities and liquefaction, which directly affect the project’s physical engineering work, are likely to be of greatest threat.

Hence, geological mapping of these areas to give maps such as the above from the BGS, will allow us to avoid such problems and secure the project’s use for future decades. However, the financial cost of this precautionary process must of course be accounted for in the budget.

Our Proposal: Hyperloop

Our proposal is to build an Hyperloop system through central London, with tubes around 6m in the air supported with regular pillars. A super-hub just outside the town of Cheshunt is central to our proposal, with pre-existing transport connections being located in close proximity to the M25 orbital. We have chosen this location because we found it to be the most efficient solution to the proposed task of connecting all 5 airports within the 20-minute transport time. The land used in our plan has been valued and purchased using our own costing formula, based somewhat on recent large scale UK infrastructure projects; along with the materials and manufacturing costs of the transport system itself. We believe that our proposal offers many advantages, as it connects all 5 airports within the stringent time allowances, and is relatively low cost in comparison to rival transport methods. Furthermore, the Hyperloop is the only train style transportation system that can travel fast enough, and with sufficient acceleration, without compromising on passenger safety and comfort.

However, previous Hyperloop plans have been built in rural locations where land is not at a premium. In comparison, central London poses many logistical issues, including (but not limited to) a high-density population, The Thames, and an ever-changing geographical relief that meant multiple tunnels were needed. We have also formulated two different business models: a public model, which provides the consumer best value for money whilst still generating a profit of **£9 billion**; whereas the private model is subject to business tax, but generates profits in excess of **£20 billion** over the course of 20 years.

In this report, we will discuss in detail how the Hyperloop works, the civil engineering feats necessary to overcome geophysical factors, and the fiscal structure of both costings and fares.

Why Our Proposal is Superior

Earlier in the research process of the project, we looked at a variety of different transport methods that could be used in order to fulfil the brief of connecting the five major airports of London together, to create a 'super airport'. Whilst many options were considered, we eventually decided that the use of a 'Hyperloop System' would be the most suitable, for reasons that we will outline.

Speed

One of the most important factors in our decision was the speed at which the different methods of train could travel at. As the brief stipulated that the journey between any two stations should be no more than 20 minutes, the selected method of transport would have to be very fast – the current time for the longest journey, Gatwick to Stansted takes around 1 hour and 40 minutes, around 5 times longer than the brief requests.

Although as a group the sustainability of the hydrogen-powered trains impressed us – the only product being water – this would not be viable as they cannot travel fast enough, ruling this design out of the question. This left us with a choice between a Maglev train, similar in design to the trains operating in Japan and China, or the Hyperloop design. In terms of speed, there is very little difference between the two designs, and both could easily operate within the timing guidelines of 20 minutes.

Running costs

Running costs was also a contributing factor between transport methods. The main cost in running a train is the energy it uses. Although trains are one of the most energy efficient methods of transport in terms of energy per passenger, they still cost many millions of pounds to run each year due to the electrification of the tracks.

The hyperloop design is very good in this area because the tubes that house the pods and tracks are covered in solar cells which can produce enough electrical energy to power the whole system (unless otherwise dictated by British weather!). This energy neutral system reduces the running costs of the system greatly, enhancing the project's ability to be sustainable and caring for the surrounding environment, whilst also increasing the project's chance of making a profit after 20 years.

Meanwhile, using a magnetic levitation train uses vast sums of energy to get the train to speeds where it can meet the time limitations. This system also requires energy to create the magnetic repulsion between the guide rail and the underside of the train. Although Hyperloop has similar energy needs, the lowered air pressure reduces the energy consumption and the solar panels create enough energy by themselves: something that Maglev trains cannot do. Therefore, based on energy use alone, we believe the Hyperloop system would be a more suitable choice.

Passenger numbers

The third factor we considered in our decision making was the ability for the system to be able to cope with the passenger numbers at peak times. The Hyperloop system has relatively small pods, carrying 28 people in each, along with their luggage. This means that the Hyperloop would require many pods, which could be very expensive.

The Maglev trains are multi-carriage trains, meaning hundreds of people and their luggage can use a single train, which would reduce costs for buying and maintaining the carriages and trains, thus the Maglev trains would be better in terms of getting large numbers of passengers around quickly.

Installation costs

The final, and most important factor that was considered was the cost of installing the systems. The aim is to be profitable within 20 years, meaning costs need to be kept to a minimum.

The cost of the Hyperloop system proved quite hard to find because there are not yet any working examples, but using Elon Musk's white paper design, the estimated cost for the pods and tracks of length 614.7km is going to be less than US $6 billion.

In comparison, the cost of building the magnetic levitation tracks and trains between Tokyo and Nagoya, just 286km apart, is expected to cost nearly US $100billion, over 40 times as costly per km. Therefore, the benefits Maglev trains could potentially present are outweighed by the extortionate costs involved in build the tracks and magnets.

Hence in conclusion, we have decided that the method of transport that our project will be based around will be the Hyperloop Alpha plans. The major advantage of Hyperloop over standard Maglev systems is that they cost a mere fraction of the latter, without compromising in terms of speed and safety.

Route Proposals

In this section, we lay out plans for the approximate journey the Hyperloop transportation system will take. We analyse each of our proposals and present our decision.

Option 1 - Orbital

Advantages	Disadvantages
Offers a 'rail' orbital around London	Massive total network weight
No extensive inner London work	

- Distance of one circuit: **217.3km**
- If a clockwise and anti-clockwise route is built: **434.6km**
- If only one circuit built, then the longest distance between the airports would be: Heathrow – Gatwick: **177.3km.**
- If two circuits the longest distance is Luton-London City: **89.8km**

Option 2 – Heathrow Hub

Advantages	Disadvantages
Weighted towards Heathrow - the largest airport with the most passengers	Central London work; crossing the Thames eight times
Close to the M25	Large network weight
	A lot of opposition to Heathrow Expansion for a third runway

- Longest distance is Gatwick – Stansted: **107.6km**
- Total Network Weight: **187.8km**
- Red dashes denote an alternative route. However, the longest distance becomes 149.9km (London City – Stansted), with the Thames still being crossed. Although this could be achieved by bus, tram etc.

OPTION 3 – NORTH LONDON (CHESHUNT) HUB: CHOSEN

Advantages	Disadvantages
Minimal Inner London work	Stansted line crosses Lee Valley Country park (with lakes)
Cheshunt has a national rail station	Long distance from Gatwick
Very close to M25	
Only crosses the Thames once	

- Longest distance is Gatwick – Stansted: **109.4km**.
- Total network weight: **158.3km**

OPTION 4 – CENTRAL LONDON HUB (EUSTON) WITH EAST-WEST SPLIT

Advantages	Disadvantages
Euston Station Hub – London Station of HS2	A lot of inner city work
Main hub in the centre of London	
Don’t have to cross the Thames	

- Maximum distance Stansted – Luton: **126.3km**.
- Total network weight: **168.6km**

Cheshunt as a Hub Location

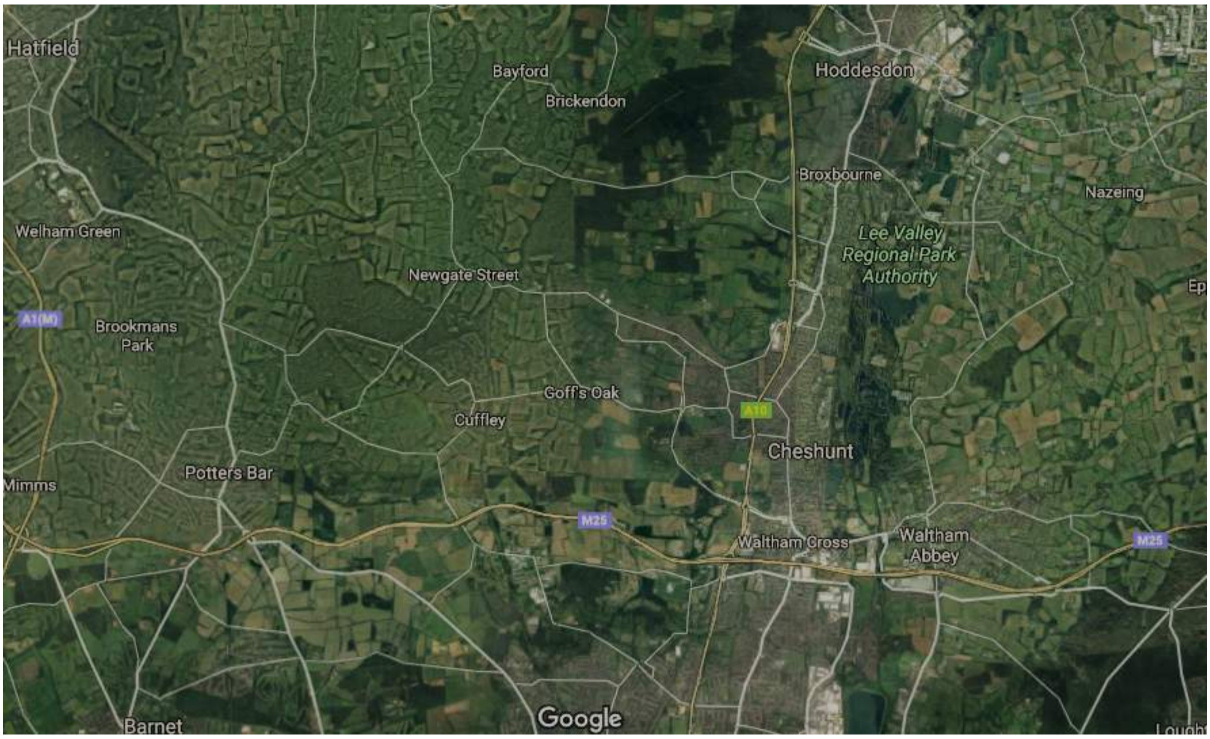


Image: Google Maps [30]

Cheshunt is a town **15 miles north** of Central London, in the county of Hertfordshire.

It is surrounded by greenfield sites to the west, north, and east, and while the use of brownfield sites would be preferential ecologically, the area contains little existing infrastructure and rather primarily expanses of farmland. These we can buy at low cost and will not constitute large-scale demolition.

The well-connected nature and geographical position of Cheshunt make it a good choice of location to construct the main hub that links our five airports, while there is also plenty of space on which it may be built without demolishing other buildings.

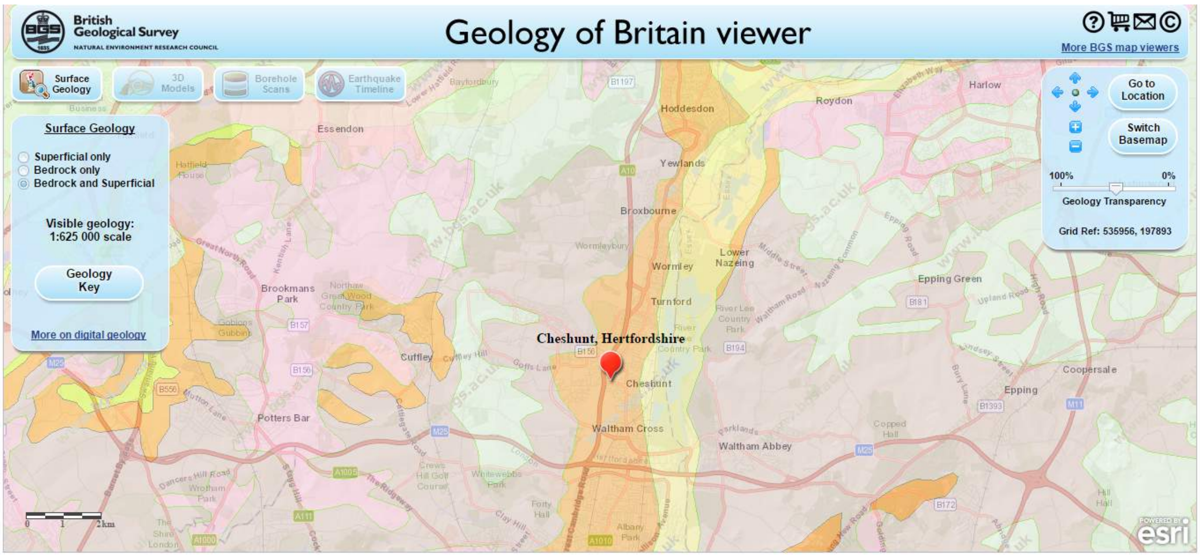
The main connections Cheshunt offers for transport are:

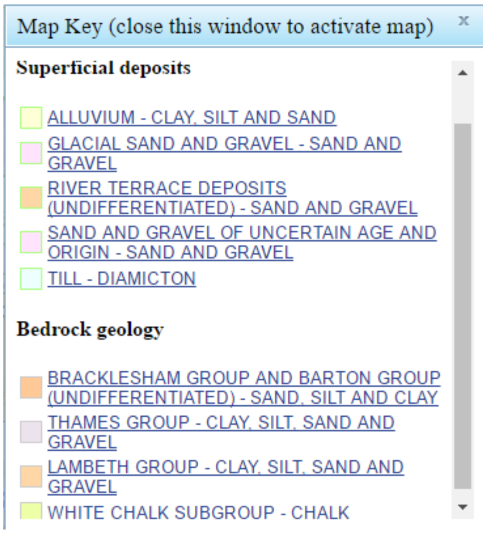
- Roads and motorways, including proximity to the M25.
- National Rail services
- Bus services and National Express coach stop

To extend these services into the countryside on the town's outskirts would not be an enormous challenge. The problems in securing this location lie in legal matters of exploiting private land, as well as the presence of the nearby **Broxbourne Woods National Nature Reserve**. [31]

The reserve is made up of four woods: Bencroft Wood and Broxbourne Wood both owned by Hertfordshire County Council, and Hoddesdon Park Wood and Wormley Wood which are both owned by the Woodland Trust. All these woodland areas are Sites of Special Scientific Interest (SSSIs) and so the possibility of building an airport hub may query the involved environmentalists.

Hence, we ought to build the hub a little south of the Nature Reserve around the area of Newgate Street and Golf's Oak.





[25] The geology of this area is a combination of superficial deposits of clays, silts, sands, and gravels, which each present engineering issues that need to be addressed prior to hub construction.

For example, the prominent lilac aspect of the above choropleth map is indicative of the Thames Group Clays, Silts, Sands, and Gravels. While the orange indicates river deposits of the latter. The problems associated with building on each of these is discussed in detail in this report's 'Geological Complications' section.

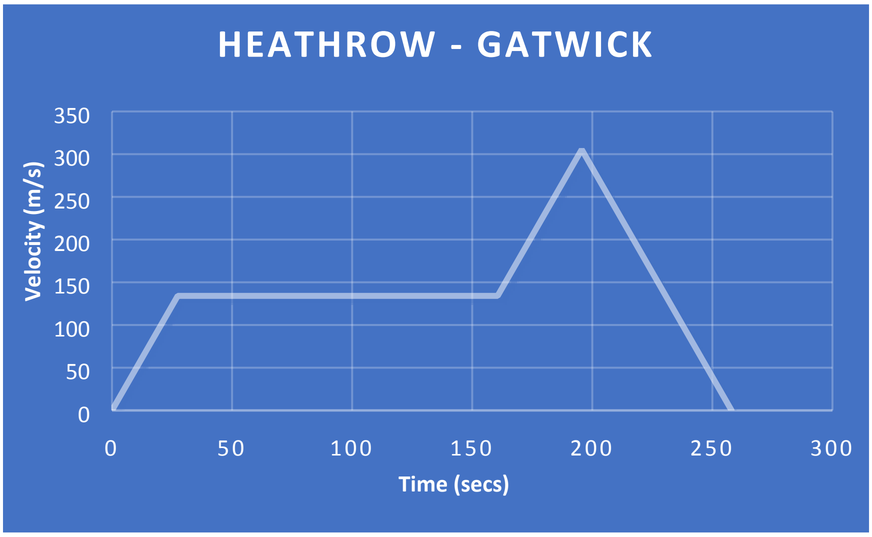
Route Specification Detailing

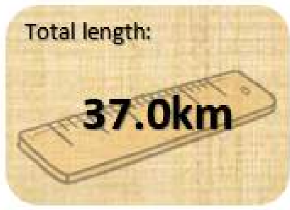
Heathrow – Gatwick Line

The pod accelerates out of Heathrow at **0.5 g*** to a recommended speed of **300mph** (134.1m/s) in urban areas.

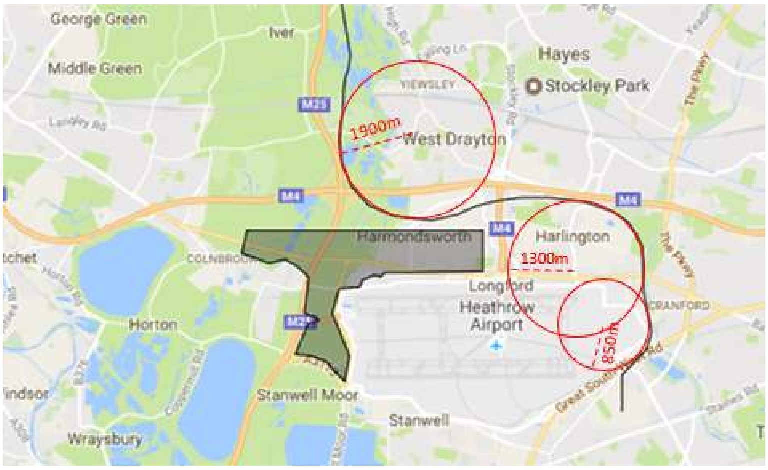
South of Ashtead it becomes more rural and curve radii are in excess of 3 miles; therefore, we can accelerate up to 760mph, although in this case because the acceleration and deceleration is limited to 4.9m/s²* we reach **683.2mph** (305.4m/s).

*Acceleration is always at no more than 0.5g to maintain passenger comfort.



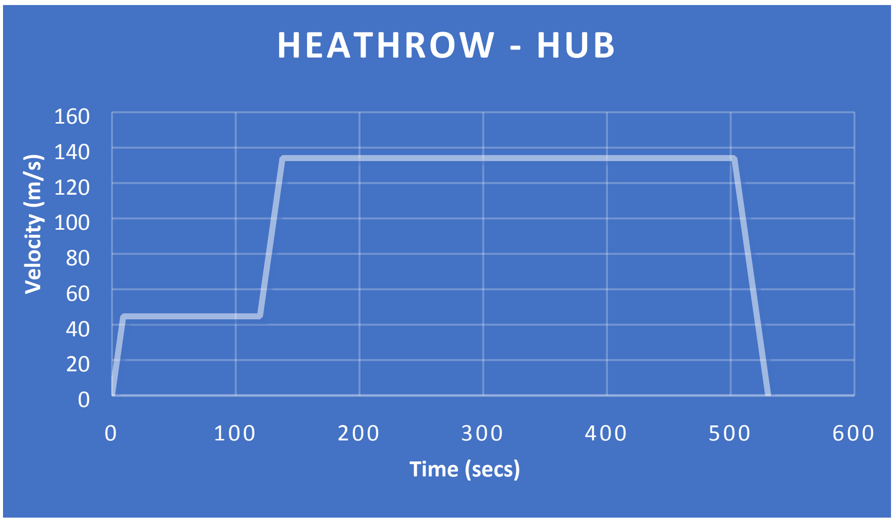


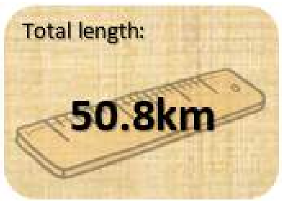
Heathrow – Hub Line



Due to the high house density surrounding Heathrow Airport and the planned Heathrow Expansion the line travels around the airport at 100mph (44.7m/s) allowing for curves with radii with 850m and 1300m. At the third marked curve the curve radii > 1 mile therefore we can accelerate past Harlington to 300mph (134.1m/s) but not to the maximum speed of 760mph as the line goes through urban areas.

There is a tight curve in the latter half of the journey, passing through Colne Valley Regional Park, where the line is of radius 1.4 miles from Uxbridge.



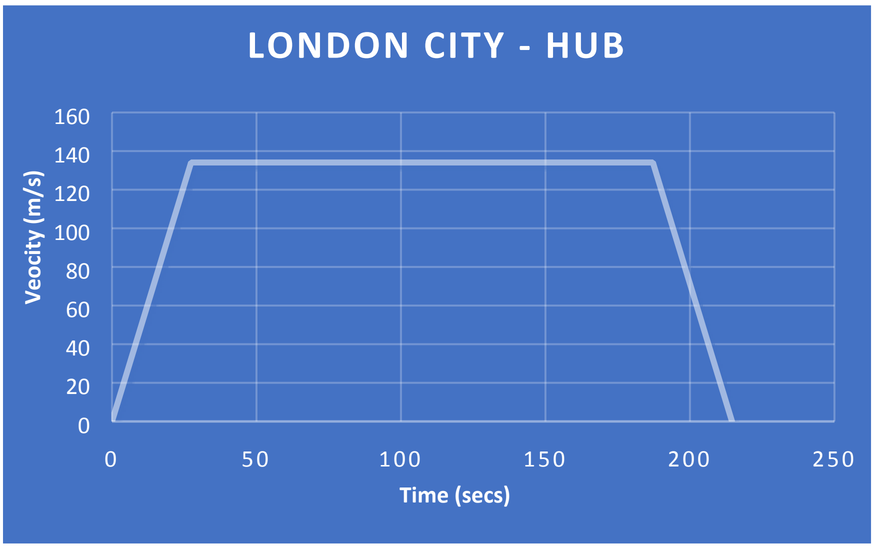


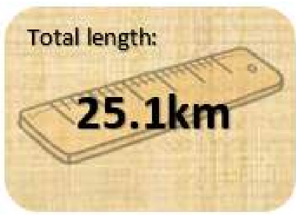
London City – Hub Line

The pod accelerates out of Heathrow at 0.5 g* to a recommended speed of 300mph (134.1m/s) in urban areas.

Due to curves with radii greater than 1 mile but less than 3 miles we can safely travel at 300mph. However, this combined with dense urban areas, means we cannot accelerate above this.

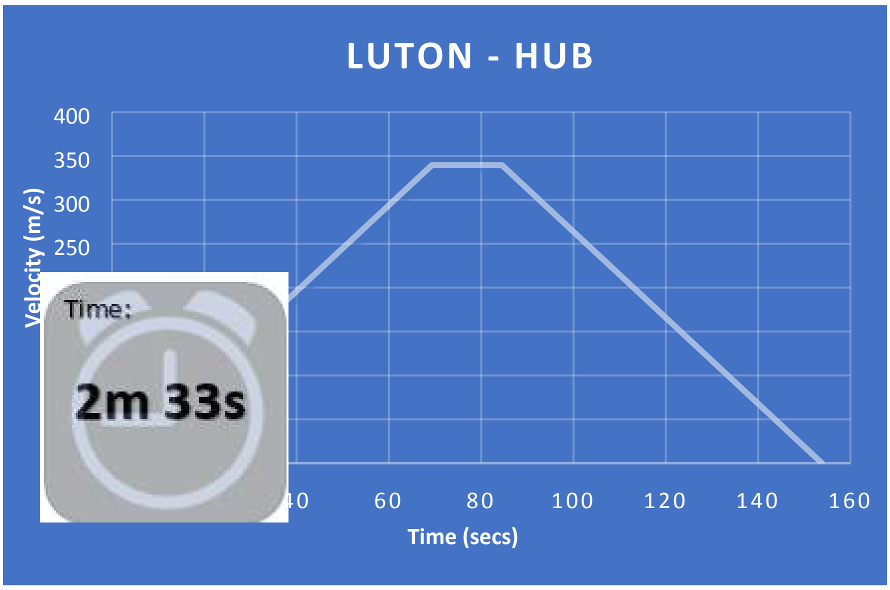
*Acceleration is always at no more than 0.5g to maintain passenger comfort.

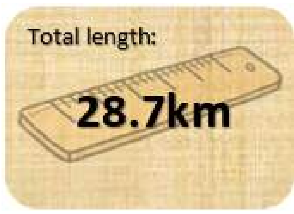




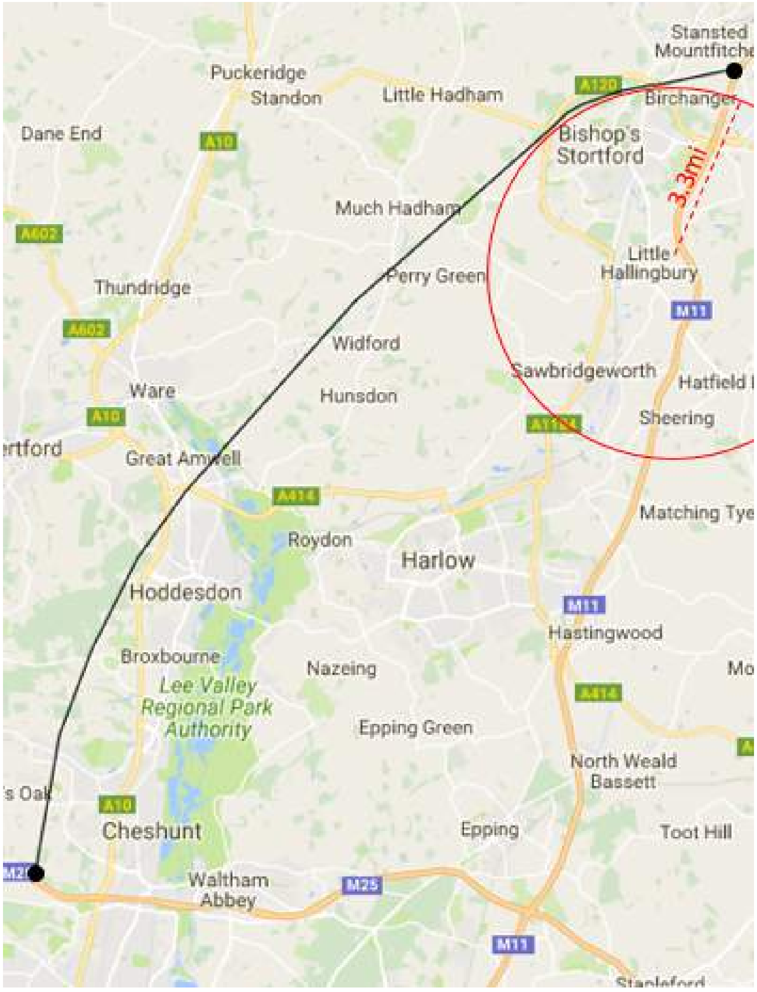
Luton – Hub Line

The pod accelerates out of Luton at 0.5 g* to a maximum speed of 760mph (339.7m/s). We can reach this speed as there are minimal curves with radii greater than 3 miles. This combined with the rural landscape with minimal urban contact the maximum speed can be used without compromising safety and causing nuisance for locals.





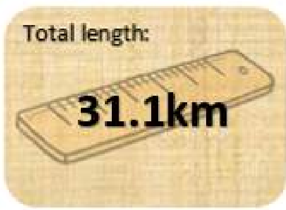
Stansted – Hub Line



The pod accelerates out of Stansted at 0.5 g* to a maximum speed of 760mph (339.7m/s). This can be reached as curve radii are in excess of 3 miles and the line goes thorough rural areas.

3.6km away from the Cheshunt hub where the train goes thorough the suburbs of Flamstead End (north-west of Cheshunt) the speed is reduced to 300mph (134.1m/s).

*Acceleration is always at no more than 0.5g to maintain passenger comfort.

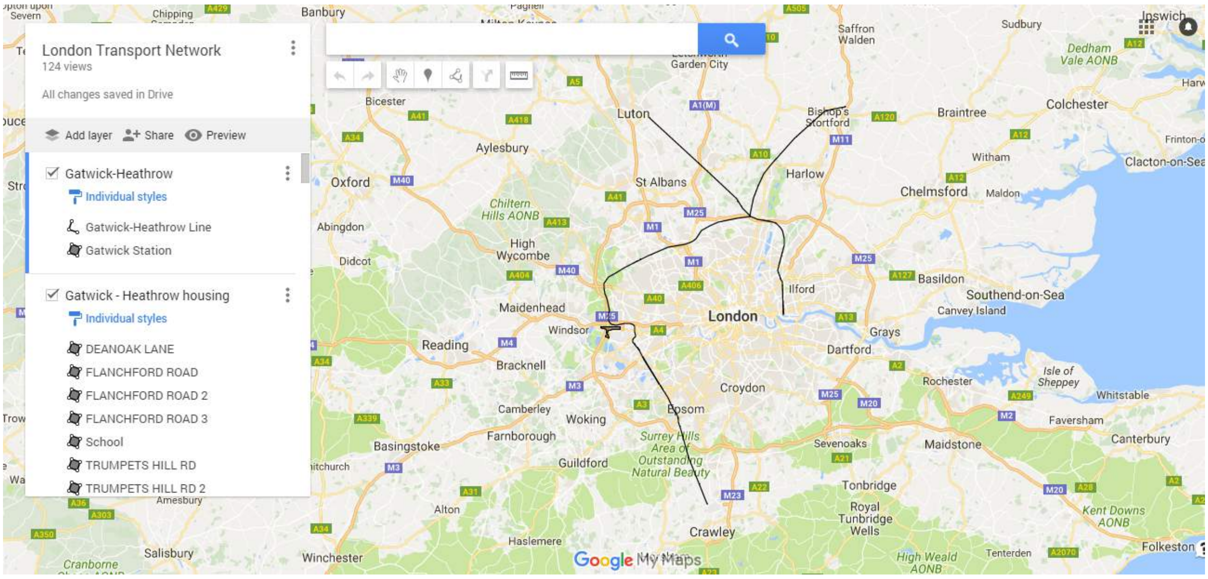


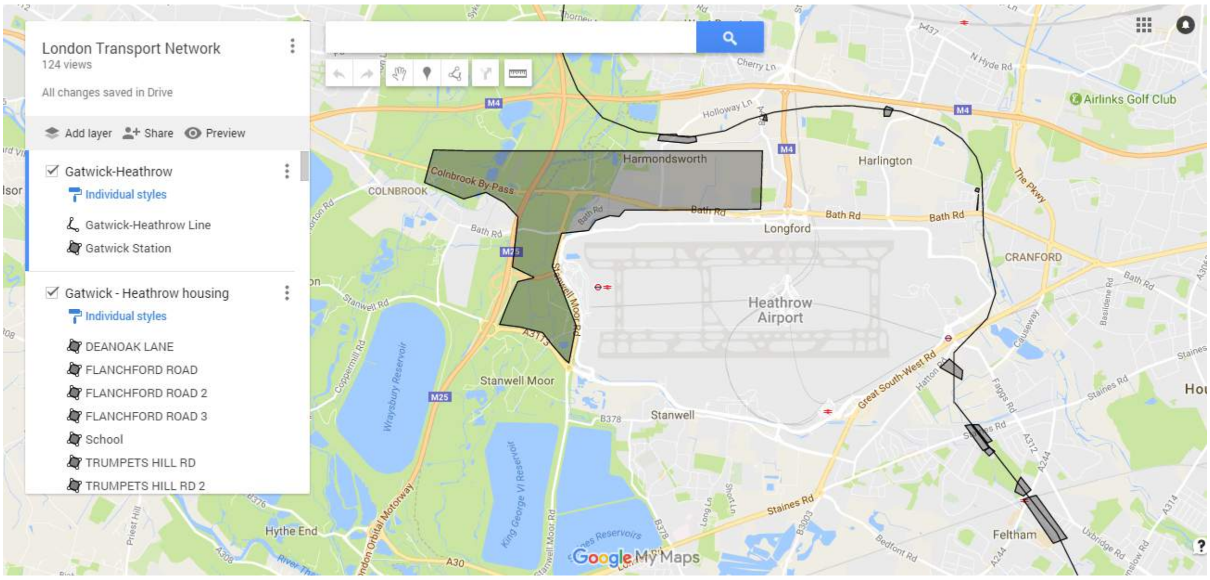
Interactive Route Map

The full route we have chosen to link the five airports to our Cheshunt Hub can be viewed online at:

https://drive.google.com/open?id=1Hb-tEhzH6KEMiOMKYVckZmRQnAM&usp=sharing

By following the link, you will be able to enlarge the route for more detailed insight into how it is laid out. You will also be able to view all the areas where we will be purchasing housing and land for demolishing, in order to make way for the Hyperloop network (see page 45).





Housing and Owned Land Consumption Costs

Gatwick to Heathrow Route

Area	Houses demolished (compulsory purchases)	Houses affected (not demolished)	Value with added 10% (£)	Houses affected reimbursement at 25% (£)	Average house price in area (£)	Total cost of house destruction (£)
Buckland	4	8	3,222,274.00	1,464,670.00	732,335.00	1,464,670.00
Reigate	5	8	4,027,842.50	1,464,670.00	732,335.00	4,686,944.00
Ashtead	3	2	2,349,131.40	355,929.00	711,858.00	4,383,771.50
The Rye	10	81	6,592,102.00	12,135,460.50	599,282.00	14,484,591.90
Hinchley Wood	48	180	27,368,140.80	23,325,120.00	518,336.00	29,917,222.00
Weston Green	32	154	28,511,964.80	31,184,961.50	809,999.00	58,553,102.30
Molesey	73	325	36,137,489.30	36,565,018.75	450,031.00	65,076,983.55
Hampton	58	399	42,885,594.40	67,050,753.00	672,188.00	103,188,242.30
Feltham	42	220	15,754,200.00	18,755,000.00	341,000.00	61,640,594.40
Miscellaneous	7	13	5,236,000.00	2,210,000.00	680,000.00	17,964,200.00
					Total cost for Gatwick to Heathrow route (£)	**361,360,321.95**

Hub to Heathrow route

Area	Houses demolished	Houses affected (not demolished)	Total number of house purchased	Average house price in area (£)	Value with added 10% (£)	Total cost of house destruction (£)
Barnet Galley Ln	2	13	15	651,253	716,378.30	10,745,674.50
Barnet Rowley Ln	0	3	3	651,253	716,378.30	2,149,134.90
Stirling Way, Barnet	4	111	115	651,253	716,378.30	82,383,504.50
Brightwen Grove	0	17	17	722,333	794,566.30	13,507,627.10

Standmore	0	4	4	729,261	802,187.10	3,208,748.40
Old Redding	1	5	6	503,407	553,747.70	3,322,486.20
Watford	1	5	6	723,817	796,198.70	4,777,192.20
Pinner Hill	2	26	28	723,817	796,198.70	22,293,563.60
Northwood Way	19	259	278	913,880	1,005,268.00	279,464,504.00
The Pyghtie	1	7	8	560,939	617,032.90	4,936,263.20
Denham Ave	0	6	6	560,940	617,034.00	3,702,204.00
Iver	0	5	5	628,253	691,078.30	3,455,391.50
Thorney Mill	3	10	13	628,254	691,079.40	8,984,032.20
West Drayton	1	48	49	360,484	396,532.40	19,430,087.60
Euro	1	3	4	360,485	396,533.50	1,586,134.00
St Peters Way	3	9	12	356,514	392,165.40	4,705,984.80
Cranes Water	0	14	14	299,289	329,217.90	4,609,050.60
					Total cost for Hub to Heathrow route (£)	**473,261,583.30**

Hub to London City Route

Area	Houses demolished	Houses affected (not demolished)	Total number of house purchased	Average house price in area (£)	Value with added 10% (£)	Total cost of house destruction (£)
London Orbital	0	152	152	342,397	376,636.70	57,248,778.40
Meridian Business Park	7	137	144	407,075	447,782.50	64,480,680.00
Lippitts Hill	0	23	23	565,711	622,282.10	14,312,488.30
Courtland Ave	0	32	32	593,686	653,054.60	20,897,747.20
Woodford Green	1	51	54	591,578	650,735.80	35,139,733.20
Henry's Ave	4	52	56	591,578	650,735.80	36,441,204.80
The Oaks	0	12	12	591,578	650,735.80	7,808,829.60
St. Peters Ave	4	27	31	431,718	474,889.80	14,721,583.80

Whipps Cross Rd	0	41	41	517,419	569,160.90	23,335,596.90
Bushwood Rd	0	46	46	517,419	569,160.90	26,181,401.40
Belgrave Rd	0	98	98	517,419	569,160.90	55,777,768.20
Green Way	121	1,742	1,863	349,726	384,698.60	716,693,491.80
					Total cost for Hub to London City route (£)	**1,073,039,304.00**

Hub to Luton Route

Area	Houses demolished (compulsory purchases)	Houses affected (not demolished)	Value with added 10% (£)	Houses affected reimbursement at 25% (£)	Average house price in area (£)	Total cost of house destruction (£)
Cuffley	0	31	N/A	4,012,833.75	517,785.00	4,012,833.75
Mill Green	8	7	3,037,944.80	604,136.75	345,221.00	3,642,081.55
Lemsford	20	62	8,034,092.00	5,660,383.00	365,186.00	13,694,475.00
Gustard Wood	3	4	1,989,147.60	602,772.00	602,772.00	2,591,919.60
Miscellaneous	9	21	4,524,300.00	2,399,250.00	457,000.00	6,923,550.00
					Total cost for Hub to Luton route (£)	**30,864,859.90**

Hub to Stansted Route

Area	Houses demolished (compulsory purchases)	Houses affected (not demolished)	Value with added 10% (£)	Houses affected reimbursement at 25% (£)	Average house price in area (£)	Total cost of house destruction (£)
Flamstead End	48	277	569,563.50	35,856,611.25	517,785.00	36,426,174.75
Wormley West End	5	3	563,333.10	384,090.75	512,121.00	947,423.85
Hailey	3	10	426,248.90	968,747.50	387,499.00	1,394,996.40

Hadham Cross	5	4	942,535.00	856,850.00	856,850.00	1,799,385.00
Miscellaneous	7	5	577,500.00	656,250.00	525,000.00	1,233,750.00
					Total cost for Hub to Stansted route (£)	**41,801,730.00**

Farmland Use

The diameter of each tube is 2.23m. We have allowed 10 m of space either side of each of the two tubes. This creates an excess of 7.77m, which adds to the safety and security of the system.

Line	**Distance of farmland required (m)**	**Width of farmland required (m)**	**Area of farmland required (m^2)**	**Cost of buying farmland per acre (£)**	**Total cost of buying farmland (£)**
Gatwick – Heathrow	24,600	20	492,000	12,500.00	1,519,698.10
Heathrow – Hub	47,450	20	949,000	12,500.00	2,931,287.59
Hub – London City	12,710	20	254,200	12,500.00	785,177.35
Hub – Luton	22,750	20	455,000	12,500.00	1,405,411.86
Hub – Stansted	27,570	20	551,400	12,500.00	1,703,173.84
				Total cost of farmland consumption (£)	**8,344,748.74**

Grand total for housing and land use: £1,988,672,548.00

Capsule Logistics

General Factors

- Passengers will be allowed to access capsules at least 1m 30 seconds in advance of the doors closing for safety checks (this is a generous allowance with London Underground trains frequently only stopping for 20 seconds in order for passengers to board/ disembark with their luggage).

    i. Luggage will be stored in the back of the capsule and will be managed by Hyperloop staff for efficiency (this could be done by simply swapping the luggage crates of arrivals and departures)

    ii. There will be two doors an entrance and an exit door to minimise time wasting in disembarking and boarding passengers

- A further 40 seconds is elapsed as passengers get themselves settled and strapped in in addition to a member of Hyperloop staff checking everyone is strapped in and obeying health and safety procedure.

- This means that staff can unload luggage until the capsule doors are shut 40 seconds before departure (giving them at least 1m 30s) and in the 40 second safety check they can wheel in the crate containing the departing passengers' luggage.

- This means that pods can depart 2m 10s after arriving although all pods will spend more time than this at each station (hub) even during peak times.

- It also means passengers can board up to 40 seconds until departure as that is when the doors are closed and luggage is loaded into the capsule.

Heathrow - Hub Line

Heathrow – London City / Heathrow – Luton / Heathrow – Stansted / Gatwick – London City / Gatwick – Luton / Gatwick – Stansted

Due to the nature of the transport network tree, six different routes all use the Heathrow-Hub line as any transfer from Gatwick must first go through Heathrow. This connection has to support 4,040* people (8,080 in both directions) an hour during peak times. To transport 4,040 people, it would require 145 passenger pods transfers. With a journey time of 8 minutes 50 seconds (8.83 minutes) we have to send multiple pods in the same tube as sending the next pod only as the previous one arrives will only result in six pod transfers an hour transporting a total of 128 passengers only 4.2% of the 4,040 people quota.

The pods would have to be released every 24 seconds (0.4 minutes) sending 150 pods every hour during peak time enabling 4,200 passengers – at maximum capacity – to travel. The issue with sending these pods at such regularity is one of safety and will be addressed in the safety section (see page 80).

The regular frequency of the shuttles and relatively long transfer time means that up to 23 pods can be in each tube (46 in both) at any one time during peak times. This is in addition to twelve pods (six at the Hub and six at Heathrow) allowing passengers to access the shuttles at least 2m 14s in advance of departure; this in turn means 58 pods are needed to support this line (at peak times).

During non-peak times this link only has to support 3,160 (6,320 in both directions) people an hour, this reduces the total needed passenger pod transfers to 113 per hour, reducing pod frequency to every 30 seconds. The frequency of every half a minute means that at maximum capacity 3,360 can be transported. Although the six seconds may sound insignificant this means that a maximum of 18 pods are now in each tube (a total of 36 for both tubes) at any one time. The decreased frequency also means the number of shuttles waiting to depart at each station can be reduced to ten (five at each station) allowing passenger access to pods 2m 30s in advance of departure. This reduces the total number of pods in the system by twelve, from 58 to 46 this means up to twelve pods can be cycled off the system for routine maintenance and cleaning during off-peak times.

*{this accounts for all transfers being at peak time simultaneously}

Total pods needed (at peak times): 58

HEATHROW – GATWICK LINE

Heathrow – Gatwick / Gatwick – Stansted / Gatwick – Luton / Gatwick – London City

At peak time this connection has to support **2400 people an hour** (4800 in both directions) by transporting them in 28 person pods. As the journey time takes 4m 18s (4.3 minutes) we have to send multiple pods in the same tube as sending the next pod only as the previous one arrives would result in only thirteen shuttles arriving within the hour transporting at total of 364 passengers only 15.2% of the needed quota.

If the pods were released at 40 seconds (0.667 minutes) intervals it would mean sending 90 passenger pods an hour (from one airport) allowing for a maximum capacity of 2,520 passengers at peak times. Because of the interval of release and the journey time (4.3 minutes/0.667 minutes = 6.45) there will be up to seven pods in each tube at any one time therefore in the parallel lines there will be up to a total of fourteen pods. This is in addition to at least four pods at both airports waiting to be sent (8 in total); this leaves at least 2m 40s passengers to board in advance of departure. Therefore, during peak times a total of 22 pods will be needed.

However, during off-peak times, it only needs to support 2150 people (or 4300 people in both directions). This means pod frequency could be reduced to one every 45 seconds which would result in up to six pods (4.30/0.75=5.73) in each tube at any one time (twelve pods in both tubes). This in addition to at least three pods at both airports (six in total), allowing passengers access to capsules at least 2m 15s in advance of departure; meaning a total of eighteen pods are needed to sustain the system. This allows for four pods not in use to be serviced and cleaned and these four ‘rested’ pods can be rotated on and off such that all the pods could be cleaned and checked at least twice a day as the peak period is only two hours.

Total pods needed (at peak times): 22

Luton – Hub Line

Luton – London City / Luton – Stansted / Luton – Heathrow / Luton – Gatwick

This connection has to support 2,320 (4,640 in both directions) people an hour at peak time. To transport 2,320 people, it would require a minimum of 83 pod transfers an hour. With a journey time of 2m 33s (2.55min) we have to send multiple pods in the same tube as sending the next pod only as the previous one arrives will only result in 23 pod transfers an hour transporting a total of 644 passengers only 27.8% of the 2,320 people quota.

In order to transfer 2,320 people an hour the pods would be released every 40 seconds (0.67 minutes) sending 90 pods and hour enabling a maximum capacity of 2,520 people. There will be a maximum of 4 pods in each tube (8 in total) at any one time in addition to at least four pods at both the hub and Luton airport (8 in total) to allow passengers access to capsules at least 2m 40s in advance of departure. Therefore, during peak times a total of 16 pods will be needed.

During off peak time the connection has to support 1,790 (3,580 in both directions) people an hour and this would require 64 pod transfers an hour. This would mean pod frequency can be reduced to one every 50 seconds which would mean up to 1,867 people an hour can be transported an hour. With pods released every 50 seconds there will be up to three pods in each tube at any one time (six in both); the reduced frequency means that there only needs to be three pods based at each airport loading and unloading passengers enabling them to access pods at least 2m 30s in advance of departure. This means the total pods needed during off-peak times is reduced to 12.

Total pods needed (at peak times): 16

London City – Hub Line

London City – Gatwick / London City – Heathrow / London City – Luton / City – Stansted

This connection has to support 1,530 (3,060 in both directions) people an hour at peak time. This would require 55 pod transfers an hour. In order to manage this amount of people pods will need to be released every minute sending 60 pods an hour – enabling a maximum capacity of 1,680 people (9.8% more than the forecasted peak passenger numbers). A journey time of 3m 34s (3.57 minutes) and a pod frequency of one minute means there will be up to four pods in each tube at any one time. The one minute frequency means that three pods are needed at each station to allow passengers access to the pods three minutes in advance of departure. Therefore 11 pods are need to sustain this connection at peak time.

During off peak time it has to transfer 1,200 (2,400 in both directions) people an hour; this would require 43 pod transfers an hour. This means that pod frequency can be reduced to 1m 20s would be able to cope with 1,260 people an hour. With pods released every 1m 20s there will be a maximum of three pods in each tube at any one time; the reduced frequency also means that only two pods are needed at each station allowing passengers access to the pod at least 2m 40s in advance of in advance of departure.

Total pods needed (at peak times): 14

Stansted – Hub Line

Stansted – City / Stansted – Luton / Stansted – Gatwick / Stansted – Heathrow

The connection has to support 1,840 (3,680 in both directions) an hour; this would require 66 pod transfers an hour. In order to manage this amount of people pods will need to be released every 50 seconds, sending 72 pods an hour - enabling a maximum capacity of 2,016 people an hour (9.6% more than the forecasted peak passenger numbers). A journey time of 2m 49s and a pod frequency of 50 seconds means that a maximum of four pods would be in each tube at any one time; this is in addition to three pods at each airport allowing passengers access to board the pods at least 2m 30s before in advance of departure. This means that a total of 14 pods would be needed during peak times.

During off peak time it has to transfer 1,460 (2,920 in both directions) people an hour; this would require 53 pod transfers an hour. This means that pod frequency can be reduced to 1 minute would be able to cope with 1,680 people an hour. With pods released every 1 minute there will be a maximum of three pods in each tube at any one time; the reduced frequency does mean that three pods are still needed at each station allowing passengers access to the pod at least 3 minutes in advance of departure.

Total pods needed (at peak times): 14

Total Pods Needed

Although routine maintenance will occur on all pods during off peak times any extra pods needed for an emergency (such as a breakdown) would only be needed during peak time with the system able to easily cope without multiple capsules during the 22-hour off peak period. Therefore, these pods help solve a short-term problem and would not be heavily relied upon.

Line	Peak times			Off-Peak times			Additional pods in case of an emergency	Total needed
	Max pods in parallel tubes	Minimum pods for boarding/ disembarking	Pods Needed	Max pods in parallel tubes	Minimum pods for boarding/ disembarking	Pods Needed		
Heathrow - Hub	46	12	58	36	10	46	4	62
Heathrow - Gatwick	14	8	22	12	6	18	2	24
Luton - Hub	8	8	16	6	6	12	2	18
London City - Hub	8	6	14	6	4	10	2	16
Stansted - Hub	8	6	14	6	6	12	2	16
							Overall total	**136**

Passenger Numbers

Below are our projections for the number of passengers to use the Capital Connect Hyperloop transportation system over the next 20 years.

Line	Peak per hour	Off-Peak per hour	Total per day	Total per year	Total over 20 years
Gatwick - Heathrow	1,200	950	23,300	8,510,092	170,201,840
Heathrow - Gatwick	1,200	950	23,300	8,510,092	170,201,840
Heathrow – City	670	510	12,560	4,587,414.4	91,748,288
City – Heathrow	670	510	12,560	4,587,414.4	91,748,288
Heathrow – Stansted	780	600	14,760	5,390,942.4	107,818,848
Stansted – Heathrow	780	600	14,760	5,390,942.4	107,818,848
Heathrow – Luton	1,100	850	20,900	7,633,516	152,670,320
Luton – Heathrow	1,100	850	20,900	7,633,516	152,670,320
Gatwick – City	310	260	6,340	2,315,621.6	46,312,432
City – Gatwick	310	260	6,340	2,315,621.6	46,312,432
Gatwick – Stansted	510	430	10,480	3,827,715.2	76,554,304
Stansted – Gatwick	510	430	10,480	3,827,715.2	76,554,304
Gatwick – Luton	670	510	12,560	4,587,414.4	91,748,288
Luton – Gatwick	670	510	12,560	4,587,414.4	91,748,288
City – Stansted	220	170	4,180	1,526,703.2	30,534,064
Stansted – City	220	170	4,180	1,526,703.2	30,534,064
TOTALS	**10,920**	**8,560**	**210,160**	**76,758,838**	**1,689,454,144**

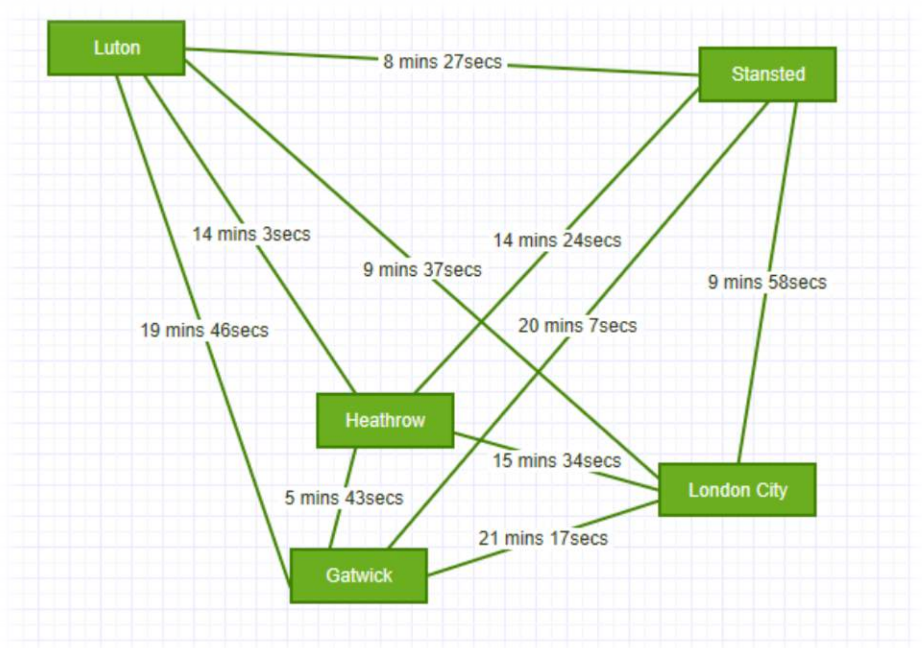
Transport Times Between Airports

Making the 20-minute deadline

The transport time is made up of travel time (in the pod), waiting time and safety checks. In this we are ignoring any time for security checks as all passengers would have already gone through security at the airport they are taking the Hyperloop pod from. Walking time between pods will be near negligible as departing and arriving pods are in close proximity. The waiting time seems unrealistically small as there are multiple pods and passengers are allowed to board up to 1m 30secs in advance of the doors closing.

Line Transfer	Max off-peak waiting time (seconds)	Safety checks (seconds)	Travel time	Total transport time
Gatwick – Heathrow	45	40	4mins 18secs	5mins 43secs
Heathrow – Hub	30	40	8mins 50secs	10mins 0secs
Hub – London City	80	40	3mins 34secs	5mins 34secs
Hub – Luton	50	40	2mins 33secs	4mins 3secs
Hub – Stansted	60	40	2mins 44secs	4mins 24mins

The longest transport time between any two airports is between Gatwick and London City, which requires three transfers (Gatwick – Heathrow, Heathrow – Hub and Hub – London City) with a total transport time of 21 mins 17 secs. With safety checks incorporated into waiting time, these make up 4mins 35secs and a total travel time of 16 mins 42secs, which is within the 20 minutes stipulated.



N.B. This diagram outlines the transport time between all airports and doesn't represent the route lines themselves.

Connecting Passengers to the Hyperloop System

For passengers flying into a London airport, it will be easy for them to access the Hyperloop network. However, many people would be looking to use the system as access to the necessary airport i.e. go to the nearest connected airport and use Hyperloop to get to their departure airport. Whilst the passenger numbers for the system are just for people arriving at an airport, in the future our system could be extended to include passengers coming from other locations in the country. For these people, there needs to be transport systems in place to allow them to do so, which will be able to cope with a further influx of people, especially at peak times of the day.

Passengers from the South

[1] Access by road – Gatwick Airport

- Road vehicles need to use the A23 (Brighton to Crawley) followed by the M23, where Gatwick airport has a specific junction – junction 9. This journey (from Portsmouth) takes around 1hr 30 minutes. Regular coach services also run from Portsmouth, with a similar travel time.

[2] Access by rail – Gatwick Airport or London City Airport

- From the South, Southern Rail run a direct route to London Victoria that stops at Gatwick airport (journey time of around 2 hours from Portsmouth).
- If Southern Rail do not service the users nearest station, then the South West Train service to London Waterloo would be used, followed by a tube ride on the Jubilee line and the Docklands Light Railway to reach London City Airport.
- As both Portsmouth and Southampton have international ports, these users can then use the railway to reach Gatwick airport.

Passengers from the South East

[1] Access by road – Gatwick Airport

- From the South East, cars and other vehicles would need to travel on the M20, the M26, M25 followed by the M23 Southbound until junction 9 at Gatwick. This journey (from Folkestone) would take around 1 hour and 10 minutes, although traffic congestion could lengthen the journey considerably.

[2] Access by rail – London City Airport

- South Eastern run services from Kent to St. Pancras, where passengers can then get the DLR to London City Airport. This service would take around 1 hour and 30 minutes from Folkestone Central, with trains every hour.
- The International Port of Dover is also connected on this high-speed line, although the journey time from Dover is 1 hour and 40 minutes.

Passengers from the West

[1] Access by road – Heathrow or Cheshunt Hub

- From the West Country, travel along the M4 until Junction 5, which is a specific junction for Heathrow. From Bristol, the estimated travel time is 1 hour and 45 minutes.
- From places such as Oxford, the closest connection would be going directly to Cheshunt, the location of the hub. Travelling along the A41 followed by the M25 (leaving at a newly created junction between junctions 25 and 24) would be the fastest, taking just 1 hour and 40 minutes.

[2] Access by rail – Heathrow

- Great Western Railway from Bristol to London Paddington takes 1h 58 minutes. From Paddington, the closest airport is Heathrow, another 15 minutes on the Heathrow express, meaning a total travel time of 2 hours and 13 minutes, nearly half an hour slower than driving.
- Getting the train from Oxford takes the traveller to Marylebone station, in a time of 1 hour and 5 minutes. From there, get the tube one stop to Paddington from which you can catch the Heathrow express, adding about 15 minutes to the journey time, giving a total journey time of 1 hour and 20 minutes.

Passengers from the East

[1] Access by road – Stansted

- From Cambridge, drive along the M11, leaving at Junction 8, a specific junction for Stansted. The journey will take around 45 minutes.
- Norwich – drive along the A11, followed by the M11, until you reach junction 8 for Stansted. Total journey time is estimated to be around 1 hour and 35 minutes.

[2] Access by rail – Stansted

- Cambridge - The train ride from Cambridge is very simple – the Cross-Country train runs directly from Cambridge to Stansted Airport. The total train journey will take 47 minutes
- Norwich – the total journey time will be 2 hours and 8 minutes, using the East Midlands Train, and changing at Cambridge onto the cross-country train line.

Passengers from the Midlands

[1] Access by road – Luton

- From Birmingham, the nearest station is Luton Airport, and by road, will take 1 hour and 38 minutes. The fastest route is using the M6, followed by the M1, taking junction 10, a direct path to Luton.

[2] Access by rail – Luton

- The fastest train from Birmingham is the Virgin Train, which takes 2 hours and 2 minutes directly to Luton. However, when HS2 is built, this journey time will be significantly reduced, and the passengers will arrive in Euston. From this station, the passengers would go to either Heathrow or London City Airport as they both have a travel time of 37 minutes on the Northern line/ DLR.

Passengers from the North

[30] *Access by road – Luton*

- From Manchester, the nearest airport is Luton. By vehicle, the journey time is around 3 hours and 10 minutes. The fastest route is using the M6 and the M1.

[20] *Access by rail – Heathrow or London City Airport*

- From Manchester, a direct train travels to London Euston in a time of around 2 hours. From Euston, the passenger has two choices as both Heathrow Airport and London City Airport are both a further 37 minutes away, using the tube. This would give a total journey time of around 2 hours and 40 minutes.

Alternative Methods of Transport for Future Connection

By Boat – London City Airport and Heathrow Airport

- For any passengers travelling upstream on the Thames, they could use London City Airport to reach their airport faster. London City Airport is situated alongside a marina and so there would also be space for people to park and leave their boats in a secure place.
- In the future, a high-speed boat could collect people from a specific location on the Thames – both up and down stream of London, and shuttle them to the nearest Airport as a method of getting many people to the airports in one go rather than just individual travellers using their own private boats. For people living upstream of the airports, the boat would take them to a location near to Dorney and Windsor, where a shuttle bus could take passengers the short distance along the M4 to Heathrow Airport. For people living downstream of the airports, the boat would take them to London City Airport, which is already adjacent to the Thames, so no further transport link would be needed.

[33] *By drone – any airport*

- Ehang, a Chinese firm, announced at CES technology fair in 2016 that they would be creating a quadcopter that will be able to carry a human – it can carry up to 260 pounds (18 stone) – for a distance of 10 miles (16 km)
- The Drone will be the size of a small car, and could fly for up to 23 minutes. The route would be programmed into a tablet in the drone before take-off, and whilst in flight, the passenger does not need to do anything in terms of piloting the drone.
- It is believed that the drone will cost between US $200,000 and US $300,000 to buy, although they are not yet available to buy. The company hope to have the product available for purchase very soon, however industry experts do have doubts as to whether it will ever work. If it were to work, there would be points where people owning one of these drones could land it, and as a business we could even loan them out as a type of taxi service for people to access our transportation network.

Uber / motorway pickups – any airport

- With the growth of Uber as a cheap alternative to taxi firms, we could create Uber pick up points on the M25 (these could be later expanded to include other motorways), either at the 4 pre-existing motorway service stations, or else create new pick up points just off the motorway at strategic junctions around the M25. At these points, passengers who would be dropped off at the airports could instead be dropped off at these points, easing congestion heading towards the airports and saving time for those who are driving.
- Alternatively, minibuses or coaches could be used for the transport from the pickup points to the airports if this proves to be more economically viable.
- In return for exclusive access to this market and advertising, we would ask Uber to pay a percentage of the costs for creating these pickup points, which would minimise the cost to our project.

Local Socioeconomic and Environmental Impacts

Visual Impacts

- There will be resistance to the Hyperloop based on the visual impact the concrete tubes will have on the environment; especially as the route goes through both the Surrey Hills area of outstanding beauty and Colne Valley Regional Park.
- To combat this trees will be planted either side of the tube to help reduce the visual impact of the line and create a valuable new wildlife habitats. This will effectively create 'green corridors' which will link up isolated wooded area wherever possible.
- The plans for HS2 [34] involve '650 hectares of land' planted with '7 million trees and shrubs' costing an estimated '£5 million'. There is much less land involved in the Hyperloop plans and far more urban areas where extensive horticulture would not be needed.
- Our plans involve the use of a total of **2,701,600m^2 of farmland** (see page 48) which is equivalent to just under **668 acres** therefore the two proposals are comparable and we estimate to spend **£5 million** on a very similar horticultural plan.

Impact to Roads and Transport

- The Hyperloop proposal crosses many existing roads, from minor country lanes through to motorways. The Hyperloop when built will be suspended above the roads with a single concrete pillar helping to support the tube between the two sides of traffic on large motorways.
- Measures will be in place to help reduce inconvenience such as marked diversion routes and temporary traffic lights in order to manage local traffic during the construction work. Although local impact will only be short term for those along the 'Hyperloop' line, for those near station or hub construction this poses a longer-term issue. As such, other measures such as rerouting bus routes, relocating bus stops and adjusting traffic light timings will be considered and used if needed.

Tunnels

- As London is not flat there will be a need for further infrastructure for this proposal to work. This will be detailed fully in the tunnelling section (see page 86).
- However, the tunnels would be included in the plans above to limit the visual impact on the landscape and to limit the impact extensive civil engineering will have on the local road users.

Staffing

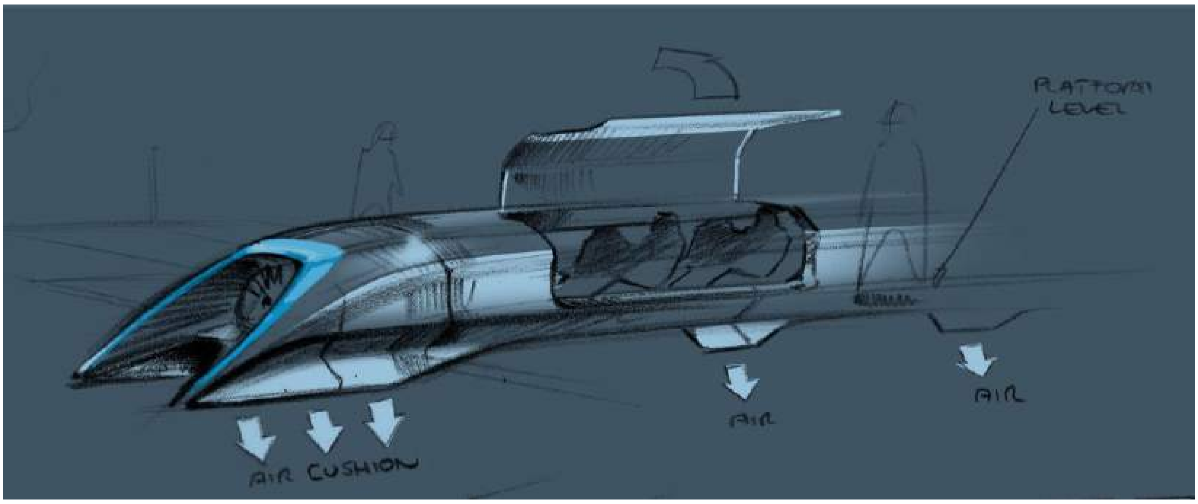
Although ticket gates and machines will be autonomous, staff will still be needed to provide security and load/unload luggage crates into and out of pods. All passengers would already have been through airport security and passengers would be in a closed system to maintain the security assured by the airport procedure. Although this is true, extra security staff would still be needed the stations at each airport as well as the hub.

Gatwick airport employs directly 2,800 people of which 1,800 are security staff. [35] The staff costs covering wages, social security and pensions stand at £178.2 million/ year. [36]

We estimate that **600 staff** will be employed spread proportionally at each airport station and the hub to act as security, baggage loaders, customer assistance and cleaners. A **further 200 staff** would be employed as engineers and as technical support control and manage the Hyperloop – they will be based in the hub. Therefore, with an estimated staff number of **800** and using the Gatwick financial figures the cost of staff will be an estimated to be **£50.9 million a year**. Assuming an average wage rise of 2% each year (matching targeted interest rates) over 20 years the total cost of staffing over the two decades would be **£1,312,370,845.**

This would provide employment for the local area with a range of skill required from manual labour (baggage loading) to engineering and management.

Capsule Structure and Design



Exterior profile

The external view of the Hyperloop capsule is as shown above. The Hyperloop is a large, cylindrical capsule with shape comparable to an ovoid (a 3-dimensional ellipse).

The door designs are twofold in Elon Musk's original California proposal: one design shows a vertically retractable door, while the other shows a sliding retractable door which minimises the need for vertical space at the station, and easier access of escape in case of emergency.

The material making up the capsule exterior will be carbon fibre. After some equations for an estimate on the surface area of the Hyperloop, we calculated that the mass of the capsule would be just under 1.5 tonnes. Not including the mass of the doors and other internal systems acting upon the capsule structure, this is close to the 3100kg estimate provided by Musk. The cost for this much carbon fibre will be around £170,000, which once the doors are factored in, will be very close to the £196,000 value Musk predicted for his Hyperloop capsule and doors.

Interior and seating

There is scope for three distinct types of capsule: coach, business and vehicle-compatible.

In the coach capsule, there will be small TV screens that display the speed of the pod at any given time interval of the journey as well as showing the distance from the destination as well as tables on the back of every seat. These features are like those found on many long-haul flight aircraft.

Business pods would differ from the standard as there would be touch-screens per seat. These would display the same information as in the coach capsules. In addition, screens can also be programmed to show the other useful displays like the outside temperature. Again, there would also be fold out tables. The seats would be made from leather, for a more luxury feel.

Both the coach and business capsule designs contain overhead storage for smaller baggage such as laptop cases and handbags.

Vehicle-compatible capsules would be able to transport cars and motorbikes between destinations, not unlike the vehicle version of the Eurostar train.

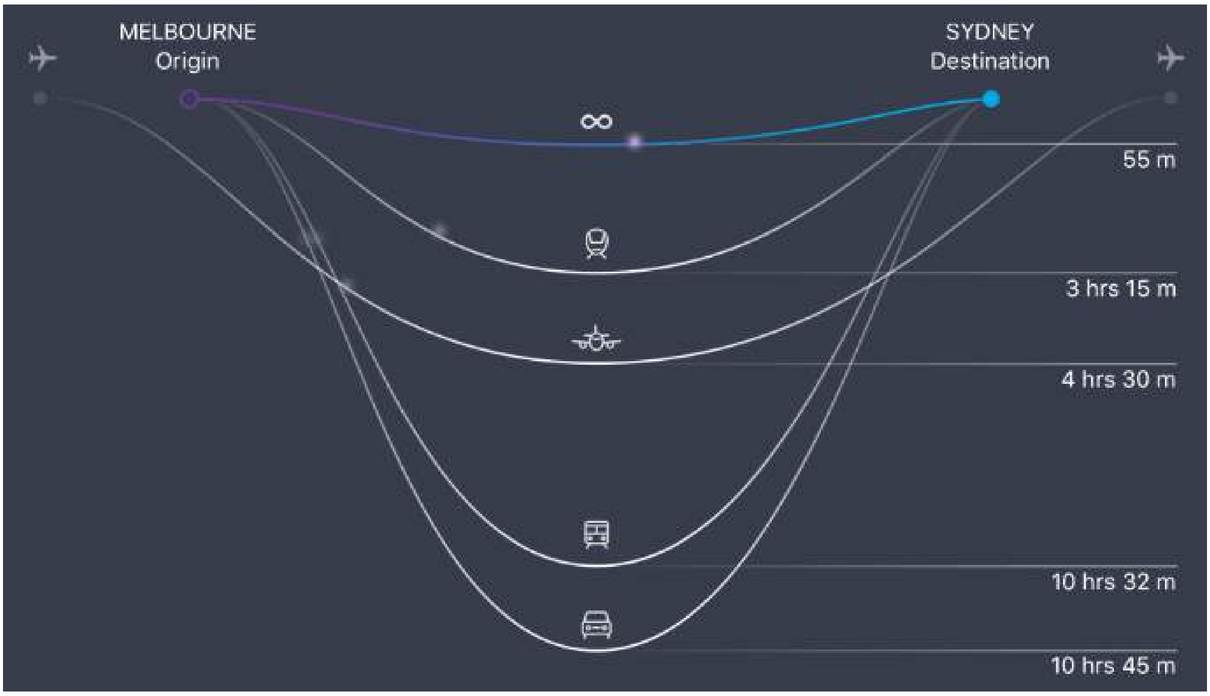
We have opted to ONLY offer the coach capsule on the basis that the journey distances between London airports are fairly short, whereas the journey from San Francisco to LA (as Hyperloop is proposed for) is much longer. The journey times are therefore very short, even for our longest route of Gatwick – Stansted at 109.4km, which is less than 20% of the distance between the two Californian counterpart destinations.

Tube design

The tubes that Hyperloop capsules will transit via operate at low pressures. It was concluded that while a vacuum would offer zero air resistance, the economics of providing this were highly unpreferable. Keeping a system such as this in a constant vacuum state would prove difficult to maintain, both mechanically and in terms of finances.

However, the Hyperloop still offers low friction, but rather with a low pressure (0.1KPa) environment. The minimal resistance compares to a high-altitude airplane, except that the Hyperloop is more efficient.

The diagram below is taken from the official website for the Hyperloop One [37] from Melbourne to Sydney, and visually displays the efficiency of the Hyperloop, compared with other common modes of transportation. So, while airplanes may seem to be the fastest vehicles on the planet, the Hyperloop sets to top this with the aid of near-sonic speeds in a low-pressure enclosure.



The exterior of the tube is reinforced to protect it from the wealth of elements that the London area holds throughout an annual period: rain, wind and gales, sleet, snow, sun exposure, heat, moisture and ice.

Solar panels are also a feature of the tube exterior (see page 72), making the system almost entirely self-powering. The panels will be arranged over the top of the tubing, converting solar energy into electrical energy.

While London is not a seismically active area, the tube system is sufficiently protected from earthquake shockwaves due to pylons that can be fabricated with adjustable dampers and expansion joints, allowing them to 'sway'. This is important, not only for seismic possibilities but also for stability; rigid structures are more likely to suffer mechanical trauma. This can be analogised to large skyscrapers in cities built to withstand earthquakes, for example Tokyo. Engineering flexibility into the structures means that less energy is needed to combat the seismic waves [38] whereas rigidity promotes stress and therefore ruptures.

The pylons themselves are built with minimal damage caused to the surrounding environment. The system being built above ground means little land space is used, especially in comparison to existing railway lines and roads. In addition, our land use is optimised with landscaping features (see page 96). This promotes preservation of the natural environment.

Interior systems

Overall, the Hyperloop capsule contains multiple component systems, which are as follows:

- Inlet
- Compressor Fan
- Compressor Motor
- Firewall
- Air Storage
- Seating
- Suspension
- Batteries

Combined together, and with the motors and electromagnets, they allow for motion of the Hyperloop. More explanation can be found in the components section (see page 64).

Components

The propulsion system has one unit has 4 basic requirements:

1. Accelerate the capsule from 0 to 300mph for relatively low speed travel in urban areas.
2. Maintain this capsule speed at about 300mph as necessary through the urban areas of London.
3. Accelerating the capsule from 300 to 760mph at 0.5g.
4. Decelerating the capsule back to 300mph, and then to rest for arrival at the stations.

Additionally, within the capsule, propulsion systems can be divided between:

a. Linear accelerators: constructed along the length of the tube at various locations to accelerate the capsules.

b. Stators: located on the capsules to transfer momentum via the linear accelerators.

PROPULSION COMPONENTS

Suspension and air bearings

Maglev technology was formerly investigated, however Musk and ourselves both conclude that it was 'prohibitive' due to material, construction and cost. The alternative chosen for the Hyperloop design was the 'air bearing suspension'. This was because 'Air bearings offer stability and extremely low drag at a feasible cost'.

The 'skis' which convert the energy supplied through the tube, are made of aluminium, and pass through an 'air gap' between copper coils to create induction from an electromagnet. Keeping constant supply of electricity to these coils will keep the blades centred and lead to a smooth ride for passengers.

Musk also gently explored the possibility of having a wheel and axel system to accelerate the vehicle to 100mph for passenger stability and to avoid instant levitation. We have taken this on board: wheels will be the source of transit in the first phase of acceleration, after which they will return to inside the system, much like landing gear on an aircraft. The skis are kept upright by injecting highly pressurized air into the air gap, following the wheel-stage. This external pressure factor creates an uneven distribution beneath the bearing, leading to lift of the capsule. The result is an effective ‘floating’ of the capsule for the majority of the duration of the journey. Again, on deceleration, the wheel axels will be deployed as the Hyperloop comes to rest.

Air bearings in more detail

When the gap between a ski and the tube wall is reduced, the air flow field around the gap exhibit a high non-linear reaction which results in restoring pressures. This increased pressure within the gap gently pushes the capsule ski away from the wall to return the capsule to its ride height.

Each ski supports the capsule by floating on a ‘pressurised cushion of air’ around 1.3mm thick, and Musk predicts the maximum pressure this air will be put to will peak at around 9.4kPa. The air skis depend on two components to pressurize the thin layer of air beneath: external pressurization and aerodynamics.

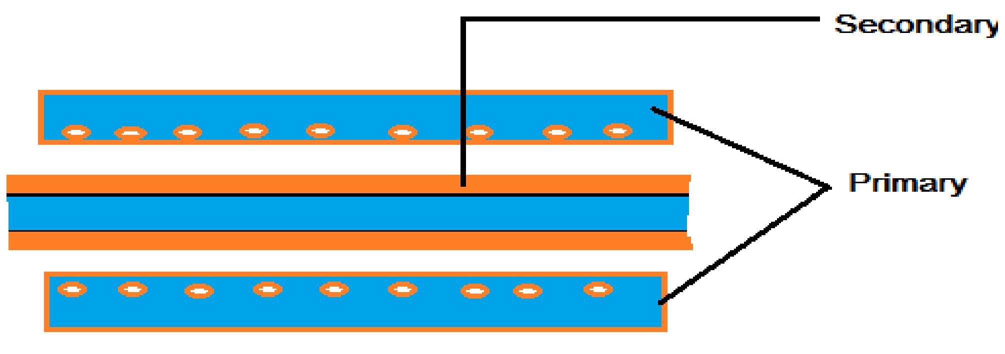
- **Aerodynamic mechanism:** becomes viable at high speeds. As the capsule accelerates, the front tip of each ski is raised to a 0.05°. Viscous forces trap a thin layer of air within the gap between the tube wall and the air ski, providing a pressurized layer of air.

- **External pressure:** pressurized air is inserted into the tube which is stored within a high-pressure air reservoir onboard the capsule. This air is released in small quantities relative to the lift needed to keep the capsule in a stable condition in air. This external pressured air can be used for slow speeds where aerodynamics is not as effective, or when the capsule is stationary. 28 air bearings make up the design of the capsule, each expected to be around 1.5 metres in length and 0.9 metres in width.

Linear induction motor

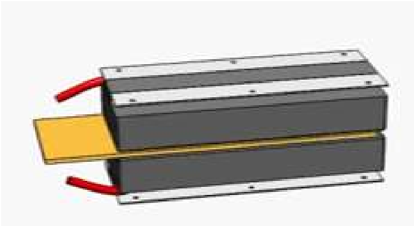
The motor system that propels the Hyperloop is the linear induction motor (LIM).

With a standard induction motor, a central, free spinning circle made of a conductive material (usually aluminium or copper) known as a rotor is surrounded by electromagnet coils, made of copper, called the stator (these do not move). When an AC current is passed through the coils, a magnetic field is produced. These copper coils are frequently magnetised and unmagnetised (at the same frequency as the AC current) in pairs that are opposite to each other. This means that the magnetic field constantly changes direction, in a rotary motion. This change in the magnetic field results in Faraday's law [42] of magnetism becoming relevant – when a magnetic field is changed, an 'emf' is created within the coils. This change in magnetic field induces an electric current within the rotor. In the rotor, the current flows around the metal sheet in a circular motion, creating a magnetic field of its own. Due to Lenz's law of magnetism, this magnetic field tries to stop the other magnetic field, by rotating at the same speed as the magnetic field in the stator. As the magnetic field in the central rotor is always trying to catch up with this ever-moving magnetic field, the rotor in the middle spins around. This spinning creates the power from the motor, and is the reason that an induction motor works.

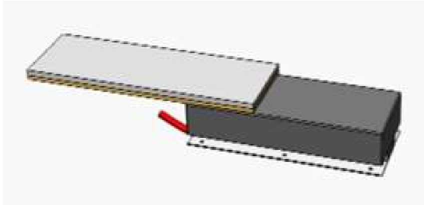


Dual Linear induction motor （DLIM）

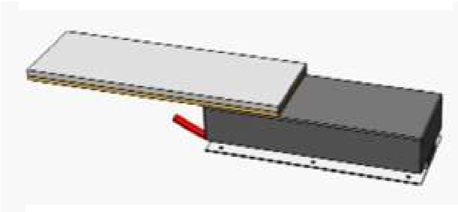
We cannot just use a standard induction motor because this type of motor produces rotational motion, [39] which is good for cars and standard trains where the motor is used to drive wheels, but for our Hyperloop that will hover a few centimetres above the guidance track on an air cushion, a rotational force would not drive the pod forwards. Instead, linear force is needed, which is why a linear motor is needed. A linear motor works using the same laws of electromagnetism, but instead of having a rotor surrounded by a circular shaped coil of stators, the stators are laid out flat (like a track). The rotor is a platform that glides past the stator, propelled forwards and hovering above the track due to the magnetic field produced when a current is passed through the stator. This idea can be seen in the diagram above, [40] where a rotor passes between two stators, which have current flowing through them, and in the series of diagrams below that explain the motion of the motor.



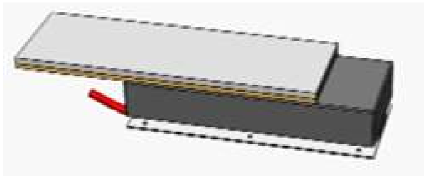
The double-sided configuration of the induction motor uses an aluminium reaction plate.



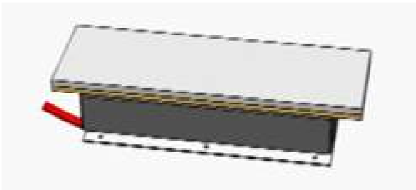
When the aluminium reaction plate is over the LIM, power is supplied to components.



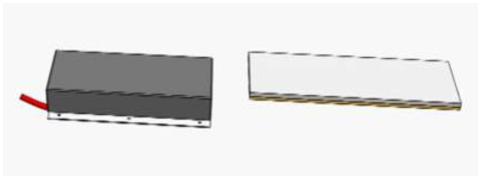
Depicted here, the motor is producing approximately 30% of full rated force.



Power is supplied in greater weighting as the reaction plate covers the LIM more fully.



With the LIM at 100% coverage, the motor is producing 100% of rated force



As the aluminium reaction plate exits the LIM, the power is taken away again.

Linear motors are better than standard electric motors for many reasons; [41]

- There are no moving parts that work together to create motion, so there is nothing that can go wrong due to wear and tear (unlike cogs, spinning rotors etc.)
- They are more energy efficient than standard motors because there is less friction acting between parts, and less friction acting between a track and wheels (However, because a linear induction motor is required to produce motion in both the upwards and forwards direction, more energy is required to power the system in the first place).
- The linear induction motor provides motion directly to the pods, meaning that no energy will be wasted in a gearbox system, meaning greater efficiency can be achieved.
- As both acceleration and braking occur due to electromagnetism, linear motors are much quieter than ordinary motors.

Halbach Array

The Halbach array is a specifically designed array of NdFeB magnets* which assist a vehicle to levitate over an induced electromagnetic field. A levitation train would have many major benefits; low frictional forces, high speeds and small noise and air pollution to name just a select few.

Recently, scientists from Lawrence Livermore have created a simpler and more sustainable maglev system design, which induces strong repulsing currents through a coiled copper (inductrack) track, forcing the train car above into levitation.

*Composition:

Neodymium: 29-32%
Iron: 64.2-68.5%
Boron: 1.0-1.2%
Aluminium: 0.2-0.4%
Niobium: 0.5-1%
Dysprosium: 0.8-1.2%

Head Physicist Richard Post led an experiment into Inductrack concept trials. His initial results showed complete control with no external forces, highlighting the system's ability to maintain stability.

Inductrack contains a permanent array (Halbach) of magnets which are placed on the vehicle and a copper coil track. 'Halbach arrays concentrate the magnetic field on one side while cancelling the current on the opposite, and when mounted on the under-base of a vehicle, the arrays generate a magnetic field which induces current in track coils, levitating the car, and stabilising it'

An electrical converter, which will be connected at various points around the track converts electrical energy into kinetic when supplied to the copper coils on the copper track. Electric motors generate magnetic fields with electric current through a coil. The magnetic field then causes acceleration through electromagnetism.

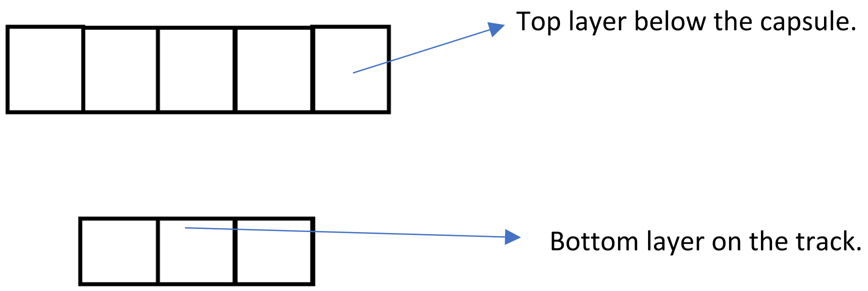


Figure 1: Schematic representation of "5 x 3" baseline Halbach array system.

The Halbach Array consists of 5x3 magnets, 5 on the vehicle and 3 on the track which induce a magnetic current which repulse each other to result in levitation. The force is exerted by forces of attraction between Halbach rows, and the configuration also provides the lateral centring.

From experiments carried out, the magnetic field cannot be used for acceleration from around 1-2 km an hour, so a mechanical system must be used to accelerate the train to minimal levitation speeds. Initial movement requires mechanical movement prior to levitation.

Batteries

The capsule's power system includes approximately **2,500 kg** = 5,500 lb of batteries to power the capsule systems in addition to the compressor motor and coolant.

A minimum of two redundant lithium ion battery packs will power the life support systems, meaning the batteries would continue to run even in a power outage. In such an event, after a capsule had been launched, all linear accelerators would be equipped with enough energy storage to bring all capsules currently in the Hyperloop tube safely to a stop at their destination. In addition, linear accelerators using the same storage would complete the acceleration of all capsules currently in the tube. For additional redundancy, all Hyperloop capsules would be fitted with a mechanical braking system to bring capsules safely to a stop.

Coolant

One of the greatest potential difficulties is cooling the Hyperloop. The heat that radiates out from any electrical system due to current flowing through each component normally would dissipate in to the air. However, as the Hyperloop operates as a low-pressure system, inside the tube is almost a vacuum and so the heat effectively has nowhere to go. This means the electronics, motor, bearings and passenger cabin will have to be cooled constantly.

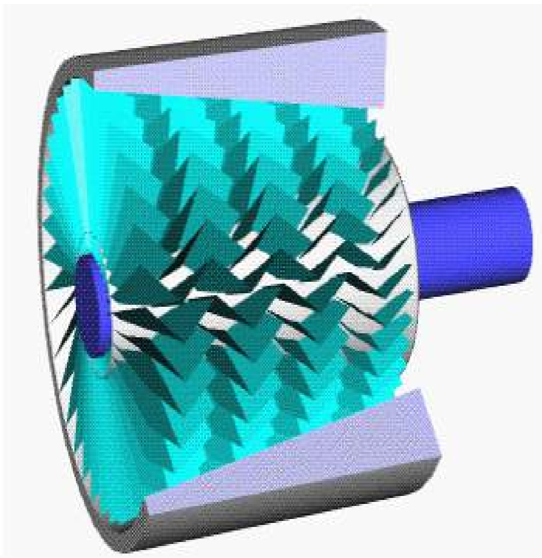
Injecting steam into the tube is a solution to this problem. The steam is pumped in to the condensers, converting it back into water. This is then heated up to around 25 degrees centigrade by means of a heat exchanger. This is then injected into the capsule as air for the passengers. Water is also pumped to the electronics, as well as oil to the mechanics of the Hyperloop.

In addition, smaller or isolated devices can be 'spot cooled' simply by feeding smaller quantities of water, which is made to evaporate to form steam. An example of these components are the wheels. These will be sprayed to the inner surface so that the water will evaporate and, following this, leave through the tube.

Air compressor

The air that is in the tube is compressed at a ratio of 20:1 via an axial compressor. 'In an axial compressor, the air flows parallel to the axis of rotation. The compressor is composed of several rows of airflow cascades. Some of the rows (rotors) are connected to the central shaft and rotate at high speed. Other rows (stators) are fixed and do not rotate.' Stators increase pressure and stop the flow from spiralling around the axis by bringing the flow parallel to the axis.

'Each blade on a rotor or stator produces a pressure variation much like the airflow of a spinning propeller. However, the blades of an axial compressor are close to one another, which seriously alter the flow around each blade. Compressor blades continuously pass through the wakes of upstream blades that introduce unsteady flow variations.'



Axial compressor above [43] with both rotors and stators. The compressor is attached to a shaft which is connected to the power turbine on the right end of the blue shaft.

Stages of Motion

Motion of the Hyperloop occurs because of a series of stages that take it from being stationary at our hub or station, to moving above ground through a near-vacuum at subsonic speeds.

Stage 1 – Levitation

This stage occurs due to many components such as the Halbach array, the linear induction motor, and the track itself all working together. The Hyperloop capsule must first enter levitation before acceleration and cruising speeds. The Halbach array of magnets and the magnetic field given off by the copper coils electromagnetism working in unison introduce repulsive forces to each other, forcing the Hyperloop capsule into levitation above the track below. The Halbach array (see page 67) is arranged in such a way in which it balances out the capsule on a levitating cushion of air to provide a smooth ride for those onboard.

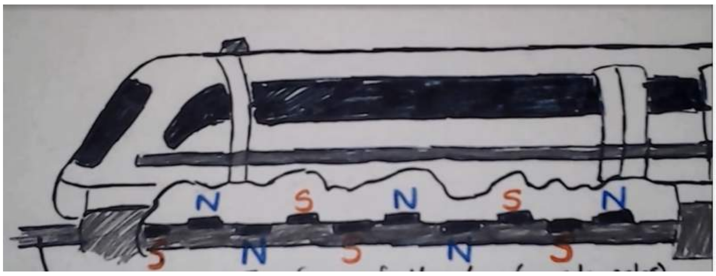
The magnetism either side of the capsule on the copper track will be equal all throughout this area, leading to equal forces pulling, and resulting in equilibrium of the capsule.

Stage 2 – Acceleration

For acceleration to occur, there are two possible methods of increasing the velocity of the aerial capsule.

i. *Copper coil tightness*
   It is well known that the greater the number of copper coils in an electromagnet per unit space, the higher the strength of the electromagnet. This can be changed at certain points during the allocated paths between airports as well as unaltered, so that the copper coil alone controls the speed of the Hyperloop. It can be sent on a certain track, automatically reaching acceleration speeds or deceleration speeds at pre-programmed points.

ii. *Input current into the copper coils*
   The other method of increasing electromagnetic strength is by increasing the inputted current at certain acceleration points along the track. Current will be inputted into the tube system by strategically located 'electricity stations' which will be placed underneath or beside the Hyperloop tube. Staff will monitor these stations constantly and will supply select currents, possibly using large scale variable resistors. This can either be powered by the grid if needed, or powered by the proposed solar panelling on the roof of the Hyperloop tube expanse. Varying the current inputted into the electromagnet will increase the strength at certain points along the tube, leading to a higher force of attraction so the capsule will be pulled along faster i.e. acceleration.



[44] As shown in this image, opposite polar magnets alternating along the bottom of the capsule and the track lead to a high force of attraction after initial movement forwards, resulting in a faster moving capsule as the strength of the electromagnet becomes higher.

The magnitude of current is proportional to the strength of the magnetic field it produces. The Biot-Savart law or the Ampere's circuital theorem well illustrate this fact.

For example, if we are using a solenoid as an electromagnet, we are familiar with the expression:

$B = \mu_0 n I$, where B is the magnetic field strength and I is the electric current.

N.B: There is an internal tube factor which also leads to levitation and acceleration, that being the air pushed through the air bearings on the underside of the capsule and pushing the capsule up.

Stage 3 – Cruising Speeds

For our smaller scale design of the Hyperloop in London, compared to original plans for a cross American track, there will only be a few sections in which cruising speeds will be capable due to time taken during acceleration and deceleration. It is hoped that the Hyperloop capsule will be able to sustain itself with minimum input energy from the current in the copper coils by exploiting the limited air resistance and low pressures. A fan on the front powered internally by onboard batteries will keep the system flowing to minimise the small amounts of air resistance and to efficiently use air to assist levitation.

The air skis will allow the small air resistance there is to break up, and result in added lift to the levitation to lower the front surface air resistance. Due to the de-pressurised tube system, there will be a much lower value for friction acting upon the front of the capsule.

Stage 4 – Deceleration

As for acceleration, there will again be different methods of achieving the 0.5g target for

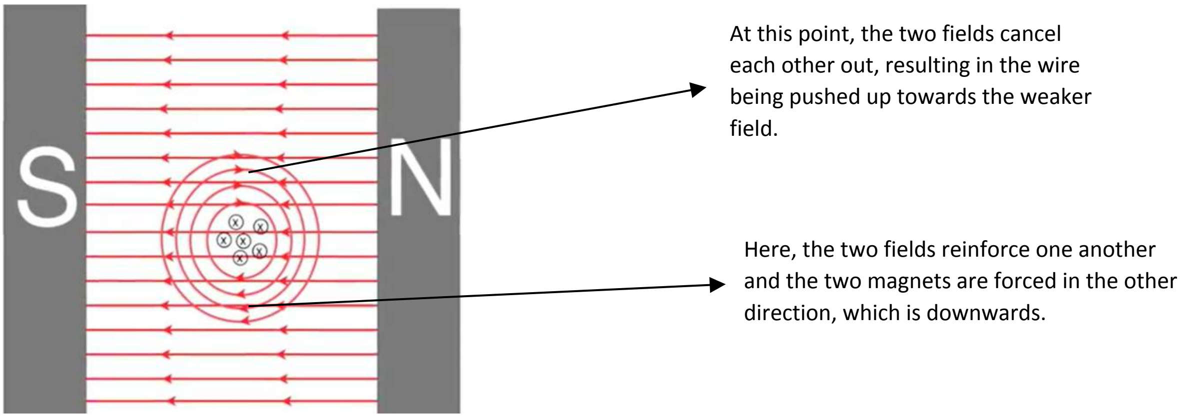
i. *Polar swap*
By introducing the current from the opposite direction to the direction of travel, the electromagnetic polar charge will flip and this will result in the opposite to acceleration. The magnets at the front of the capsule will push against the track magnets in front (these magnets will not change polarity due to being permanent magnets) resulting in repulsing forces causing gradual deceleration.

ii. *Input current*
Another method of controlling the speed of the Hyperloop is simply by changing the current inputted to that section of track, meaning a lower strength magnetic field, again causing gradual deceleration.

iii. *Coil Gap*
The final method is simply by increasing the coil gap in reverse to what was explained for the acceleration. This reduces the magnetic field strength, causing repulsive forces to be lowered which ends with deceleration.

Should any problem arise, the input current throughout the entirety of the tube at any point can be manually changed to decelerate the capsule to avoid any crashes, particularly those at high speeds.

'Semi - conductor switches' will be in use which optimise the track to certain parts of highest speed, where the input current will be significantly higher to cause acceleration or reversed to cause deceleration.



Shown here in this diagram, the north to south magnetic field can be seen, as well as the wire current field shown too.

This effectively explains the movement of the Hyperloop capsule as the copper coils inducing a current transfer electricity into kinetic energy through the linear induction motor, as the magnets are pushed away from the weaker field. This happens multiple times along the coil until the capsule hits a terminal velocity given the current conditions.

As shown earlier, the increased current can lead to a stronger magnetic attraction, meaning the magnets move faster and accelerate.

Citing many Hyperloop articles, it becomes evident that the Hyperloop capsule cannot move from a standstill without using a very high current, so a mechanical system will be put into place to raise the Hyperloop speed to around 1-5km/h, in which the energy required for levitation and propulsion will be significantly lower.

Solar Panels

A self-powering system

A key feature of the Hyperloop system, and a factor in our decision to use this method of transportation, is its claim to be completely off grid i.e. no need to purchase and use electricity from power stations. This is managed by covering the top side of the tubes that house the pods and tracks in solar panels. The plan from Space X [32] states that 'The Hyperloop can generate far in excess of the energy needed to operate. This takes into account storing enough energy in battery packs to operate at night and for periods of extended cloudy weather.'

Calculating power production

The solar panels used Musk's design are said to produce 120 W/m^2 when solar intensity is at its peak (in Los Angeles, peak irradiance is 7.83 kwh/m^2/day) and the planned width of solar panels used on the tube would be 4.25m. Therefore, for our project with a total tube length of 345.4km, we would have a solar panel area of 1,467,950 m^2. To work out the peak power output we could expect in London from the solar panels, we used the following steps:

- 120 W/m^2 ÷ 7.83 kwh/m^2/day = 15.3256
- 15.3256 × 4.86=72.9 W/m^2 (4.86 is the peak irradiance for London)
- 72.9 × 0.75 = 54.675 W/m^2 (solar panels only work at around 75% efficiency)
- 54.675 W/m^2 × 1467950m^2 = 80260166 W = 80.3MW

However, solar irradiance is rarely at peak levels, as it varies with each month depending on the earths relation to the sun, weather patterns etc.

Using a website [45] that gives the average solar irradiance per month for central London, and averaging this out across the year gives us a mean irradiance level of 2.7075 kwh/m^2/day. Using the same method as above, we found that the average power output from the solar panels would be 45.7 MW.

- 120 W/m^2 ÷ 7.83 kwh/m^2/day =15.3256
- 15.3256 × 2.7075 kwh/m^2/day = 41.494062 W/m^2
- 41.494062 × 0.75 = 31.120546 W/m^2
- 31.120546 W/m^2 × 1467950m^2 = 45683405 W = 45.7MW

In the proposal for California, it is stated that the average power required by the Hyperloop would be 21MW. The figure we will need will be very similar to this, although we have a much shorter track length. This power figure of 21MW includes the running of the motor that generates motion of the pods; powering vacuum pumps for the reduction of pressure within the tube, and of on board compressors. Therefore, the solar panels would produce over double the average power needed.

However, there will be more pods travelling at any given time for the Capital Connect Hyperloop and, in addition, the 6 stops we propose, rather than the 2 used in the Californian proposal, mean there will be more acceleration and deceleration per unit distance. Accelerating and decelerating are the most power consuming processes of the journey.

Power shortages during acceleration and deceleration

The estimation is that the process of accelerating and decelerating the pods will consume nearly 3 times as much power, nearly 60MW, which would mean that at certain points of the journey, we would not have enough power. To combat this shortfall, the approximate 20MW that are not needed for the pod whilst it is at cruising speed can be stored in arrays at each acceleration point on the track, which will be drawn upon when the pods require acceleration or deceleration. The result is that, although the power produced by the solar panel system is less than the power required at peak times, there would be no need to draw on power from the national grid. In other words, the Hyperloop network will indeed be self-powering.

Connection to the Grid

The system would still be connected to the national grid as a safety precaution in case the power produced in the solar panels and transferred to the propulsion systems were to stop working or be limited in its efficiency for some reason. Moreover, during extended periods without strong sunlight, the national grid may be required to ‘top up’ the power produced in the solar panels, in order to maintain the Hyperloop.

Maintenance

Solar panels are mostly self-cleaning, and a small amount of dust and general dirt does not affect the power production capabilities of the panels. Regular rainfall also helps with the cleaning process, as it washes off the dirt on the panels. Therefore, the solar panels will be fairly low maintenance once installed - they should not need cleaning once they are in place.

Capsule Costs

For the initial calculations for costing the Hyperloop mechanical systems, we looked to the Hyperloop Alpha plans. From the plans, the cost of all the capsules required for the California rail (40) is estimated to be under or around 1% of the total budget. Musk provides a predicted breakdown of the different interior and exterior components in the makeup of the Hyperloop capsule and their costs:

Vehicle Component	Cost ($)	Weight (kg)	Cost (£)
Capsule structure and doors	$ 245,000.00	3100.00	£ 196,000.00
Interior and seats	$ 255,000.00	2500.00	£ 204,000.00
Propulsion Systems	$ 75,000.00	700.00	£ 60,000.00
Suspension and air bearings	$ 200,000.00	1000.00	£ 160,000.00
Batteries, Motor and Coolant	$ 150,000.00	2500.00	£ 120,000.00
Air Compressor	$ 275,000.00	1800.00	£ 220,000.00
Emergency Braking	$ 50,000.00	600.00	£ 40,000.00
General Assembly	$ 100,000.00	N/A	£ 80,000.00
Passengers and luggage	N/A	2800.00	
Total per capsule =	$ 1,350,000.00	15000.00	£ 1,080,000.00

Each Hyperloop capsule will cost **£1.08 million** once transferred through a dollar to pound conversion. From Musk's designs, the predicted the weight of an Hyperloop passenger capsule is around **15 tonnes** (15000kg).

Component Costs [32]

There are many individual components which make up the total cost of the Hyperloop capsule. Those detailed below will progress in the order as they appear in the table above.

Capsule structure and doors

The cost of the capsule structure will cover the cost of the material used to structure the outside of the capsule to maximise aerodynamics of the capsule. This cost will also cover the construction of the sliding doors, which must be sealed shut to avoid release of air or passenger exposure to vacuum. The material used for these components are not specified under Musk's individual plans. (Check theoretical section 3 for cost derivations on different sample materials which could be used).

Interior and seats

Interior components are expected to be around **2500kg** including seats, restraint systems, interior and door panels, luggage compartments and entertainment displays. Seat designs have been given, but no true values for seating or interior dimensions have been given.

Propulsion system

An advanced linear system would accelerate the capsule to around **760mph**. The system includes a motor (rotor) which converts the electricity converted from the skis which are picked up from the stationary motors, which power the vehicle from the tube.

Suspension and air bearings

Elon Musk investigated the use of maglev technology, only to conclude that it was 'prohibitive' due to material, construction, and cost. The alternative he chose to use for his design was the 'air bearing suspension'. This was because 'Air bearings offer stability and extremely low drag at a feasible cost'.

These 'skis' which convert the energy supplied through the tube, are made of aluminium, and will pass through and 'air gap' between copper coils to create induction from an electromagnet. Keeping constant supply of electricity to these coils will keep the blades centred and lead to a smooth ride for passengers. Musk also gently explored the possibility of having a wheel and axel system to accelerate the vehicle to 100mph for passenger stability and to avoid instant levitation.

The skis are kept upright by injecting highly pressurized air into the gap. This external pressure factor creates an uneven distribution beneath the bearing, leading to lift of the capsule.

Batteries, motor, and coolant

As mentioned previously, the motor is an onboard linear induction motor which can convert energy from an electromagnet connected to the tube to give thrust or deceleration to the capsule due to magnetic repulsion, also leading to the levitation.

The batteries will be stored at the back of the capsule according to Musk, and will be recharged at each acceleration and deceleration point due to inducted electricity passed onto the battery from the linear motor, or they can be recharged manually via the grid (or otherwise) at each station.

4000kg of batteries are estimated to provide **45 minutes** of onboard compressor power to supply the capsules with air.

The onboard batteries will be changed at each stop, and charged at each of the stations.

The coolants are within the air compression and within the aerodynamics of the capsule.

Air compressor

This system allows the capsule to traverse the relatively narrow tube without choking air flow creating a build-up of air-mass in front of the capsule, possibly largely increasing the drag force. The system compresses air that is bypassed through the capsule, and supplies the air to the air bearings (in the skis) that support the weight of the capsule.

There is a detailed system which is listed within the original Alpha plans by Elon Musk, in which we will simplify to the components.

1. Tube air is compressed 20:1 via an **axial compressor**.
2. 60% is bypassed through the capsule through two methods:
    i) Air passes through a narrow gap towards the underside of the capsule tail.

    ii) A nozzle which expands at the tail creating thrust to mitigate (negate) some of the aerodynamic and air bearing drag.
3. Air is cooled and compressed 5.2:1 with additional cooling within the **intercoolers** afterwards.
4. Onboard **water tank** is used for cooling of air.
5. Compressor is powered by a **325kW onboard electric motor**:
    i) Motor Mass: **169kg**

    ii) **1500 kg of batteries** provide 45 minutes of onboard compressor power, more than sufficient for travel time plus added reserve backup power.

Emergency braking
The cost of an emergency braking system is not specified under Elon Musk's Alpha plans. In the costs section of this report, we have assumed a value for this, in line with our calculations.

General assembly
The general assembly cannot be commented on as it is just a rough estimate provided by Musk. However, we predict to be fully up and functioning by 2024.

Theoretical Design Costs

We have researched and have been able to provide some additional information on materials and how different interior designs could be favourable.

Capsule structure
We have researched different materials in which could be used in the construction of the Hyperloop. The one material we found a stark similarity with for the numbers in which Musk produced was carbon fibre.

After some equations for an estimate on the surface area of the Hyperloop, we found that the mass of the capsule would be **just under 1.5 tonnes**. Not including the mass of the doors, this is not too far off from the **3100kg** estimate provided by Musk. The cost for this amount of Carbon Fibre will also be around **£170,000**, which once the doors are factored in, the value will be very close to the **£196,000** value Musk predicted for the Hyperloop capsule and doors.

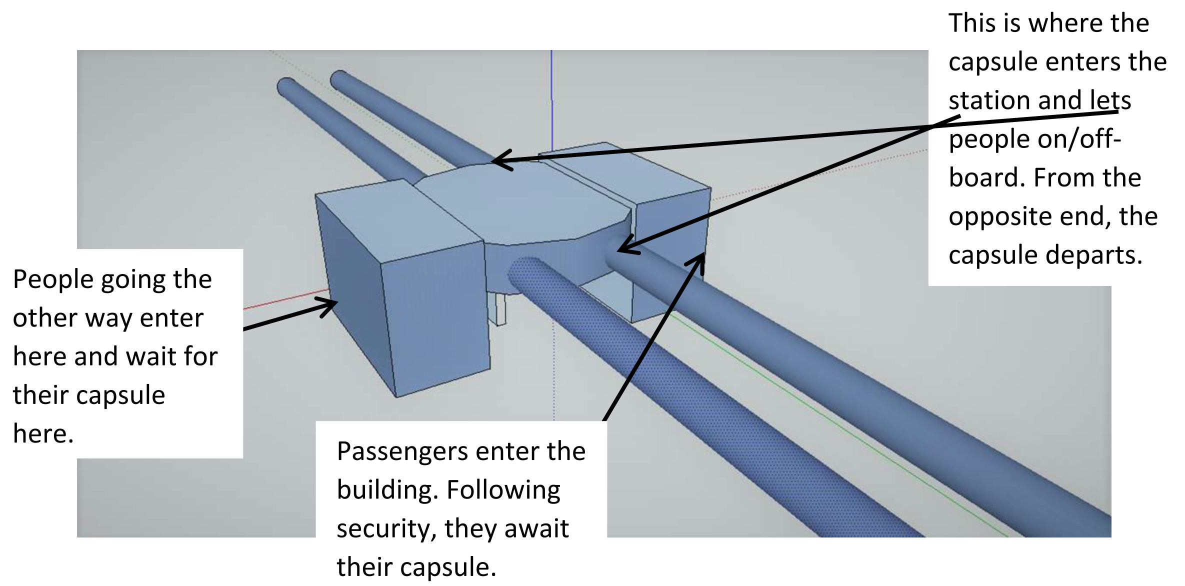
Station Design

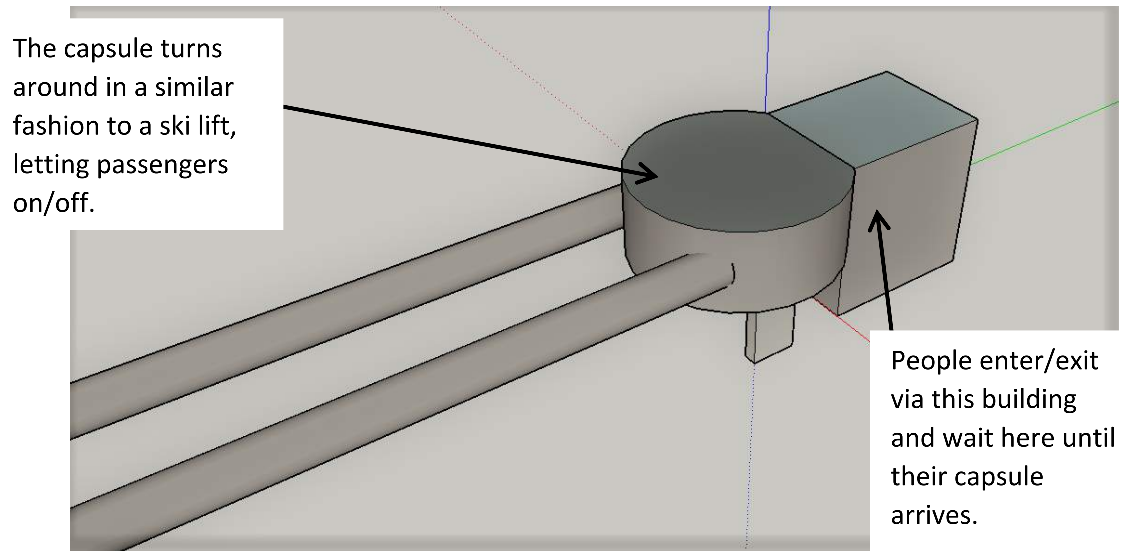
The train station is designed to be as fluent and as fast moving as possible meaning that there is less waiting time and the trains are more efficient.

There are two buildings which are connected:

- A concentric / circular building where the capsules enter and exit.
- Adjacent waiting areas where security monitors passengers (see 'Safety') before they enter the loading and offloading complex.

The diagrams below, drawn in Sketch Up Make, depict our impressions of station designs.





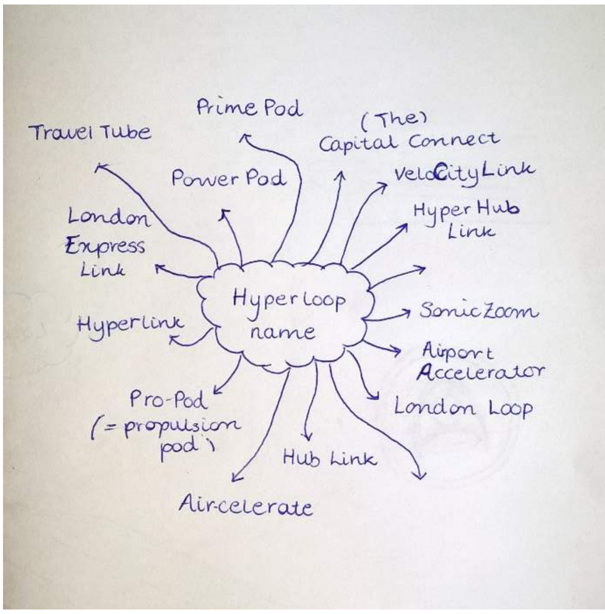
[32] Once a capsule has entered the station and collected passengers, it enters an air lock in which the pressure is equalized with the station before being released into the transit area.

When a capsule re-enters at its destination station, the luggage pod breaks away and staff unload the baggage, putting it on a conveyor belt for the passengers to collect later (similar to that of an airport). The passengers get off the capsule as it moves very slowly round to the other side of the station for staff to load luggage and passengers to enter the capsule.

Tickets are purchased electronically, rather than from personnel behind windows (as you would find in most rail stations). Autonomous ticket gates are also used to make the system more efficient.

Name and Logo Design

While our proposal is an adaptation of Elon Musk's up-and-coming Hyperloop system, ours is to be unique. For example, primarily it serves a different function: it greatly improves efficiency of connecting airport users to their airport destinations, while Musk's is merely to connect two cities (Los Angeles and San Francisco). For this reason, we have devised a brand name and logo for our London airport scenario.



Designing the Hyperloop Name

Adjacent is the original mind-map we planned to come to the conclusion that our system is to be:

CAPITAL CONNECT

We decided that this name was:

- straight-forward
- memorable
- reflective of the system's purpose

Essentially, our clients (transport users) will be clear on the purpose of the system: to connect between areas of the country's capital.

Designing the Hyperloop Logo

On deciding a name, we decided to engineer a logo. [46] [47] We came up with two main designs, but decided upon the one below:

Safety

Emergency Stop

- A major safety concern is that with pods being sent with a frequency of every 24 seconds, is that if an emergency occurs in front of the pod it would not be able to stop in time.

- If the pod in front stops immediately without warning (an unrealistically unfortunate scenario), the pod behind would apply an emergency brake of between 0.9-1.0g (equivalent to a deceleration of 8.82-9.8m/s^2). If this were to occur in the Heathrow-Hub line, the closest distance apart that any two pods could be would occur when the pod behind is just about to decelerate – at this point the pods are 1411.2m apart. When the pod's immediate stop is detected, an emergency brake equivalent to 1g of force is applied resulting in that pod decelerating form 134.1m/s to 0m/s in 917.5m nearly 0.5km behind the first pod.

- Another scenario would be if the pod's propulsion system malfunctioned resulting in the pod losing speed (due to the drag force produced by the reduced air pressure acting on the pod). If the pod had already reached maximum speed it could 'cruise' to the station with pods behind it reducing their speed accordingly to maintain a safe distance. However, if the pod had not reached the necessary velocity to 'cruise' to the station' the mechanical brakes would be deployed on that pod and on all pods behind it. Once all capsules behind the stranded capsule had been safely brought to rest, capsules would drive themselves to safety using small on-board electric motors to power deployed wheels meanwhile specialist engineers would attend to the stranded capsule.

Power Outage

- The batteries in the capsules would contain enough energy to complete their entire journey and therefore from the perspective of the passengers nothing would happen. As an extra precaution, two redundant batteries in each pod power the life support systems and, in addition to this, the mechanical braking system can provide further redundancy.

Incident in the Capsule

- Passengers are far less at risk of violent assault on the capsule than on public transport, due to airport level security checks meaning that any sharps are left in baggage and any potential explosives are detected and dealt with. However, in the case of physical or sexual assault, on-board cameras can record the evidence and passengers can contact both Hyperloop staff and the emergency services. Security staff and eventually the police would be waiting for the assailant as the pod arrives at its destination.

- Equally, if a medical emergency occurred during transit Hyperloop operators can be contacted who would then alert paramedics based at the airports/ hub enabling the passenger in distress to be greeted by paramedics almost imminently upon arrival. This is in addition to first aid equipment found on every capsule.

Risks of Depressurised Tubes

- A major depressurisation will trigger pressure sensors that will then communicate to all tubes heading towards the damage to apply their emergency mechanical brakes. Major incidents also will result in oxygen masks being deployed as on aeroplanes. A further contingency plan would be to stop all capsules and restore normal air pressure to the tube.

- A minor depressurisation of the tube can be managed with a proportional increase in vacuum pump power. This would not be possible if the tube was containing a vacuum rather than reduced air pressure. The environment control system can also compensate for the slight loss in air pressure.

Terrorism

- Airport level security at the stations acts to prevent any terrorist attack both in the capsule and at each station.

- A fence along the length of the route will protect the concrete pillars. The type of fencing would depend on the risk of a trespass, and the type of area. We would also use trees, shrubs, and other plants to make an effective boundary and improve the look of the fencing itself. We would also actively monitor the railway boundary through fibre optic cabling adjacent to the fence, a technique now being implemented for HS2. This would alert the operator if a trespasser crosses the fence and can access the concrete pillars, allowing operators to act immediately.

- If a terrorist were to compromise the tube by means of explosives the resulting depressurisation of the tubes would trigger all tubes to apply their emergency brakes. The pods closest to the explosion can apply a critical emergency brake of up to 2g to prevent the pod falling out of the tube. Only one pod would be at risk in this sort of attack as the pod behind would be too far away. CCTV cameras both inside and outside the tube would assist in determining further plans based on the terrorist's actions. Anti-terror police would be alerted and capsules could be sent back to their nearest station either by driving themselves to safety using small onboard electric motors to power deployed wheels or via their traditional magnetic propulsion.

- The damage of a terrorist attack like this occurring would harm public opinion of the Hyperloop greatly but the actual risk to life dwarfs in comparison to an explosive device derailing a conventional train.

Cyber Attack

- Recent events have highlighted the importance of cybersecurity in battling cyber-attacks with threats ranging from Russia and Iran to terror groups. All computer systems and servers that help deliver the Hyperloop will be protected with airport level cyber-security; both secret services as well as the government office for Cyber Security will assist in keeping this expensive piece of infrastructure safe both from cyber-attacks and more conventional terrorist actions.

Contingency Plans

Currently, when there is a fault on the National Rail line that causes trains to stop running, be it strikes or engineering works, rail replacement buses are used to try and fulfil the timetable and get passengers to their destination as quickly as possible. If an event such as this was to happen to the Hyperloop system (be it the whole system or just one line) a contingency plan would need to be in place in order to avoid leaving passengers stranded on the 'wrong side' of London, which would lead to many passengers missing their flights - an issue for the passenger, airlines and the Hyperloop business as compensation would have to be made for the hold ups created. Therefore, we need a contingency plan of our own that is fairly quick and can cope with the extra passenger numbers.

As all the airports have National Rail stations nearby, the best solution to any problem that would result in our transport system having to stop would be to use the train system currently operating in London. The hub, located just west of Cheshunt, also has a National Rail station within the area and so the hub could be reached fairly easily using trains.

Both Gatwick and Heathrow airport have stations within the airports themselves, which makes using the train network for these two stations very applicable. The Docklands Light Railway serves London City Airport from within the airport, and a National Rail station is located on the other side of the Thames (passengers would alight at Woolwich Dockyard). Luton airport has a National Rail station around a mile away, where a shuttle bus service exists, and Stansted also has a national rail station connected to the airport.

With all these available connections, using the train network would be our preferred method of transportation in the event of the shutdown of the Hyperloop. This would also be the fastest method of transport available. Furthermore, the train network can cope with the influx of passengers that would be experienced if the contingency plan did need to be invoked.

Using the National Rail network would still be much slower. For example, the 4 minutes and 18 second journey from Gatwick to Heathrow via Hyperloop would take around 1 hour and 20 minutes on the Gatwick Express, but despite the extended journey time, at least passengers will be able to reach their destination.

If the train network was also not running between certain areas (i.e. if issues with the Hyperloop coincided with engineering works etc.) then buses would have to be used as the only other form of transport on a large enough scale to transport the thousands of people per hour around London. This would take an extended period of time, and may result in passengers missing their flight because of the congestion on London roads and the lower speeds that buses travel at. Using the Gatwick to Heathrow example again, the journey would take 1 hour and 4 minutes without any congestion. Therefore, the actual journey is expected to take much longer, possibly up to 1 hour and 45 minutes in total. Buses are also less favourable because they cannot transport as many people in one go as trains can, and they would be an additional cost as we would not be using a pre-existing transport network as we would do with the train network.

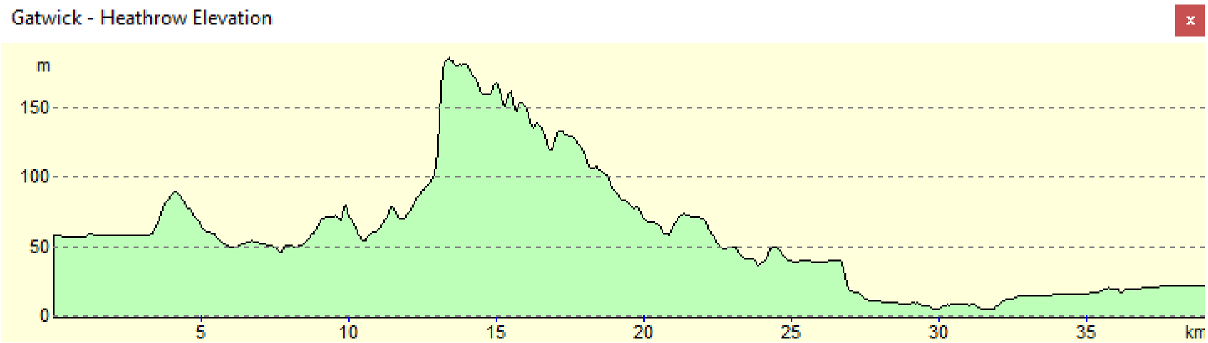
In incidents that cause significant inconvenience, we would have to offer passengers compensation for at least **50% of the ticket price** (the same compensation level as National Rail offer). The cost of this would be more than covered by **£500 million** of contingency factored into our total costs, meaning that this issue is not of substantial concern.

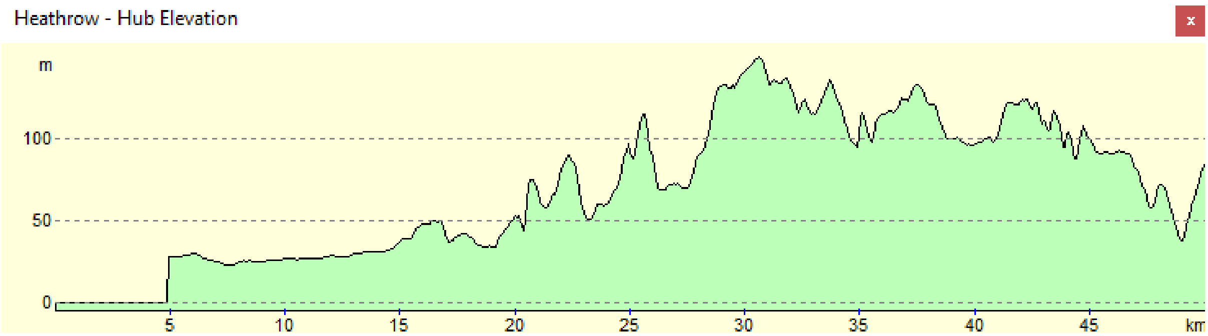
The Problem of Elevation

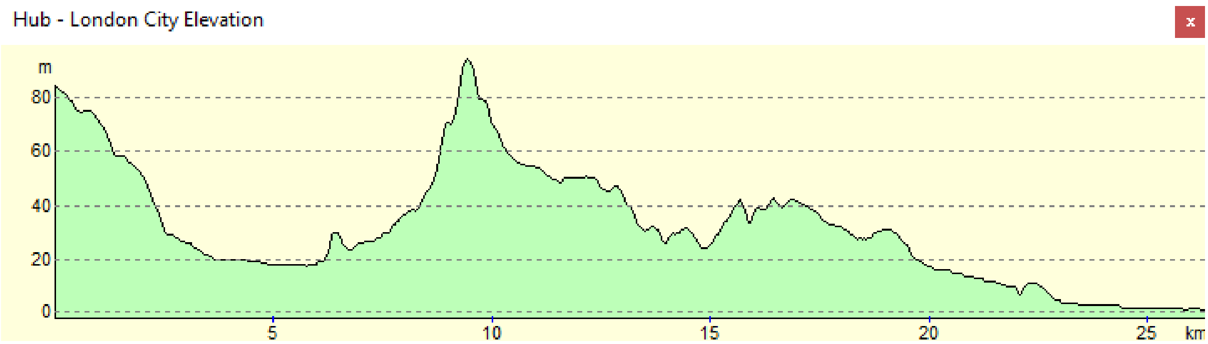
Though the relief of most the south-east of England is relatively flat compared with, for example, the Scottish Highlands, the Alps etc. the contouring is nonetheless varied.

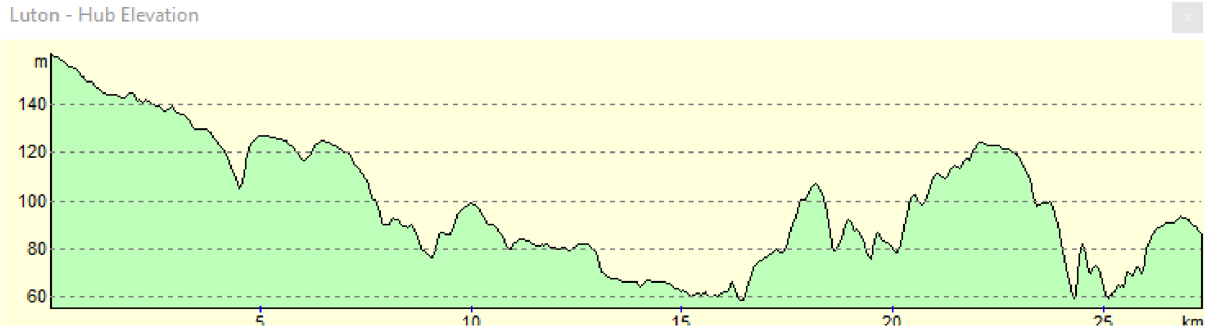
If all the pillars that the Hyperloop tubes will be supported by were constructed to the same height, then there would be inconsistencies in the gradient at which the train travels. In fact, what is really needed is for there to be no gradient, as any deviation from the horizontal allows the force of gravity to influence the train's motion through the tubes. This would make accelerating and decelerating somewhat challenging, even at our low friction levels. Accelerating uphill requires more energy to reach the same cruising velocity; and decelerating downhill requires either more braking force (and therefore more energy) or for the train to begin decelerating earlier in its journey.

The following topographical cross-section graphs for each of the routes show the elevation changes.

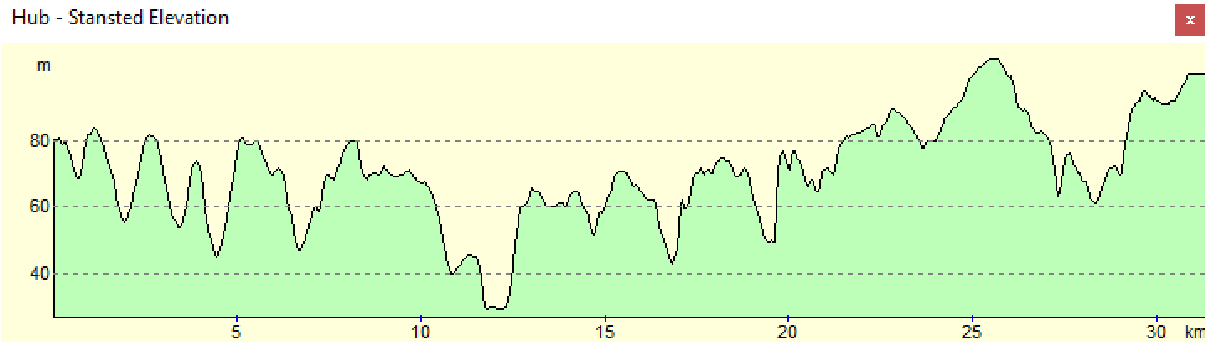








NB: elevation axis here is not from 0m.



NB: elevation axis here is not from 0m.

In order to decrease the fluctuations in elevation, it may be necessary to manufacture the pillars at different heights. While keeping 100% of the track at a gradient of 0 is not going to be feasible, we can build the tracks so that the contouring effect is lessened.

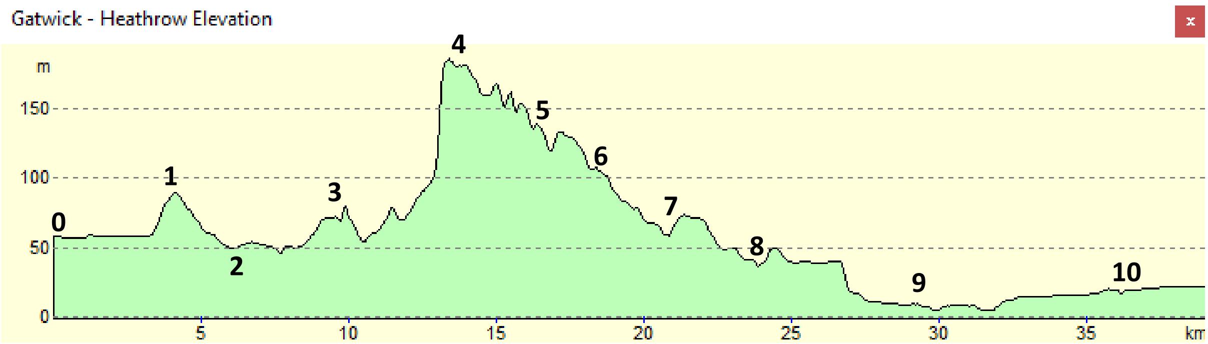
The greatest range is **185 – 5 = 180m** on the Gatwick – Heathrow line. It would dangerous to construct a 180m pillar to put at the 5m elevation mark, as it would be far too high for easy maintenance by vehicles such as cherry-pickers; while too the prospect of it toppling would be greater and increasing the base area is not an ideal compromise for this. However, we can increment pillar height changes gradually, which would reduce the gradient angle up/downhill.

E.g. Gatwick – Heathrow

Route length = 37km

Pillars needed every 30m = 0.03km

37 ÷ 0.03 = 1233.33… = 1234 pillars minimum = 33 for one direction per km.



Calculated example:

Route points	**0 to 1**	**1 to 2**	**2 to 3**	**3 to 4**	**4 to 5**	**5 to 6**	**6 to 7**	**7 to 8**	**8 to 9**	**9 to 10**
Distance from Gatwick (km)	4.2	6.0	9.8	13.4	16.3	18.4	20.9	23.9	29.2	36.1
Distance between points (km)	4.2	1.8	3.8	3.6	2.9	2.1	2.5	3.0	5.3	6.9
Approx. no. of pillars needed	4.2 x 33 = 139	1.8 x 33 = 59	3.8 x 33 = 125	3.6 x 33 = 119	2.9 x 33 = 96	2.1 x 33 = 69	2.5 x 33 = 83	3.0 x 33 = 99	5.3 x 33 = 175	6.9 x 33 = 228
Greatest sudden Δ elevation (m)	32.0	39.8	30.5	129.6	48.0	26.0	49.0	36.6	34.3	16.8

The Gatwick – Heathrow example is the 'worst case scenario' of this problem. Crawley is just south of Gatwick. This aerial topographical view of the South Downs the Hyperloop will traverse:

As is seen, the gradient change per division of the route is very irregular. Incrementing the pillars for each division would be by different amounts via various calculated functions specific to the area. Therefore, geology plays an important role in this as deciding which areas could even support the possibility of taller and thus heavier pillars would relate to the strength and stability of rock strata in that area.

In places such as the peak on our Gatwick – Heathrow line where there is a sharp incline, another option to be considered is **tunnelling**. However, this is an expensive prospect that diverges from the main USP of the Hyperloop design being overhead and therefore easy to maintain.

Tunnelling

There is no question that the London basin is not as flat as would be desired. This poses significant problems for engineering of the pillars that support the Hyperloop network in order to keep a near constant zero gradient. In many places, we will be able to increment the pillar height according to the elevation of the surrounding landscape i.e. have taller pillars in more lowland areas to equilibrate with the elevation of those on higher ground. Unfortunately, this is not always possible as some lines cross a transect of elevation ranges as great as 180m. Therefore, tunnelling must be considered.

[48] There are two kinds of tunnel boring machines necessary for this project. This is because the geology differs from route to route between cohesive earth materials (clays) and incohesive granular materials (sands and gravels). Both machines have their pros and cons and can also be subject to breakdowns if used in the wrong conditions, hence the need for both.

NB: *The costs laid out here in this following section reflecting tunnelling are only approximations based on similar projects such as HS2's proposals and general assumptions we can make with our knowledge of our chosen transportation system.* [51] [52]

Earth Pressure Balance (EPB) Tunnel Boring Machine [49]

The Earth Pressure Balance machine is for cohesive geology such as clays, which run through and under many parts of London. As the name suggests, they intend to maintain a pressure balance whilst under the earth. This is achieved by means of a screw conveyor and pressure bulkhead that equilibrate the subsurface to atmospheric pressure.

EPBs such as those designed for China's Chengdu Metro Line 2, are powerful machines. The manufacturer Two Robbins design theirs with High-powered, modular cutter head drive systems and screw conveyors capable of 230kNm of torque force.

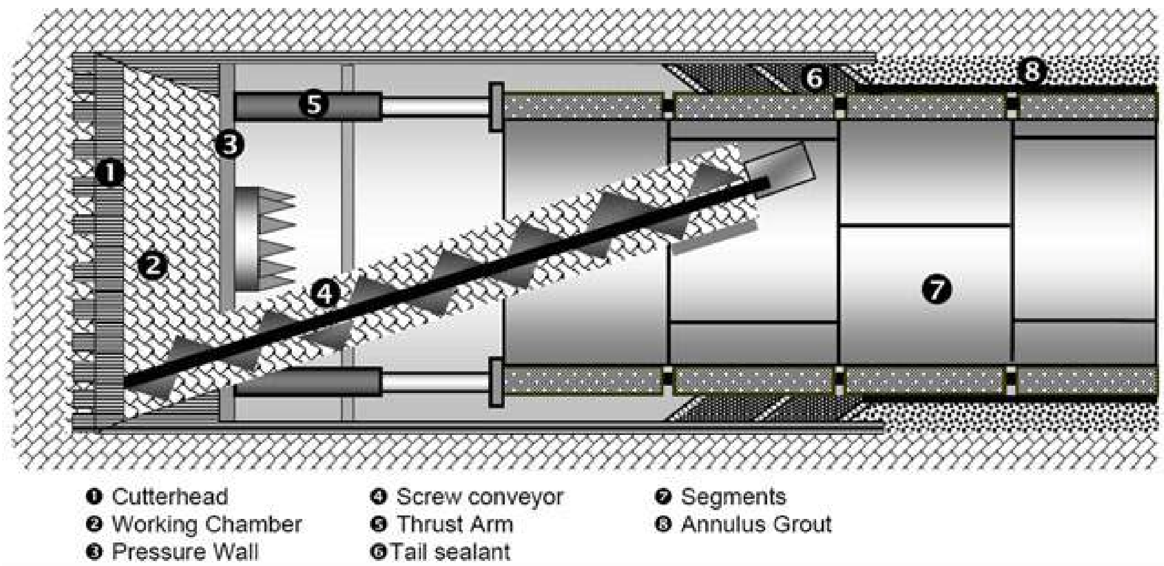
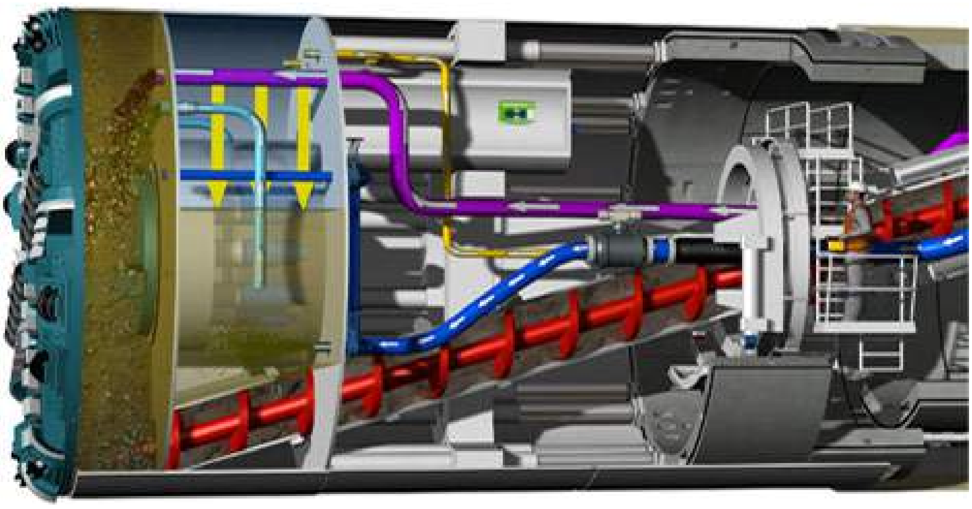


Diagram: [50]

Advantages and Assets	Disadvantages and Drawbacks
- Can be fitted with various carbide cutting tools to reflect the nature of the materials.	- Large cost: **£18,000,000**
- Ribbon-type screws allow the EPB TBM to drill where there are large cobbles and boulders as they are passed through the screw to a boulder collecting gate.	- Encounters with hard rocks result in damaging abrasion of the blades.
- Adaptable to varying conditions (more so than Slurry machines).	- Fixed cost of maintenance and running can be as much as
- Clay material exiting the EPB machine does not need to be treated before exportation.	- Inferior to Slurry machines regarding high water pressures.

Slurry Tunnel Boring Machine [49]

The Slurry machine is designed for incohesive geology such sands and gravels or other rock classifications with a particulate, stony profile. ‘Slurry’ refers to a churned mixture of slurry and mud that is pumped into an enclosed mud screen system to maintain the pressure. The mixture is recycled as the machine bores further.

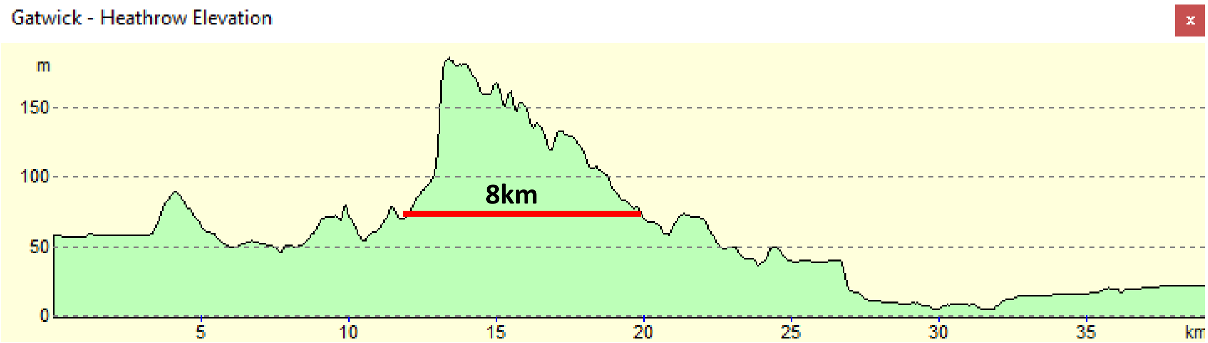


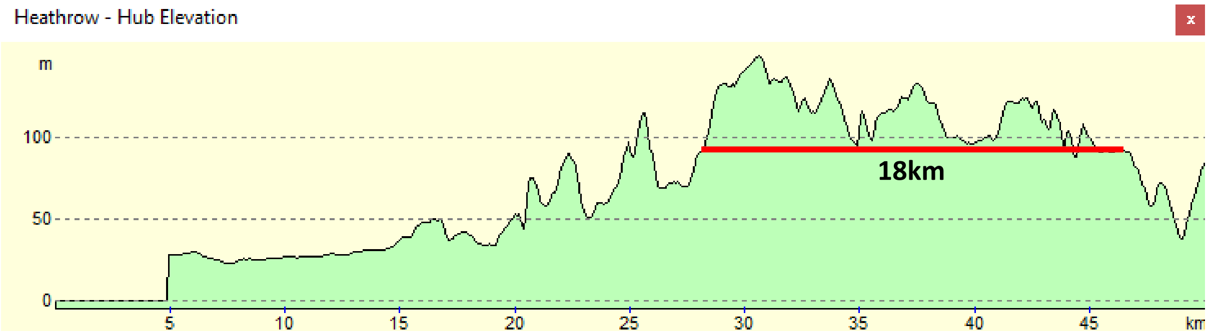
In general, Slurry machines react quicker to changing conditions due to the pump pressure. However, this superiority is only really reserved for granular materials. This is because larger chips can be crushed before entering the slurry pipes.

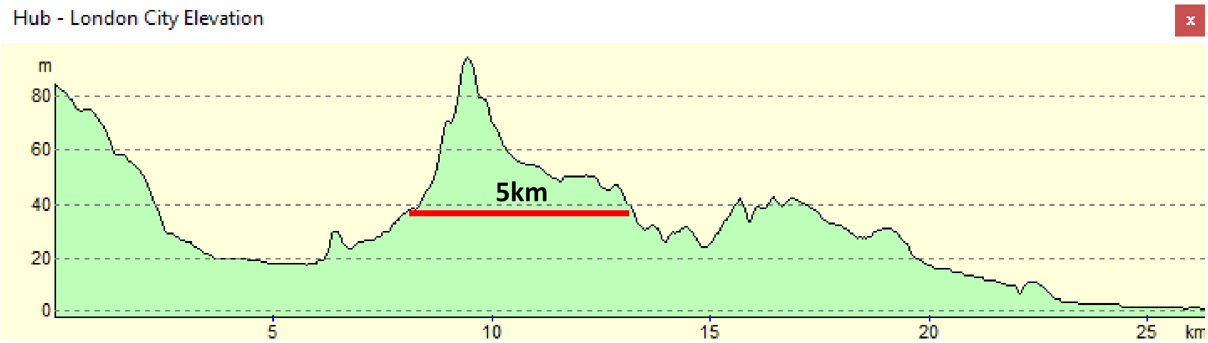
Advantages and Assets	Disadvantages and Drawbacks
- Slurry machines react quicker than EPBs due to their crusher mechanisms.	- Large buying cost: **£16,000,000**
- Slurry machines can cope with higher water pressures: those above 2 bar. Despite the standard of EPBs increasing in this field, slurry borers are preferable.	- A proportionally larger slurry plant to the machine is needed to process the material.
- Effects of abrasive hard rocks felt less significantly than EPBs. However, drilling into hard rock is still very damaging.	- Not effective in wet, cohesive geologies such as clay.

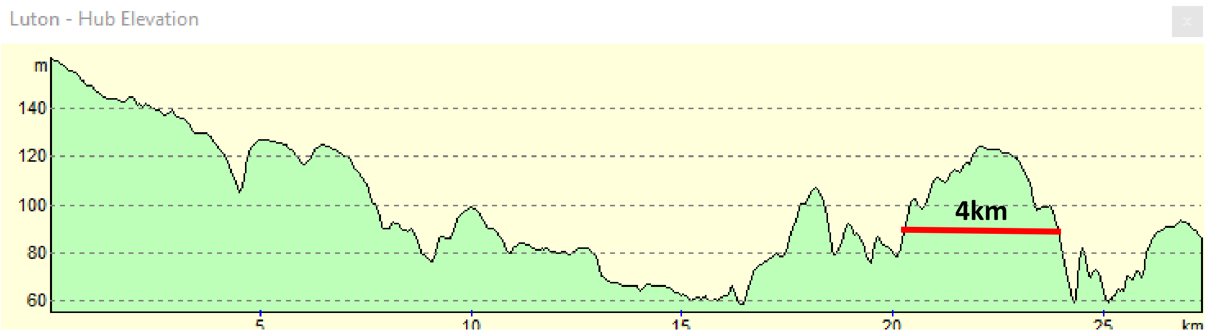
Where will we Tunnel?

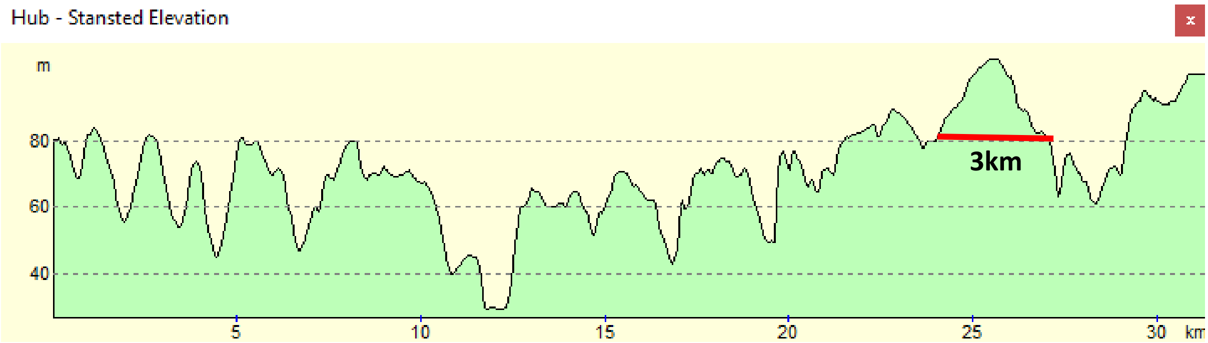
Represents a length of tunnelling.











We have decided not to tunnel as much as may be expected for the Stansted – Hub Line and rather to increment pillars more significantly than along other routes because each section of tunnel would be uneconomically short. Disruption levels over such short distances is not worth the construction costs.

Total length of tunnels required (twinned value): 8 + 18 + 5 + 4 + 3 = 38 km

The topographical cross section graphs show that there are some areas where tunnelling is absolutely necessary as the gradient change without them would be too steep.

Construction Times

Productivity of tunnel construction and tunnel debris clear out are assumed as **100m per week** and **500m per week** respectively. However, the tunnels for each of the 5 routes can be constructed simultaneously, so long as the procedures used are not the same all at once (since buying 2 tunnel boring machines per route is an unnecessary expense) e.g. while the Slurry machine is digging one route, another can be using the EPB machine, another having ventilation units installed etc.

- 38000m construction at 100m/week per route:
  - 38000m ÷ 100 m/week = 380 weeks
  - 380 weeks ÷ 5 routes = 76 weeks
- 38000m debris clear out at 500/week per route:
  - 38000m ÷ 500m/week = 76 weeks
  - 76 weeks ÷ 5 routes = 15.2 weeks
- 76 + 15.2 = **91.2 week's tunnel work**

Breakdown of Tunnelling Costs [51] [52]

Total length of twinned tunnel systems = 38km = 21.5% of total route distances.
Construction time and debris clear out time = 91.2 weeks

NB: *Costs are based on a twinned route system i.e. Hyperloop tubes in both directions.*

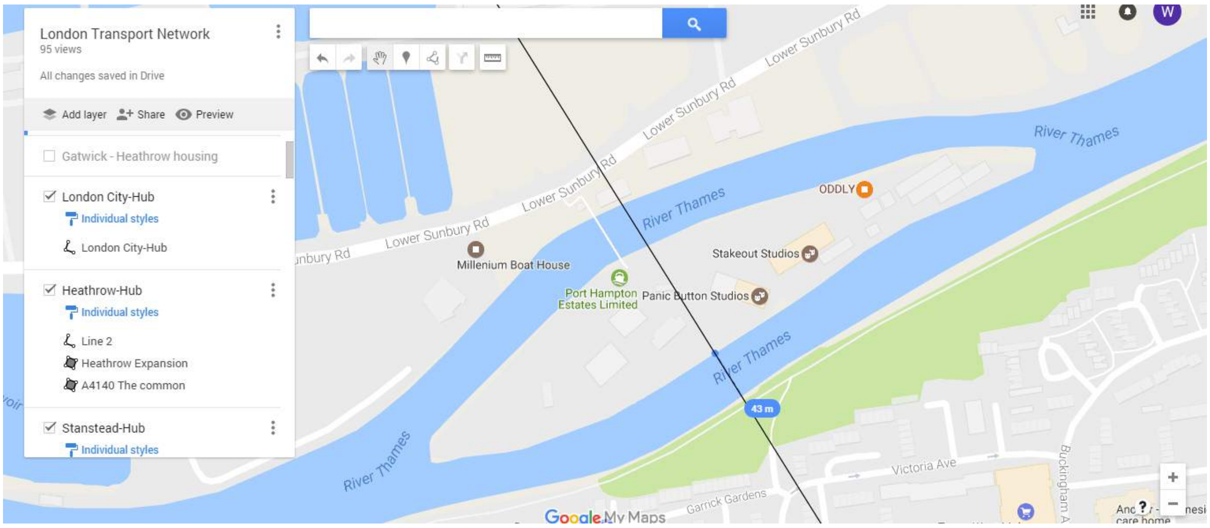
Cost type	Description	Quantity	Unit	Cost per unit (£)	Total (£)
Purchase of machines	EPB machine	1	-	£18,000,000	£18,000,000
	Slurry machine	1	-	£16,000,000	£16,000,000
Tunnelling support costs	EPB machine fixed costs	1	Sum	£35,000,000	£35,000,000
	Slurry machine fixed costs	1	Sum	£45,000,000	£45,000,000
	Time related and labouring costs *	91.2	Weeks	£1,100,000	£100,320,000
Tunnel construction inc. materials	Using EPB machine (assumed 50%)	19000	Route metres	£22,000	£418,000,000
	Using Slurry machine (assumed 50%)	19000	Route metres	£25,000	£475,000,000
Waste material disposal	Sent to landfill / commercial tip	0	Route metres	£4,500	£0
	Sustainable use of material	38000	Route metres	£3,000	£114,000,000
Shafts	Ventilation shafts + lifts every 3km	9	-	£12,000,000	£108,000,000
Mechanical and electrical systems	Systems for tunnels' operation, safety, and security	38000	Route metres	£4,000	£152,000,000
				Total tunnelling costs (£):	**£1,481,320,000**

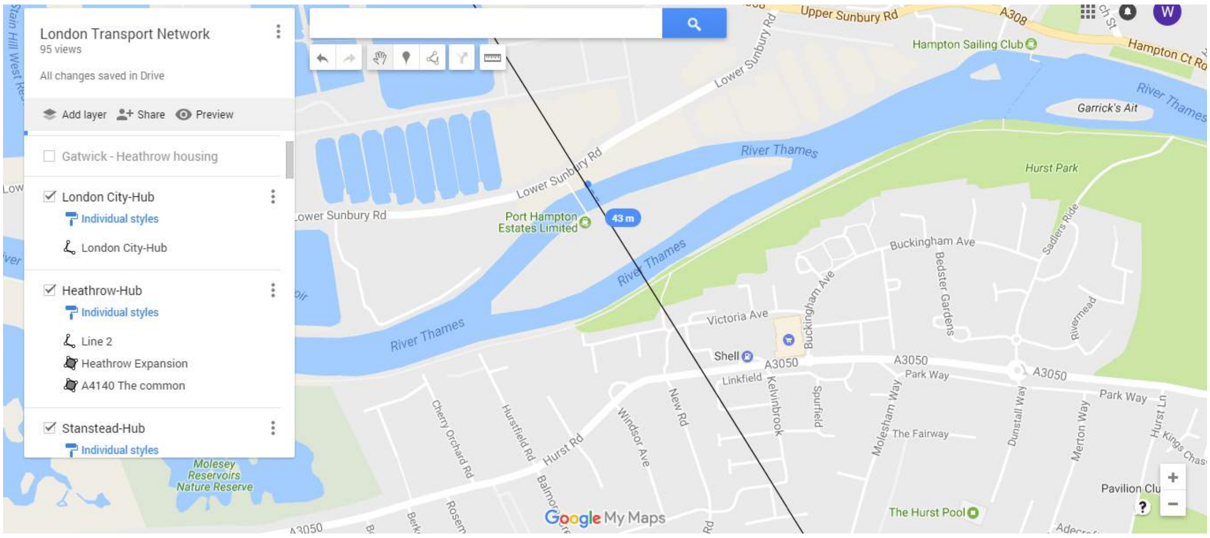
** Labouring costs include:*

- Labour costs for management
- Supervision and general site based labour
- Hired plant and equipment servicing the site
- Security of the site
- Cleaning and maintenance costs

The Thames Bridge

There is a point on the Gatwick – Heathrow line near to Hampton and Kingston upon Thames - where our Hyperloop line crosses The River Thames. As shown on the maps below, this will create an issue because the river is 43m on both sides of the central island, which is a longer distance than should be between consecutive concrete pillars of 30m. Also, the width of the river is 193m from bank to bank. Therefore, we either must put a concrete pillar into the river on each side of the island, or else build a bridge across the river. *Image:* Google Maps [30]





OPTION 1: BUILD PILLARS IN THE RIVER

- As concrete sets via a chemical reaction between water and the cement in the concrete, the pillars would theoretically set under water. However, due to the flow of the water, the force of the river could wash the concrete away before it has a chance to harden sufficiently, meaning that a huge amount of concrete would be wasted before the pillars would set – wasting large sums of money and resources.
- It would be cheaper to build pillars across the river and the island compared with building a bridge as the materials used cost less, and the process of assembling the pillars is cheaper too, as well as being faster.

- On the other hand, putting a pillar in the middle of each side of the Thames would result in an already narrow portion of the river (caused by the island in the middle) being narrowed further, potentially to the point of making it impassable for certain sized boats, something we do not want to do as the Thames is used by so many, especially in this section of it.
- Also, building in the Thames itself may not even be possible if the Environment Agency and the Thames Conservancy decide that the plan could not go ahead.

Option 2: Beam Bridge

- A Beam Bridge is where a reinforced concrete slap is laid across the top of steel girders.
- Due to the span of the water, a multi girder beam bridge could not be used as they require a girder every 3 0r 4 metres. However, a beam bridge of ladder deck construction could be used – lots of girders are set perpendicular to each other, and then concrete can be laid across the top of this structure. The span of a ladder deck bridge can be up to 80 m, more than enough for the span of 23m across the water.
- Expansion joints would be needed to avoid the bridge breaking, which can be costly to insert into the structure of the bridge.
- Mainly used for Road bridges rather than rail bridges.

Option 3: Truss Bridge

- A truss is a triangulated framework of individual metal beams which act primarily in tension or compression. Trusses have been used as arches (Sydney Harbour Bridge) or as cantilevers (Forth Rail Bridge)
- Truss bridges are often very expensive because of the labour-intensive method of creating the bridge from many different components. However, they are widely used in the UK for footbridges, gantries, and longer span railway bridges (over 50m) – exactly what we could use if we do not use the island as a mid-point for support, depending on the cost of building each style of bridge.

Option 4: Tied – Arch Bridge [53]

- Cable ties between the arch above and the ‘floor’ of the bridge provide tension, holding it together.
- This bridge is good in areas where the ground is soft, such as next to a river, because the design puts very little stress on the ground itself, because nearly all the weight is supported by the cables and the arch.
- The bridge can also be very low to the surface of the water if necessary because of the arch design.

Option 5: Suspension Bridge

- Two cables are suspended between two tall towers, in a shallow curve, and a deck is supported from the two cables by a series of hangers along their length, held up due to tension. In most cases the cables are anchored to the ground on the river bank.
- As well as carrying traffic, the deck acts as a stiffening girder running the length of each span. The stiffening girder spreads the load and provides stiffness against both bending and twisting actions.
- Often used to span long distances because of the resistance to movement.

MATERIALS FOR THE BRIDGES

- The main material would be structural steel, which is relatively cheap and of a high quality as it is prefabricated in factory conditions.
- However, without a coating, the steel would corrode due to weather conditions. To combat this, the steel is covered in a spray containing aluminium or zinc, and sometimes containing silicon too because these metals are non-corrosive.
- Steel bridges now have a proven life span extending to well over 100 years, a significantly longer period than the Hyperloop system itself would last without repair. Corrosion is a surface effect, which means the structural integrity of a bridge is very rarely affected, and any problems may be swiftly addressed by repainting the affected areas, meaning the bridge could be repaired easily.

WHICH METHOD SHOULD BE USED?

A Tied Arch Bridge crossing the River Usk in Newport.

The best method of crossing The Thames will be option 4 – the tied arch bridge – for many reasons. Option 1 would not be worth the expense of inserting normal pillars into the river itself, and the other bridge designs, whilst all perfectly good structures, may not be suitable for the geology of the riverbed.

On the other hand, the Tied Arch bridge is designed to work in areas of unstable ground (the geology of that area of London is mainly clays and river silts) which are very soft, especially after heavy rainfall. Therefore, the Tied Arch Bridge would be good at coping with this, as little force is exerted on the ground itself because much of the horizontal force is bore by the bridge deck, rather than the foundations.

Another reason for selecting this type of bridge is the cost – for the length of bridge needed, building a suspension bridge would not be economically worthwhile due to the tall towers that would need construction, truss bridges are very expensive due to the large quantities of material needed, and beam bridges would require concrete posts in the water, negating any benefit of building a bridge. Therefore, the only remaining option is the Tied Arch Bridge, which is both fairly inexpensive, suitable for the area and easy to maintain – there are no mechanical components and the ties holding up the bridge deck can be replaced fairy easily.

A generally accepted cost for the construction of tied arch bridges is **\$4500 US dollars per m^2**. The total area of the bridge we require is **3900 m^2** (using an average standard width of 20m, the same width that we used for buying farmland). Therefore, the total cost of building the tied arch bridge across the River Thames will be **\$17,300,000** US dollars.

Construction Materials, Installation and Waste

Concrete Pillars

The 30m spacing of the Hyperloop pillars helps contribute to its strength and stability; this helps protect against earthquakes and would be very resistant to any impact whether accidental or vicious in nature. This spacing would mean that only a central pillar would be needed in bridging a four-lane motorway meaning no separate bridge structure would be needed. The pillars will be no shorter than 6m but will vary in height in hilly areas or other obstacles. This 6m clearance does not pose any risk if it were to bridge a motorway with the average motorway bridge having 5.1m clearance. [55]

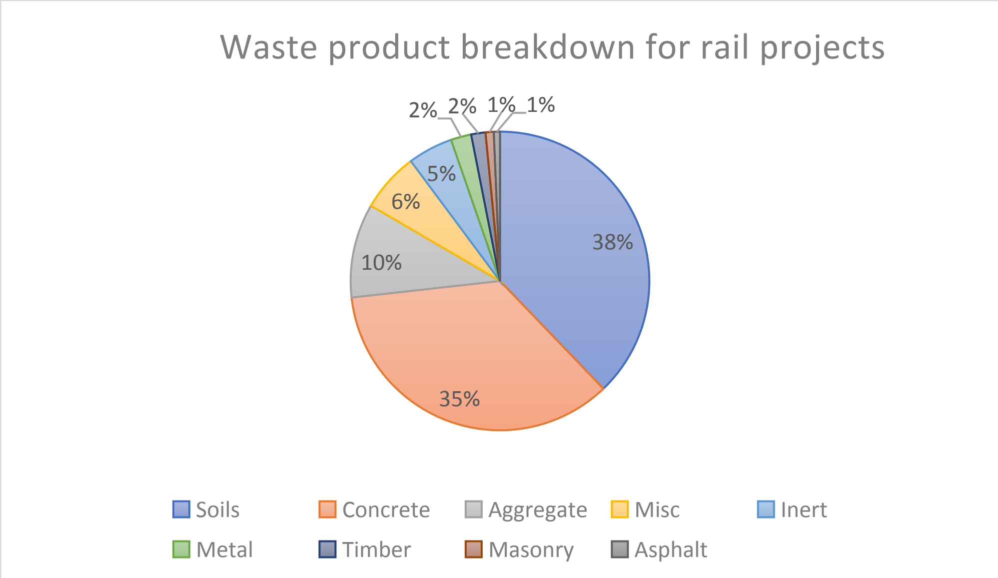
Construction Waste Management

This proposal will use the exact same method of calculating construction waste as is currently being applied in HS2 proposals. Construction waste has been forecast based on the data derived from industry-wide benchmark performance data procured from the Building Research Establishment (BRE) [56] specifically for railway projects.

	Construction tonnes/ £100k	Construction tonnes/ $100k	Demolition tonnes/ £100k	Demolition tonnes/ $100k
Average	26.4	33.0	17.3	21.6
Railways	34.4	43.0	14.8	18.5
Stations	14.1	17.6	28.2	35.3
Bridges	6	7.5	1.5	1.9
Tunnels	24.5	30.6	0	0

The report by the Building Research Establishment also broke down the material make up of construction waste on railway projects and analysed these projects to calculate that on average 39.5% of waste is landfilled with the other 60.5% recovered, reused or recycled.

Construction	**Cost ($)**	**Tonnes waste ($100k)**	**Estimated waste material (tonnes)**	**Estimated waste material in landfill (tonnes)**
Vacuum Tube	196,825,000	43.0	84,634.8	33,430.7
Concrete Pillar	772,158,000	43.0	332,027.9	131,151.0
Vacuum Pumps	3,028,000	33.0	999.2	394.7
Solar Panels	63,589,000	33.0	20,984.4	8,288.8
Airport Stations	625,000,000	17.6	110,156.3	43,511.7
Hub	150,000,000	17.6	26,437.5	10,442.8
Thames Bridge	17,300,000	7.5	1,297.5	512.5
Tunnels	1,851,650,000	30.6	567,067.8	223,991.8
		Totals	**1,143,605.4**	**451,724.1**



Cost of Disposing of Construction Waste

The standard gate fee as found by WRAP's gate fee report 2013 was £21/tonne for non hazardous waste but this rose to £85/tonne including landfill tax [57]. With a total of 451,724.1 tonnes of construction waste estimated this would result in a total cost of £38,396,550 including tax but if this was to be a government backed project this cost can be reduced to £9,486,206.

Construction	Waste Percentage	Breakdown of waste material in landfill – 451,724.1 tonnes	Cost of disposal including landfill tax at £85/tonne (£)	Cost of disposal without landfill tax at £21/tonne (£)
Soils	37.6%	169,848.3	14,437,103	3,566,814
Concrete	35.2%	159,006.9	13,515,586	3,339,145
Aggregate	10.1%	45,624.1	3,878,052	958,107
Misc.	7.0%	31,620.7	2,687,759	664,034
Inert	4.8%	21,682.8	1,843,034	455,338
Metal	2.2%	9,937.9	844,724	208,697
Timber	1.5%	6,775.9	575,948	142,293
Masonry	0.9%	4,065.5	345,569	85,376
Asphalt	0.7%	3,162.1	268,776	66,403
	Totals	**451724.2**	**£ 38,396,550**	**£ 9,486,206**

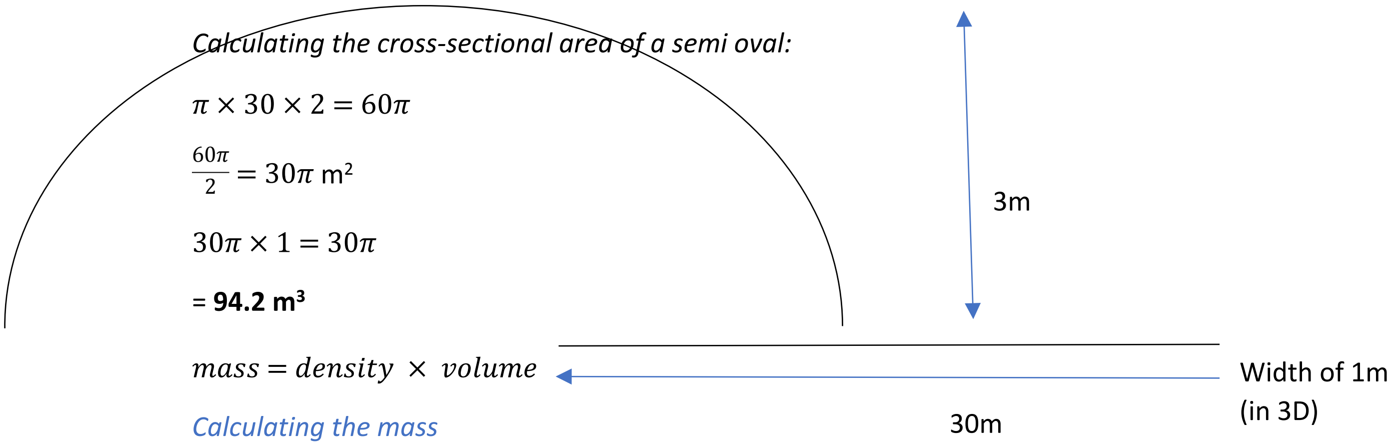
Landscaping

The dirt excavated from network sites is tested for environmental concerns. Dirt that is contaminated is incinerated. Dirt that is partially contaminated can be used as soil cover in landfills, helping waste decomposition. Dirt that is clean and fertile can be redistributed to places where it is needed. For example, some is used for structural foundation while some can be used in making hills. It can be shaped and utilized to make a better finished product around the bases of Hyperloop tubing.

There are **169,848.3 tonnes** of waste dirt that can generated into mounds underneath the Hyperloop, which will then be covered by grass to create a more aesthetically appealing look of the Hyperloop.

Calculating the volume of the mounds

Dirt that is loose and moist has a density of 1250 kg/m^3



Calculating the cross-sectional area of a semi oval:

$\pi \times 30 \times 2 = 60\pi$

$\frac{60\pi}{2} = 30\pi$ m^2

$30\pi \times 1 = 30\pi$

= **94.2 m^3**

$mass = density \times volume$

Calculating the mass

$30\pi \times 1250 = 117809.7245$

= 117.8097245

→ **117.8 tonnes**

Length covered by the mounds

314.1592654 tonnes for every 30 m

$\frac{117.8097245}{0.03} =$ 3926.990817

tonnes per km

$\frac{169848.3}{3926.990817}$

$= 43.25151443\ km \rightarrow$

43.3 km

Business Models

We have outlined in this next section two different business models each bring their own advantages and drawbacks. The private model will produce a greater profit however will face increased higher tax and interest rates, more political opposition as well as an increased cost to consumers. Whereas the public model would minimise costs to consumers by reducing the ticket price but still managing to make a profit within the 20 years stipulated. In addition to this, a slightly more generous loan interest rate of 3.5% (considering interest rates are targeted at 2% [58]) would apply to the public model compare to the 5% faced by the private model.

VAT will not be applied to any ticket as train tickets are exempt from this however business tax would be applied to the private model. The main part of business tax is corporation tax which is currently 20% of the company's profit however in the 2016 Budget the government announced a decrease to 17% [59] by 2020 to make the UK a more competitive market. This tax is applied on profits after running costs and loan interest payments have been made but do not take into account any outstanding loan payments themselves.

The public model could strangely be a more realistic option as this is likely to gain more public approval and therefore political backing which is greatly needed for this project to proceed.

Private Model

Fare Prices

Our fare prices are based on a range of different factors including distance, time and demand. We will beat both National Rail and National Express (our two biggest market competitors) on like-for-like ticket comparisons (see page 16). Additionally, not only will we beat our market competitors on price, but also on time (see page 39).

Based on the type of service we are offering (24hr inter-airport transfers) we recognise that our main market will be the professional / business class and therefore we estimate that **90%** of passengers using the Hyperloop will pay the full adult price. However, we also recognise that there will be concessions (both OAPs and children) that will use this service, making up an estimated **10%** of total passenger make-up. These concessions will pay a reduced-price, equivalent to at least two thirds of the full ticket price a **massive saving of 33%**.

Line	Peak/hour	Off-Peak/hour	Peak fare – Adult (£)	Off peak fare – Adult (£)	Peak fare – Concession (£)	Off peak fare – Concession (£)	Total/day (£)
Gatwick - Heathrow	1200	950	22.00	19.00	14.50	12.50	434,515
Heathrow - Gatwick	1200	950	22.00	19.00	14.50	12.50	434,515
Heathrow – City	670	510	20.00	18.00	13.00	12.00	221,090
City – Heathrow	670	510	20.00	18.00	13.00	12.00	221,090
Heathrow – Stansted	780	600	22.00	18.00	14.50	12.00	262,830
Stansted – Heathrow	780	600	22.00	18.00	14.50	12.00	262,830
Heathrow – Luton	1100	850	22.00	18.00	14.50	12.00	372,130
Luton – Heathrow	1100	850	22.00	18.00	14.50	12.00	372,130
Gatwick – City	310	260	22.00	18.00	14.50	12.00	112,703
City – Gatwick	310	260	22.00	18.00	14.50	12.00	112,703
Gatwick – Stansted	510	430	22.00	18.00	14.50	12.00	186,279
Stansted – Gatwick	510	430	22.00	18.00	14.50	12.00	186,279
Gatwick – Luton	670	510	22.00	18.00	14.50	12.00	223,703
Luton – Gatwick	670	510	22.00	18.00	14.50	12.00	223,703

City – Stansted	220	170	18.00	15.00	12.00	10.00	61,886
Stansted – City	220	170	18.00	15.00	12.00	10.00	61,886
City – Luton	220	170	18.00	15.00	12.00	10.00	61,886
Luton – City	220	170	18.00	15.00	12.00	10.00	61,886
Stansted – Luton	330	260	20.00	15.00	13.00	10.00	95,678
Luton – Stansted	330	260	20.00	15.00	13.00	10.00	95,678
							£ 4,065,400

Ticket Income by Year

The government permits ticket prices to rise with inflation [60], however any current forecasts are redundant for use in our proposal as predicting financial statistics over 6 years away are nigh on impossible. We do know that inflation predictions are vague and ambiguous post-Brexit however there is a self-set target by the Bank of England to achieve 2% inflation per annum [61]. This, combined with the fact that rail tickets rose by an average of 2.3% in 2017 [62], we have applied a conservative estimate of an average annual rise annual rise in inflation of 1.5%; therefore, resulting in a 1.5% increase in ticket prices each year. The effect of leap years will also have a minor effect on annual ticket sales as we are providing a service 24/7 throughout the year. Although we recognise that there will be times and days where demand would drop significantly as we are using average passenger numbers we have assumed that this accounts for periods of both high and low demand.

Year	**Total ticket income (£ million)**	**Ticket income breakdown for each line (£ million)**									
		Gatwick – Heathrow	**Gatwick – London City**	**Gatwick – Luton**	**Gatwick – Stansted**	**Heathrow – London City**	**Heathrow – Luton**	**Heathrow – Stansted**	**London City – Luton**	**London City – Stansted**	**Luton – Stansted**
2024	1487.9	318.1	82.5	163.8	136.4	161.8	272.4	192.4	45.3	45.3	70.0
2025	1506.1	322.0	83.5	165.8	138.0	163.8	275.7	194.7	45.9	45.9	70.9
2026	1528.7	326.8	84.8	168.2	140.1	166.3	279.9	197.7	46.5	46.5	72.0
2027	1551.7	331.7	86.0	170.8	142.2	168.8	284.1	200.6	47.2	47.2	73.0
2028	1579.2	337.6	87.6	173.8	144.7	171.8	289.1	204.2	48.1	48.1	74.3
2029	1598.6	341.7	88.6	175.9	146.5	173.9	292.6	206.7	48.7	48.7	75.2
2030	1622.5	346.8	90.0	178.6	148.7	176.5	297.0	209.8	49.4	49.4	76.4
2031	1646.9	352.0	91.3	181.2	150.9	179.1	301.5	212.9	50.1	50.1	77.5
2032	1676.1	358.3	92.9	184.5	153.6	182.3	306.9	216.7	51.0	51.0	78.9

2033	1696.6	362.7	94.1	186.7	155.5	184.5	310.6	219.4	51.7	51.7	79.9
2034	1722.1	368.1	95.5	189.5	157.8	187.3	315.3	222.7	52.4	52.4	81.1
2035	1747.9	373.6	96.9	192.4	160.2	190.1	320.0	226.0	53.2	53.2	82.3
2036	1779.0	380.3	98.6	195.8	163.0	193.5	325.7	230.0	54.2	54.2	83.7
2037	1800.8	384.9	99.8	198.2	165.0	195.9	329.7	232.8	54.8	54.8	84.8
2038	1827.8	390.7	101.3	201.1	167.5	198.8	334.6	236.3	55.6	55.6	86.0
2039	1855.2	396.6	102.9	204.2	170.0	201.8	339.6	239.9	56.5	56.5	87.3
2040	1888.2	403.6	104.7	207.8	173.0	205.4	345.7	244.1	57.5	57.5	88.9
2041	1911.3	408.6	106.0	210.3	175.1	207.9	349.9	247.1	58.2	58.2	90.0
2042	1939.9	414.7	107.6	213.5	177.8	211.0	355.1	250.8	59.1	59.1	91.3
2043	1969.0	420.9	109.2	216.7	180.4	214.2	360.5	254.6	59.9	59.9	92.7
2044	2004.0	428.4	111.1	220.5	183.7	218.0	366.9	259.1	61.0	61.0	94.3
Total	**36339.6**	**7768.0**	**2014.8**	**3999.2**	**3330.2**	**3952.5**	**6652.7**	**4698.7**	**1106.4**	**1106.4**	**1710.5**

This formula provides us with a pre-tax total ticket income of **£36,339,550,000** over the 20-year period.

Total Outlay of Costs

The table below includes all costs and the respective currency conversions for all components of the system, excluding staffing and maintenance (see page 60). The values are expressive of earlier calculations and research in this report.

Initial Outlay		Cost ($)	Cost (£)
Hyperloop Infrastructure		1,035,600,000	828,480,000
	Vacuum Pumps	3,028,070	2,422,456
	Tube	196,824,561	157,459,649
	Pillar Construction	772,157,895	617,726,316
	Solar Panels	63,589,474	50,871,579
Capsules/Pods (x136)		183,600,000	146,880,000
	Air Compressor	37,400,000	29,920,000
	Interior and Seats	34,680,000	27,744,000
	Capsule structure + doors	33,320,000	26,656,000
	Suspension + Air Bearings	27,200,000	21,760,000
	Batteries, Motor and Coolant	20,400,000	16,320,000
	Propulsion Systems	10,200,000	8,160,000
	Emergency Braking	6,800,000	5,440,000
	General Assembly	13,600,000	10,880,000
Civil Engineering		2,723,195,688	2,178,556,550
	Tunnels	1,851,650,000	1,481,320,000
	Thames Bridge	17,300,000	13,840,000
	Construction waste (incl. tax)	47,995,688	38,396,550
	Station (x6)	625,000,000	500,000,000
	Hub	175,000,000	140,000,000
	Landscaping	6,250,000	5,000,000
Land purchase		2,485,840,685	1,988,672,548
	Heathrow – Gatwick housing	451,700,403	361,360,322
	Heathrow – Hub housing	591,576,979	473,261,583
	London City – Hub housing	1,341,299,130	1,073,039,304
	Luton – Hub housing	38,581,075	30,864,860
	Stansted – Hub housing	52,252,163	41,801,730
	Farmland	10,430,936	8,344,749
Misc.			
	Contingency	625,000,000	500,000,000
	Total:	**$ 7,053,236,373**	**£ 5,642,589,098**

PROFITS

Presented below are our projections for returning the Hyperloop initial loan of **£5,642,589,098** based on revenue generated from ticket purchases. This is inclusive of cumulative annual interest that increases the starting loan value. In addition to this a 17% corporation tax is applied to the annual profits of each year with taxed profits acting to pay off the loan balance in the first five years of the project.

Year	Starting loan balance (£)	Loan interest (5% APR) (£)	Staffing + maintenance (£)	Total ticket income (£)	Taxable profits (£)	Taxed profits (£)	Annual balance (£)
2024	5,642,589,098	282,129,455	50,900,000	1,487,900,000	1,154,870,545	958,542,552	-4,684,046,546
2025	4,684,046,546	234,202,327	51,918,000	1,506,100,000	1,219,979,673	1,012,583,128	-3,671,463,417
2026	3,671,463,417	183,573,171	52,956,360	1,528,700,000	1,292,170,469	1,072,501,489	-2,598,961,928
2027	2,598,961,928	129,948,096	54,015,487	1,551,700,000	1,367,736,416	1,135,221,226	-1,463,740,702
2028	1,463,740,702	73,187,035	55,095,797	1,579,200,000	1,450,917,168	1,204,261,249	-259,479,453
2029	259,479,453	12,973,973	56,197,713	1,598,600,000	1,529,428,314	1,269,425,501	1,009,946,048
2030	0	0	57,321,667	1,622,500,000	1,565,178,333	1,299,098,016	2,309,044,064
2031	0	0	58,468,100	1,646,900,000	1,588,431,900	1,318,398,477	3,627,442,541
2032	0	0	59,637,462	1,676,100,000	1,616,462,538	1,341,663,906	4,969,106,447
2033	0	0	60,830,212	1,696,600,000	1,635,769,788	1,357,688,924	6,326,795,371
2034	0	0	62,046,816	1,722,100,000	1,660,053,184	1,377,844,143	7,704,639,514
2035	0	0	63,287,752	1,747,900,000	1,684,612,248	1,398,228,166	9,102,867,680
2036	0	0	64,553,507	1,779,000,000	1,714,446,493	1,422,990,589	10,525,858,269
2037	0	0	65,844,577	1,800,800,000	1,734,955,423	1,440,013,001	11,965,871,269
2038	0	0	67,161,469	1,827,800,000	1,760,638,531	1,461,329,981	13,427,201,250
2039	0	0	68,504,698	1,855,200,000	1,786,695,302	1,482,957,100	14,910,158,350
2040	0	0	69,874,792	1,888,200,000	1,818,325,208	1,509,209,922	16,419,368,273
2041	0	0	71,272,288	1,911,300,000	1,840,027,712	1,527,223,001	17,946,591,273
2042	0	0	72,697,734	1,939,900,000	1,867,202,266	1,549,777,881	19,496,369,154
2043	0	0	74,151,689	1,969,000,000	1,894,848,311	1,572,724,098	21,069,093,253
2044	0	0	75,634,722	2,004,000,000	1,928,365,278	1,600,543,180	22,669,636,433

Grand total profits: £ 22,669,636,433

Public Model

Fare Prices

The fare prices have been slashed in half as the main purpose of publicly owned infrastructure should not be maximising profits but providing a good value service for the taxpayer. In addition to this providing a well-priced transport system around London that will pay for itself in a matter of a few years is likely to be popular with voters and therefore will hold a fair bit of political clout.

Line	Peak/hour	Off-Peak/hour	Peak fare – Adult (£)	Off peak fare – Adult (£)	Peak fare – Concession (£)	Off peak fare – Concession (£)	Total/day (£)
Gatwick - Heathrow	1200	950	11.00	9.50	7.25	6.25	217,258
Heathrow - Gatwick	1200	950	11.00	9.50	7.25	6.25	217,258
Heathrow – City	670	510	10.00	9.00	6.50	3.00	107,179
City – Heathrow	670	510	10.00	9.00	6.50	3.00	107,179
Heathrow – Stansted	780	600	11.00	9.00	7.25	3.00	127,455
Stansted – Heathrow	780	600	11.00	9.00	7.25	3.00	127,455
Heathrow – Luton	1100	850	11.00	9.00	7.25	3.00	180,455
Luton – Heathrow	1100	850	11.00	9.00	7.25	3.00	180,455
Gatwick – City	310	260	11.00	9.00	7.25	3.00	54,636
City – Gatwick	310	260	11.00	9.00	7.25	3.00	54,636
Gatwick – Stansted	510	430	11.00	9.00	7.25	3.00	90,302
Stansted – Gatwick	510	430	11.00	9.00	7.25	3.00	90,302
Gatwick – Luton	670	510	11.00	9.00	7.25	3.00	108,486
Luton – Gatwick	670	510	11.00	9.00	7.25	3.00	108,486
City – Stansted	220	170	9.00	7.50	3.00	2.50	29,876
Stansted – City	220	170	9.00	7.50	3.00	2.50	29,876
City – Luton	220	170	9.00	7.50	3.00	2.50	29,876
Luton – City	220	170	9.00	7.50	3.00	2.50	29,876
Stansted – Luton	330	260	10.00	7.50	6.50	2.50	46,409
Luton – Stansted	330	260	10.00	7.50	6.50	2.50	46,409
						Total:	**£ 1,983,860**

Ticket Income by Year

As before, a modest ticket price increase of 1.5% per annum is applied on the 24/7 service provided by the Hyperloop.

Year	**Total ticket income (£ million)**	**Ticket income breakdown for each line (£ million)**									
		Gatwick – Heathrow	**Gatwick – London City**	**Gatwick – Luton**	**Gatwick – Stansted**	**Heathrow – London City**	**Heathrow – Luton**	**Heathrow – Stansted**	**London City – Luton**	**London City – Stansted**	**Luton – Stansted**
2024	726.1	159.0	40.0	79.4	66.1	78.5	132.1	93.3	21.9	21.9	34.0
2025	737.0	161.4	40.6	80.6	67.1	79.6	134.1	94.7	22.2	22.2	34.5
2026	748.0	163.8	41.2	81.8	68.1	80.8	136.1	96.1	22.5	22.5	35.0
2027	759.3	166.3	41.8	83.0	69.1	82.0	138.1	97.6	22.9	22.9	35.5
2028	772.8	169.3	42.6	84.5	70.3	83.5	140.6	99.3	23.3	23.3	36.2
2029	782.2	171.3	43.1	85.5	71.2	84.5	142.3	100.5	23.6	23.6	36.6
2030	793.9	173.9	43.7	86.8	72.3	85.8	144.4	102.0	23.9	23.9	37.1
2031	805.9	176.5	44.4	88.1	73.4	87.1	146.6	103.5	24.3	24.3	37.7
2032	820.2	179.6	45.2	89.7	74.7	88.6	149.2	105.4	24.7	24.7	38.4
2033	830.2	181.8	45.7	90.8	75.6	89.7	151.0	106.7	25.0	25.0	38.8
2034	842.7	184.6	46.4	92.2	76.7	91.1	153.3	108.3	25.4	25.4	39.4
2035	855.3	187.3	47.1	93.5	77.9	92.4	155.6	109.9	25.8	25.8	40.0
2036	870.5	190.7	47.9	95.2	79.2	94.1	158.4	111.9	26.2	26.2	40.7
2037	881.2	193.0	48.5	96.4	80.2	95.2	160.3	113.2	26.5	26.5	41.2
2038	894.4	195.9	49.3	97.8	81.4	96.6	162.7	114.9	26.9	26.9	41.8
2039	907.8	198.8	50.0	99.3	82.6	98.1	165.1	116.6	27.3	27.3	42.5
2040	923.9	202.4	50.9	101.0	84.1	99.8	168.1	118.7	27.8	27.8	43.2
2041	935.2	204.8	51.5	102.3	85.1	101.1	170.1	120.2	28.2	28.2	43.8
2042	949.3	207.9	52.3	103.8	86.4	102.6	172.7	122.0	28.6	28.6	44.4
2043	963.5	211.0	53.1	105.4	87.7	104.1	175.3	123.8	29.0	29.0	45.1
2044	980.6	214.8	54.0	107.2	89.3	106.0	178.4	126.0	29.5	29.5	45.9
Total	**17779.8**	**3894.2**	**979.3**	**1944.5**	**1618.6**	**1921.1**	**3234.6**	**2284.6**	**535.5**	**535.5**	**831.9**

This formula provides us with a total ticket income of **£17,779,800,000** over the 20-year period.

TOTAL OUTLAY OF COSTS

The table below includes all costs and the respective currency conversions for all components of the system, excluding staffing and maintenance (see page 60). The values are expressive of earlier calculations and research in this report.

		Cost ($)	Cost (£)
Hyperloop Infrastructure		1,035,600,000	828,480,000
	Vacuum Pumps	3,028,070	2,422,456
	Tube	196,824,561	157,459,649
	Pillar Construction	772,157,895	617,726,316
	Solar Panels	63,589,474	50,871,579
Capsules/Pods (x136)		183,600,000	146,880,000
	Air Compressor	37,400,000	29,920,000
	Interior and Seats	34,680,000	27,744,000
	Capsule structure + doors	33,320,000	26,656,000
	Suspension + Air Bearings	27,200,000	21,760,000
	Batteries, Motor and Coolant	20,400,000	16,320,000
	Propulsion Systems	10,200,000	8,160,000
	Emergency Braking	6,800,000	5,440,000
	General Assembly	13,600,000	10,880,000
Civil Engineering		2,687,057,758	2,149,646,206
	Tunnels	1,851,650,000	1,481,320,000
	Thames Bridge	17,300,000	13,840,000
	Construction waste (excl. tax)	11,857,758	9,486,206
	Station (x6)	625,000,000	500,000,000
	Hub	175,000,000	140,000,000
	Landscaping	6,250,000	5,000,000
Land purchase		2,485,840,685	1,988,672,548
	Heathrow-Gatwick housing	451,700,403	361,360,322
	Heathrow-Hub housing	591,576,979	473,261,583
	London City-Hub housing	1,341,299,130	1,073,039,304
	Luton-Hub housing	38,581,075	30,864,860
	Stansted-Hub housing	52,252,163	41,801,730
	Farmland	10,430,936	8,344,749
Misc.			
	Contingency	625,000,000	500,000,000
	Total:	**$ 7,017,098,443**	**£ 5,613,678,754**

PROFITS

Presented below are our projections for returning the Hyperloop initial loan of **£5,613,678,754** based on revenue generated from ticket purchases. This is inclusive of cumulative annual interest that increases the starting loan value.

Year	Starting loan balance	Loan interest (3.5% APR)	Staffing + maintenance costs	Total ticket income	Annual profits	Annual Balance
2024	£5,613,678,754	£196,478,756	£50,900,000	£726,092,760	-£5,134,964,750	-£5,134,964,750
2025	£5,134,964,750	£179,723,766	£51,918,000	£736,984,151	-£4,629,622,365	-£4,629,622,365
2026	£4,629,622,365	£162,036,783	£52,956,360	£748,038,914	-£4,096,576,594	-£4,096,576,594
2027	£4,096,576,594	£143,380,181	£54,015,487	£759,259,497	-£3,534,712,765	-£3,534,712,765
2028	£3,534,712,765	£123,714,947	£55,095,797	£772,759,755	-£2,940,763,753	-£2,940,763,753
2029	£2,940,763,753	£102,926,731	£56,197,713	£782,208,116	-£2,317,680,082	-£2,317,680,082
2030	£2,317,680,082	£81,118,803	£57,321,667	£793,941,237	-£1,662,179,315	-£1,662,179,315
2031	£1,662,179,315	£58,176,276	£58,468,100	£805,850,356	-£972,973,335	-£972,973,335
2032	£972,973,335	£34,054,067	£59,637,462	£820,179,038	-£246,485,827	-£246,485,827
2033	£246,485,827	£8,627,004	£60,830,212	£830,207,183	£514,264,141	£514,264,141
2034	£0	£0	£62,046,816	£842,660,291	£780,613,475	£1,294,877,615
2035	£0	£0	£63,287,752	£855,300,195	£792,012,443	£2,086,890,058
2036	£0	£0	£64,553,507	£870,508,136	£805,954,628	£2,892,844,686
2037	£0	£0	£65,844,577	£881,151,643	£815,307,066	£3,708,151,752
2038	£0	£0	£67,161,469	£894,368,918	£827,207,449	£4,535,359,202
2039	£0	£0	£68,504,698	£907,784,452	£839,279,753	£5,374,638,955
2040	£0	£0	£69,874,792	£923,925,606	£854,050,813	£6,228,689,768
2041	£0	£0	£71,272,288	£935,222,237	£863,949,949	£7,092,639,717
2042	£0	£0	£72,697,734	£949,250,571	£876,552,837	£7,969,192,553
2043	£0	£0	£74,151,689	£963,489,329	£889,337,640	£8,858,530,194
2044	£0	£0	£75,634,722	£980,620,961	£904,986,239	£9,763,516,433

Grand total profits: £9,763,516,433

Impacts of the Heathrow Expansion

'A growth in passenger numbers of 5% p.a. from 2025 to 2030 is expected at Heathrow Airport, once the third runway becomes operational in 2025. Thereafter we assume a central case 2.4% p.a. growth in passengers'. This section outlines the impact this would have on capsule logistics, coping with the extra influx of passengers as well as the resultant increase in profits. [24]

Passenger numbers

These figures are generated from the predicted figures forming the basis of the project and a proportional 5% increase in passenger numbers arriving and departing from Heathrow between 2025 and 2030 (as outlined in the Heathrow Expansion proposal). After that a 2.4% increase is applied per annum capped at a factor of 1.54x the original passenger numbers as Heathrow is expanding by a factor of 1.54 from 480,000 ATM's/annum (Air Transport Movements) to 740,000 ATM's/annum. [63]

	Passenger numbers departing Heathrow Airport per hour at peak time				**Passenger numbers arriving at Heathrow Airport per hour during peak time**			
	Heathrow – Gatwick	**Heathrow – London City**	**Heathrow – Luton**	**Heathrow – Stansted**	**Gatwick – Heathrow**	**London City – Heathrow**	**Luton – Heathrow**	**Stansted – Heathrow**
2024	1200	670	1100	780	1200	670	1100	780
2025	1260	704	1155	819	1260	704	1155	819
2026	1323	739	1213	860	1323	739	1213	860
2027	1389	776	1273	903	1389	776	1273	903
2028	1459	814	1337	948	1459	814	1337	948
2029	1532	855	1404	995	1532	855	1404	995
2030	1608	898	1474	1045	1608	898	1474	1045
2031	1647	919	1509	1070	1647	919	1509	1070
2032	1686	941	1546	1096	1686	941	1546	1096
2033	1727	964	1583	1122	1727	964	1583	1122
2034	1768	987	1621	1149	1768	987	1621	1149
2035	1811	1011	1660	1177	1811	1011	1660	1177
2036	1848	1032	1694	1201	1848	1032	1694	1201
2037	1848	1032	1694	1201	1848	1032	1694	1201
2038	1848	1032	1694	1201	1848	1032	1694	1201
2039…	1848	1032	1694	1201	1848	1032	1694	1201
…2044	1848	1032	1694	1201	1848	1032	1694	1201
Increase	**648**	**387**	**635**	**450**	**648**	**387**	**635**	**450**

Capsule Logistics

Heathrow – Gatwick

In 2044 the Heathrow expansion is expected to result in a total increase of an extra 1,296 passengers an hour using this line (648 in each direction) meaning this line would increase its passenger load from 4,800 passengers/hour to 6,096 passengers/hour. To transport 6,096 passengers an hour it would require a minimum of 109 passenger transfers in each direction (with a pod capacity of 28 people) meaning pod frequency has to increase by eight secs to every 32 secs. At this frequency, at least 112 pod transfers leave from each station every hour; resulting in a maximum capacity of 6,272 passengers/hour during peak time.

The frequency of the pods and the journey time of 4m 18secs means that there will be up to eighteen pods (258secs/32secs) in both tubes at any one time (nine in each direction). These are in addition to ten pods (five at each end of the line) allowing passengers to access the shuttles at least 2m 40secs in advance of the doors shutting for safety checks and baggage loading. A further four pods are needed to help combat any emergency occurring during peak time meaning a total of 32 pods are needed to support this line (at peak times).

Total pods needed: 32 - an additional (8) pods

Heathrow – Hub:

By 2044 the Heathrow expansion is expected to result in a total increase of 2,944 passengers an hour (1472 in each direction) as this line is affected by the growth in passenger numbers going to London City (774), Luton (1270) and Stansted (900). The line would increase its passenger load from 8,080 passengers/hour to 11,024 passengers/hour. To transport 11,024 passengers an hour it would require a minimum of 197 passenger transfers in each direction meaning pod frequency has to increase by seven secs to every 18 secs; meaning at least 200 pod transfers leave from each station every hour. This results in a maximum capacity in both directions of 11,200 passengers/hour.

The frequency of the pods and the journey time of 8m 50secs means that there will be up to sixty pods in both tubes at any one time (thirty in each direction). These are in addition to sixteen pods (eight at each end of the line) allowing passengers to access the shuttles at least 2m 24secs in advance of the doors shutting for safety checks and baggage loading. A further six pods are needed to help combat any emergency/malfunction occurring during peak time meaning a total of 82 pods are needed to support this line (at peak times).

Total pods needed: 82 - an additional (24) pods

London City – Hub:

By 2044 the Heathrow expansion is expected to result in a total increase of 774 passengers an hour (387 each way) increasing the lines capacity from 3,060 passengers/hour to 3,834 passengers/hour. To transport 3,384 passengers an hour it would require a minimum of 69 passenger transfers in each direction meaning pod frequency has to increase by nine secs to every 51 secs; meaning at least 70 pod transfers leave from each station every hour. This results in a maximum capacity in both directions of 3,952 passengers/hour.

The frequency of the pods and the journey time of 3m 34secs means that there will be up to ten pods in both tubes at any one time (five in each direction). These are in addition to six pods (three at each end of the line) allowing passengers to access the shuttles at least 2m 33secs in advance of the doors shutting for safety checks and baggage loading. A further two pods are needed to help combat any emergency/malfunction occurring during peak time meaning a total of 18 pods are needed to support this line (at peak times).

Total pods needed: 18 - an additional (4) pods

Luton – Hub:
By 2044 the Heathrow expansion is expected to result in a total increase of 1,270 passengers an hour (635 each way) increasing the lines capacity from 4,640 passengers/hour to 5,910 passengers/hour. To transport 5,910 passengers an hour it would require a minimum of 106 passenger transfers in each direction meaning pod frequency has to increase by seven secs to every 33 secs; meaning at least 109 pod transfers leave from each station every hour. This results in a maximum capacity in both directions of 6,104 passengers/hour during peak time.

The frequency of the pods and the journey time of 2m 33secs means that there will be up to ten pods in both tubes at any one time (five in each direction). These are in addition to eight pods (four at each end of the line) allowing passengers to access the shuttles at least 2m 12secs in advance of the doors shutting for safety checks and baggage loading. A further two pods are needed to help combat any emergency/malfunction occurring during peak time meaning a total of 20 pods are needed to support this line (at peak times).

Total pods needed: 20 - an additional (4) pods

Stansted – Hub:
By 2044 the Heathrow expansion is expected to result in a total increase of 900 passengers an hour (450 each way) increasing the lines capacity from 3,680 passengers/hour to 4,580 passengers/hour. To transport 4,580 passengers an hour it would require a minimum of 82 passenger transfers in each direction meaning pod frequency has to increase by eight secs to every 42 secs; meaning at least 85 pod transfers leave from each station every hour. This results in a maximum capacity of 4,760 passengers/hour during peak time.
The frequency of the pods and the journey time of 2m 49secs means that there will be up to ten pods in both tubes at any one time (five in each direction). These are in addition to eight pods (four at each end of the line) allowing passengers to access the shuttles at least 2m 48secs in advance of the doors shutting for safety checks and baggage loading. A further two pods are needed to help combat any emergency/malfunction occurring during peak time meaning a total of 20 pods are needed to support this line (at peak times).

Total pods needed: 20 - an additional (4) pods

In summary, in order to cope with the influx of passengers resulting from the Heathrow Expansion an additional 44 pods would be needed resulting in an extra cost of $55 million (£44 million). However, this increase in numbers also increases ticket sales and in turn profits.

Ticket income - Private model

Values start at the same value as the private business model in 2024 but there is an annual increase of 5% for the first five years of the new terminal opening in 2025 (in accordance with the predictions outlined previously (see page 99). After that a 2.4% increase is applied per annum capped at a factor of 1.54x as used for the increased passenger numbers; this point is reached in 2036. In addition to this throughout the 20-year timeframe, as before, a 1.5% annual increase in ticket prices is applied in accordance with predicted inflation figures

With an increased ticket income of £9,407,500,000 taking away the £44 million needed for the extra pods to support this increase gives an increased profit of **£9,363,500,000.**

Year	**Total ticket income (£ million)**	**Ticket income breakdown for each line (£ million)**			
		Heathrow - Gatwick	**Heathrow-London City**	**Heathrow-Luton**	**Heathrow-Stansted**
2024	944.7	318.1	161.8	272.4	192.4
2025	1006.8	339.0	172.4	290.3	205.1
2026	1073.0	361.3	183.8	309.4	218.5
2027	1143.6	385.1	195.9	329.7	232.9
2028	1218.8	410.4	208.7	351.4	248.2
2029	1298.9	437.4	222.5	374.5	264.5
2030	1384.3	466.1	237.1	399.2	281.9
2031	1438.8	484.5	246.4	414.9	293.0
2032	1495.4	503.5	256.1	431.2	304.6
2033	1554.3	523.4	266.2	448.2	316.5
2034	1615.4	544.0	276.7	465.8	329.0
2035	1679.0	565.4	287.6	484.1	342.0
2036	1739.3	585.6	297.9	501.6	354.3
2037	1765.4	594.3	302.4	509.1	359.6
2038	1791.9	603.3	306.9	516.7	365.0
2039	1818.7	612.3	311.5	524.5	370.4
2040	1846.0	621.5	316.2	532.3	376.0
2041	1873.7	630.8	320.9	540.3	381.6
2042	1901.8	640.3	325.8	548.4	387.4
2043	1930.3	649.9	330.6	556.7	393.2
2044	1959.3	659.6	335.6	565.0	399.1
Total	32479.4	10935.6	5563.0	9365.7	6615.1
Without expansion	23071.9	7768.0	3952.5	6652.7	4698.7
Increase of:	**9407.5**	**3167.6**	**1610.5**	**2713.0**	**1916.4**

Ticket Income – Public model

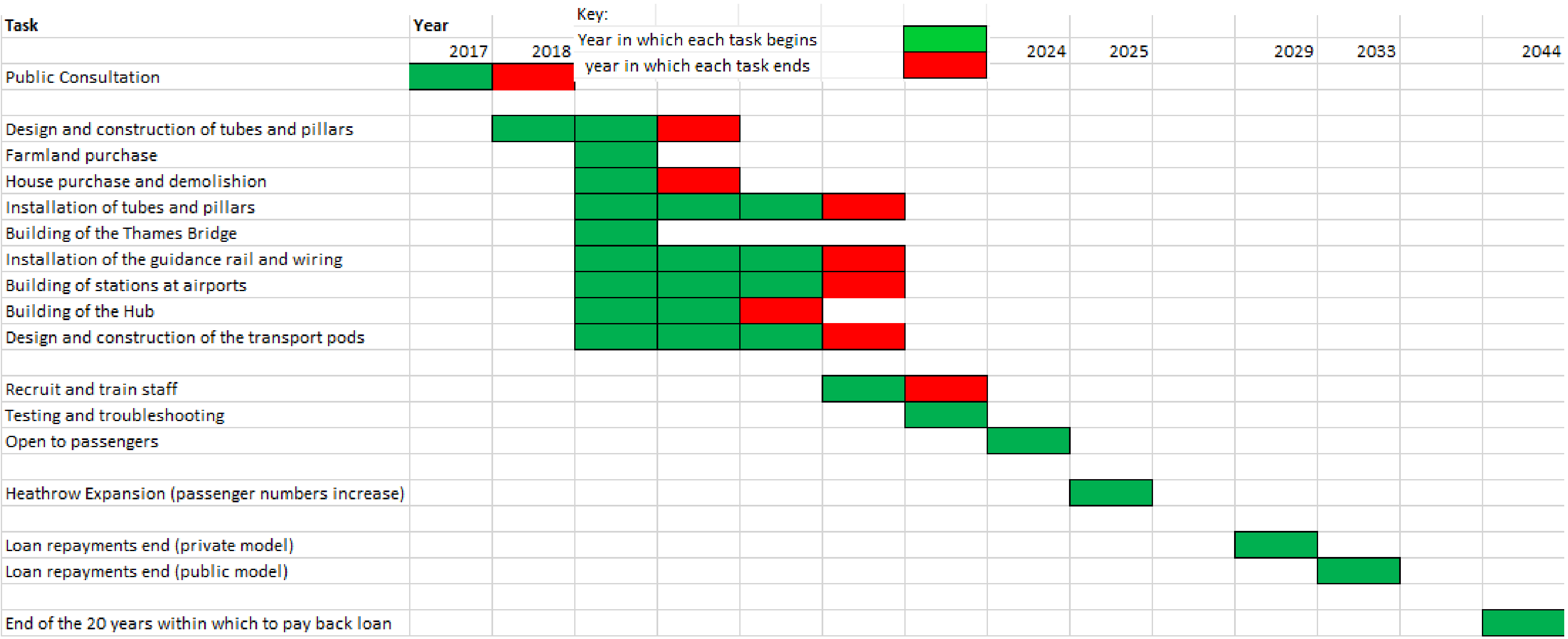
Year	Total ticket income (£ million)	Ticket income breakdown for each line (£ million)			
		Heathrow – Gatwick	Heathrow – London City	Heathrow – Luton	Heathrow – Stansted
2024	462.9	159.0	78.5	132.1	93.3
2025	493.3	169.5	83.7	140.8	99.4
2026	525.8	180.6	89.2	150.0	106.0
2027	560.3	192.5	95.0	159.9	112.9
2028	597.2	205.1	101.3	170.4	120.4
2029	636.4	218.6	107.9	181.6	128.3
2030	678.3	233.0	115.0	193.6	136.7
2031	705.0	242.2	119.6	201.2	142.1
2032	732.7	251.7	124.3	209.1	147.7
2033	761.6	261.6	129.2	217.3	153.5
2034	791.6	271.9	134.2	225.9	159.5
2035	822.7	282.6	139.5	234.8	165.8
2036	852.2	292.7	144.5	243.2	171.8
2037	865.0	297.1	146.7	246.9	174.4
2038	878.0	301.5	148.9	250.6	177.0
2039	891.2	306.1	151.1	254.3	179.6
2040	904.5	310.7	153.4	258.2	182.3
2041	918.1	315.3	155.7	262.0	185.1
2042	931.9	320.0	158.0	266.0	187.8
2043	945.9	324.8	160.4	269.9	190.7
2044	960.0	329.7	162.8	274.0	193.5
Total	15914.8	5466.1	2699.0	4541.9	3207.8
Without expansion	11334.5	3894.2	1921.1	3234.6	2284.6
Increase of…	**4580.3**	**1571.9**	**777.9**	**1307.3**	**923.2**

Values start at the same value as the public business model in 2024 but there is an annual increase of 5% for the first five years of the new terminal opening in 2025 (in accordance with the predictions outlined previously (see page 104). After that a 2.4% increase is applied per annum capped at a factor of 1.54x as used for the increased passenger numbers; this point is reached in 2036. In addition to this throughout the 20-year timeframe, as before, a 1.5% annual increase in ticket prices is applied in accordance with predicted inflation figures.

With an increased ticket income of £4,580,300,000 taking away the £44 million needed for the extra pods to support this increase gives an increased profit of **£4,536,300,000.**

Timeline of Events

Below is a spreadsheet document laying out our projected timeline for beginning construction, completing construction and moving into the phases of public service.



Conclusion

"To design a system for transferring passengers between the existing airports."

The Capital Connect Hyperloop network epitomises this brief. We have designed a system that not only transfers passengers with superior efficiency, but we have created an asset to London – one of the world's most dynamic cities. [64]

At present, the five airports serving the city of London do not operate as one unit. The introduction of the Capital Connect Hyperloop will increase connectivity between airports on a large scale, while being conservative of land, capital and time.

Up and running by 2024 and costing an astoundingly low **£5,642,589,098** (private model) or **£5,613,678,754** (public model), our Hyperloop proposal offers unparalleled benefits over our rivals, not least its ability to be in use with minimal disruption in terms of both construction and everyday use. Such a low expenditure figure also means that returning our loan will be possible within less than 10 years.

For airline passengers taking the Capital Connect, transfers are revolutionised. They are able to connect to their destination at near-sonic speeds, cutting their travel time immeasurably. Passengers also needn't have concerns of being caught in traffic jams as the Hyperloop is a standalone, closed and entirely reliable system.

The global demand for energy is already a struggle without new high-powered systems being introduced. The Capital Connect is, however, capable of running itself. Our use of solar panels atop the Hyperloop tubes harness solar energy and optimise it for power extensively in excess of what is needed. This has profound prospects for a utopian future Earth where energy is always accessible and never wasted.

In summary, the Capital Connect provides London with exactly what it needs: unrivalled interconnections between forefronts of economic turnover with negligible adverse implications. Our Hyperloop system will change lives and ultimately change the world.

Project review

As a team, we have worked tirelessly on completing this project to the highest possible standard. This has opened our eyes to the real world of engineering: the problems associated with large feats; their impacts on those who use these, and crucially how to plan such colossal tasks.

Since starting the project in November 2016, the team has encountered various problems and unforeseen circumstances that have encouraged us to think conceptually so as to come to innovative solutions. Major problems, for example, included crossing the Thames, dealing with inconsistencies in topography and understanding and explaining the mechanics and inner workings of the Hyperloop.

Piecing this project together has definitely been ruthless at times. However, all five of us conclude that it has granted us access to engineering at an earlier stage in our lives than would have otherwise been possible. We have thoroughly enjoyed this!

Bibliography

This bibliography is a complete guide to all the resources, data and software applications used in researching for the Capital Connect project. Navigate using the superscript numbers in the document and correlate them to those below. You will find them in ascending order.

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