Airport to Airport Challenge 2016-17

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Overall Description

At present the system of travelling between London airports is inefficient in terms of time, money and resources. These are some of the most valuable things to the modern day passenger and so we believe there is room for innovation.

We aim to design a train network system powered using linear induction and magnetic levitation to quickly transport passengers from one hub to another, expanding Heathrow into a large and efficient mega airport.

Our ideas have come from a variety of sources such as current and in-development projects with similar characteristics, magazines like ‘New Scientist’ and ‘How it Works’ and speaking to professionals on the subject such as an ex-civil engineer from the city of Birmingham council. Predominantly however, the ideas and concepts we use are from our own thoughts and imaginations.

Magnetic levitation and magnetic acceleration

We decided upon this combination after a thorough assessment of factors such as environmental impact, energy efficiency, and speed.

Through a complex point-scoring system it became clear the maglev way the way to go; scoring well in nearly all categories. This is because of three main points: it does not directly use fossil fuels; it a proven technology that has already been refined to a good standard by other mass transit projects; it is incredibly fast and currently holds the world speed record for rail based travel.

After looking at the hyperloop, a transport system designed by Elon Musk, we decided that the vehicle should travel through a partial vacuum in a tube to slash air resistance - the main loss of kinetic energy for any transport system travelling at high velocity. Our take on this uses a unique design and has never been built before although the technology required is available today. The reason that our designs are unique is that it takes the best parts of this design and incorporates additional ideas and advancements bade by other company and - more commonly - our own innovative ideas. A detailed description of how this happens can be found in our mechanical and electrical engineering section

Planning and Environment

Location

Being the second largest city in europe, London is an incredibly difficult workplace for an engineering feat on this scale. Land is incredibly expensive and rarely undeveloped.

The solution we found for this was to retrofit the current mass transit routes throughout the city with tracks and send our trains parallel to them.

Fortunately the vast majority of the track could be constructed parallel to and alongside the current motorways surrounding London. This land can be bought more cheaply than developed land and would circumvent complaints of spoiling the environment.

Why Linear Induction?

We decided upon linear induction (i.e mag-lev) after a thorough assessment of factors such as environmental impact, energy efficiency, and speed.

Through a complex point-scoring system it became clear the mag-lev way the way to go; scoring well in nearly all categories.

Our unique design has never been built before although the technology required is available today. The tubes through which our trains operate will be kept at vacuum pressure to slash wind resistance - The main loss of kinetic energy for any transport system travelling at velocity.

The Big Spreadsheet

In order to keep our ideas and tables of values together, we created a large multi-page spreadsheet. This simplified the process of information gathering and comparison greatly as well as allowing us to carry out complex formulae on vast data sets almost instantly. It was a vital part of the design process and the only way to illustrate the complexity of it, we are showing a few snippets of it here.

	PASSENGERS EACH HOUR		PASSENGERS EACH YEAR	
LINK	**PEAK**	**AVERAGE**	**PEAK**	**AVERAGE**
Heathrow - Gatwick	1,200	950	10,519,200	8,327,700
Gatwick - Heathrow	1,200	950	10,519,200	8,327,700
Heathrow - Luton	1,100	850	9,642,600	7,451,100
Luton - Heathrow	1,100	850	9,642,600	7,451,100
Heathrow - Stansted	780	600	6,837,480	5,259,600
Stansted - Heathrow	780	600	6,837,480	5,259,600
Heathrow - City	670	510	5,873,220	4,470,660
City - Heathrow	670	510	5,873,220	4,470,660
Gatwick - Luton	670	510	5,873,220	4,470,660
Luton - Gatwick	670	510	5,873,220	4,470,660
Gatwick - Stansted	510	430	4,470,660	3,769,380
Stansted - Gatwick	510	430	4,470,660	3,769,380
Stansted-Luton	330	260	2,892,780	2,279,160
Luton - Stansted	330	260	2,892,780	2,279,160
Gatwick - City	310	260	2,717,460	2,279,160
City - Gatwick	310	260	2,717,460	2,279,160
City - Stansted	220	170	1,928,520	1,490,220
Stansted - City	220	170	1,928,520	1,490,220
City-Luton	220	170	1,928,520	1,490,220
Luton - City	220	170	1,928,520	1,490,220
	Total	9,420	**Total**	82,575,720

Per year			
LOCATION	IN	OUT	TOTAL I/O
Gatwick	18,846,900	18,846,900	37,693,800
Luton	15,691,140	15,691,140	31,382,280
Heathrow	25,509,060	25,509,060	51,018,120
Stanstead	12,798,360	12,798,360	25,596,720
City	9,730,260	9,730,260	19,460,520

Max per hour			
LOCATION	IN	OUT	TOTAL I/O
Gatwick	2,690	2,690	5,380
Luton	2,320	2,320	4,640
Heathrow	3,750	3,750	7,500
Stanstead	1,840	1,840	3,680
City	1,420	1,420	2,840

Per hour			
LOCATION	IN	OUT	TOTAL I/O
Gatwick	2,150	2,150	4,300
Luton	1,790	1,790	3,580
Heathrow	2,910	2,910	5,820
Stanstead	1,460	1,460	2,920
City	1,110	1,110	2,220

LINK	Distances (Km)
Heathrow - Gatwick	40
Heathrow - Luton	45
Heathrow - Stansted	70
Heathrow - City	35
Gatwick - Luton	80
Gatwick - Stansted	90
Stansted-Luton	45
Gatwick - City	45
City - Stansted	45
City-Luton	50
Total	545

	Minimum average Velocity		
LINK	**Km/h**	**m/s**	**Mph**
Heathrow - Gatwick	120	33	75
Heathrow - Luton	135	38	84
Heathrow - Stansted	210	58	130
Heathrow - City	105	29	65
Gatwick - Luton	240	67	149
Gatwick - Stansted	270	75	168
Stansted-Luton	135	38	84
Gatwick - City	135	38	84
City - Stansted	135	38	84
City-Luton	150	42	93

Finance

Budget calculator	
Total passengers	82,575,720
Cost of a ticket	£15.00
Ticket Income	**£1,238,635,800.00**

Income	
A2A tickets	£1,238,635,800.00
Extra tickets	£112,000,000.00
Electricity generation	£8,000,000.00
Food sales	£50,000,000.00

Expenses	
Electricity usage	£61,529,178.06
Fuel	£5,000.00
Maintenance	£10,000,000.00
Staff	£15,000,000.00
Tracks	£50,000,000.00
Carriages	£200,000,000.00
Terminals	£90,000,000.00
Land Buying	£100,000,000.00

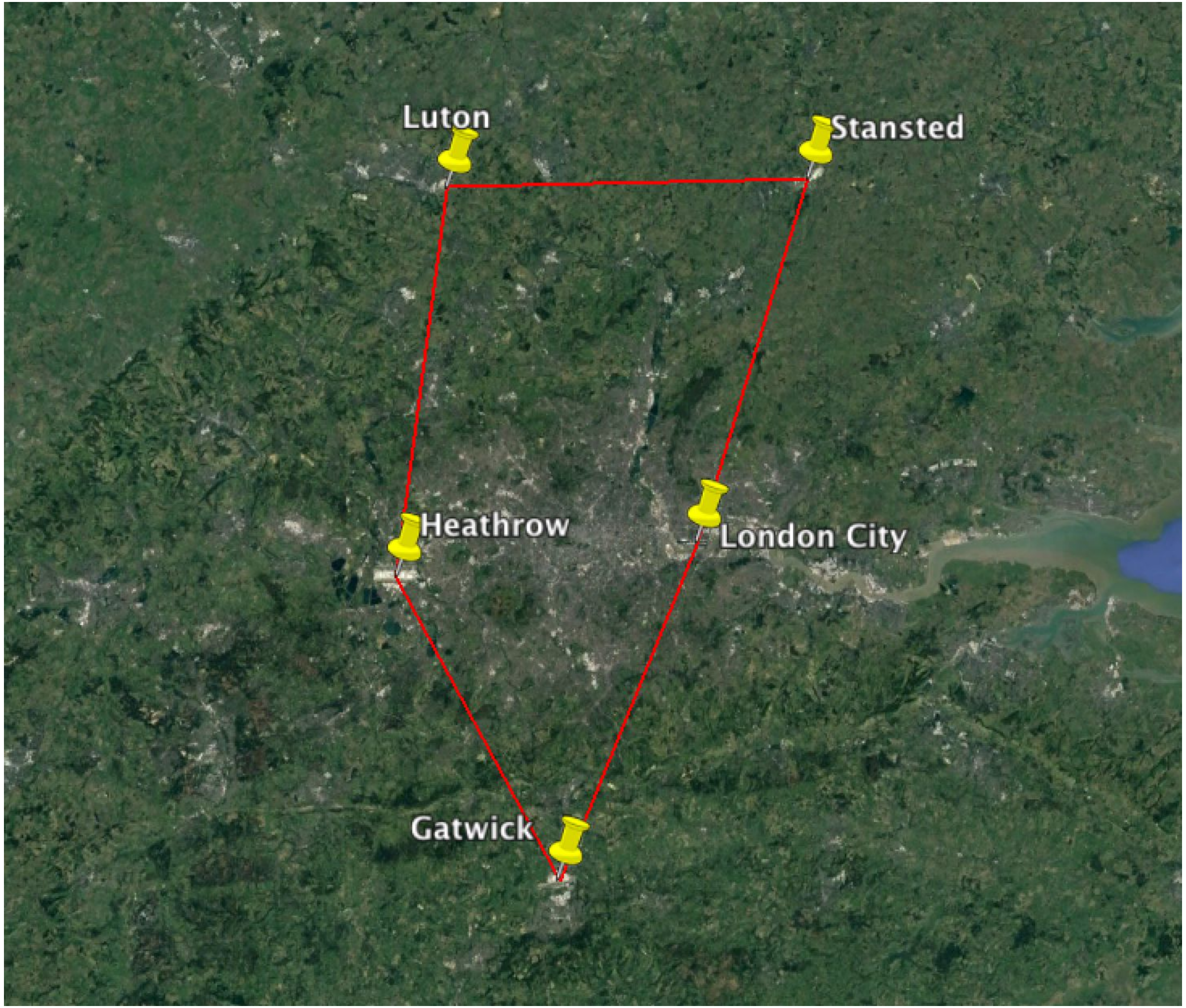
Loan interest calculator	
Money borrowed	£526,534,178.06
Rate	0.05
loan cost	£870,517,748.27
Overall cost	**£1,397,051,926.33**

Power cost calculator	
Total kilowatts of power used	140,343
Price per kilowatt/hour	£0.05
Cost of power	**£61,529,178.06**

Total Remaining	
As a value	**£11,583,873.67**
As a percentage	**1%**

Please note that all figures are early estimates only.

Civil engineering



The Most direct circular route is 215 km long.
A route through London's center is plausible as engineers could retrofit the current mass transit routes through the city with our tubular design and send our trains parallel with them. The advantage of this layout is it's short length and the way that it cuts the time taken between Stansted and Gatwick airport by traveling directly through London City

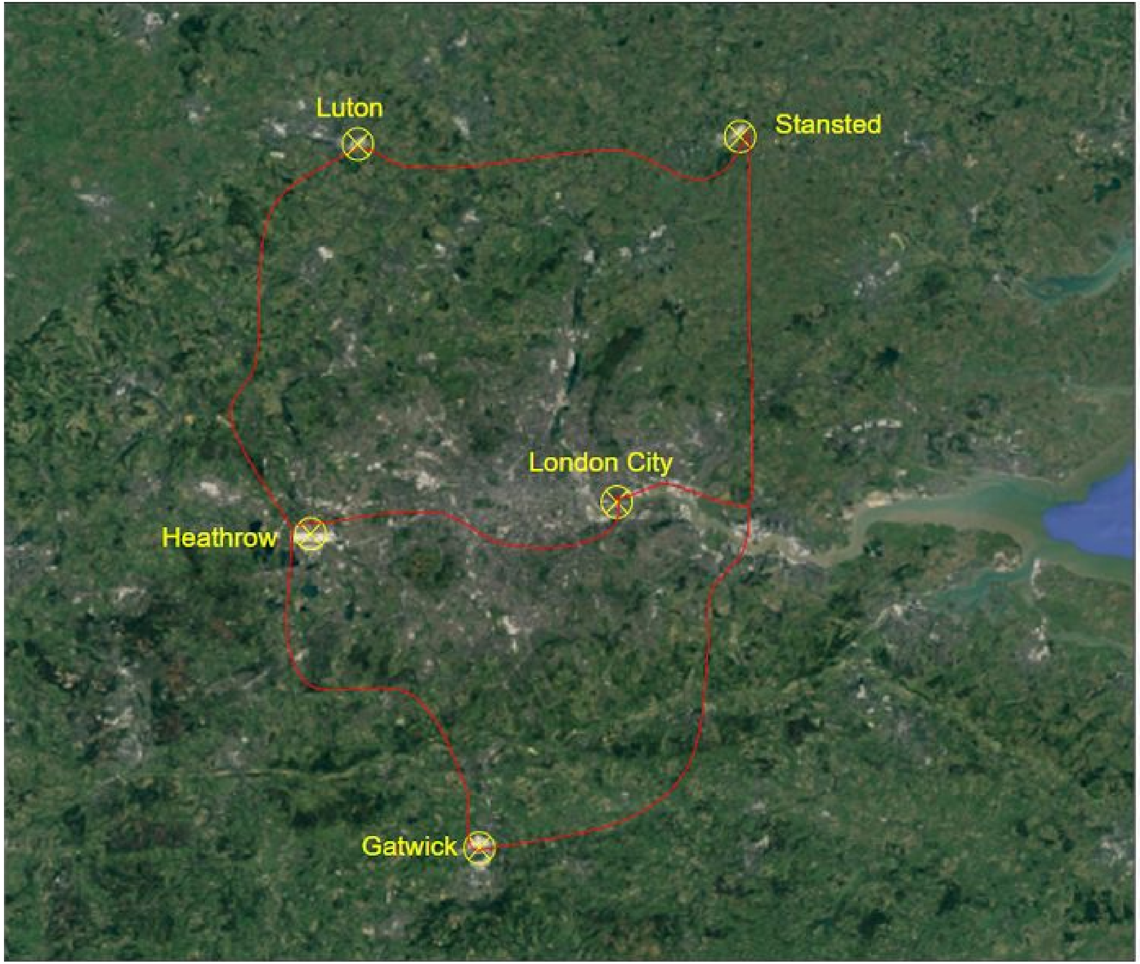
Direct Route

This data is pivotal, it reveals that the most direct route (as shown on the previous slide) actually has an elevation gain of 856 meters. Estimating the mass of the train at 20 tonnes (The mass of the average train carriage) gives us a value of 1.7 X 10^8 joules of energy converted to GPE. This is 170 million J of wasted energy. Another option is to follow main motorway routes by adding our tube to the side of the carriageway. This is likely to be a path with minimal elevation.
Unfortunately as this technology is so modern there is currently very little information on the efficiency and power consumption of maglev trains, any estimate on our part would be inaccurate. However we can assume that 170 million joules of energy is a relatively large amount. (Enough to send three African bush elephants to the top of Everest.)

Indirect Route

This elevation table is that of a less direct route that closely follows main roads between the airports.

The distance is greater but more importantly the elevation is 35% less. This will greatly reduce the energy consumption of the maglev train. This model is more of a draft than a final graph as during the construction stage engineers could find ways of following the contours of the land more effectively.



This, more complex route, was one that we found to be vastly superior. The main feature of it is it's incorporation of existing infrastructure, geographical features and the buildings and settlements it passes through. Even though it's path is approximately 280 km - 30% further than the most direct route - it's advanced economic considerations mean that it is the route of choice for our transport system where efficiency is of great concern. By following major roads we expect to vastly reduce congestion because a large proportion of motorists on these roads are travelling to and from the airports in our hub system. By encouraging these motorists to use our trains we will be doing lots to slash greenhouse gases in and around london.

Mechanical and electrical engineering

Specification calculation

In order to understand just how the system must be able to perform, we took the most challenging route - from Stansted to Gatwick - and calculated exactly what the minimum requirements would be if we were to be constantly accelerating for one half the journey, and decelerating for the other, all while covering the entire 90km distance in 20 minutes.

The conclusion from this was that whatever system we used, it must be able to provide a constant acceleration of 0.25 meters per second per second and be capable of attaining a maximum velocity of 150 meters per second.

The only feasible technology that could provide this was found to be magnetic levitation trains using linear induction motors.

Accelleration required to travel from stansted to Gatwick in 20 minutes

$v = u + at$
$v^2 = u^2 + 2as$
$s = ut + \frac{1}{2}at^2$

u = initial velocity
v = final velocity
s = displacement (distance)
a = accelleration
t = time

$u = 0$
$v = ?$
$s = 45000$
$a = ?$
$t = 600$

Accelleration and decelleration each take ½ the journey so distance and time are halved

$45000 = 0 \times 600 + \frac{1}{2} \times a \times 600^2$
$90000 = a \times 600^2$
$0.25 = a$
$v = u + at$
$v = 0 + 0.25 \times 600$
$v = 150$

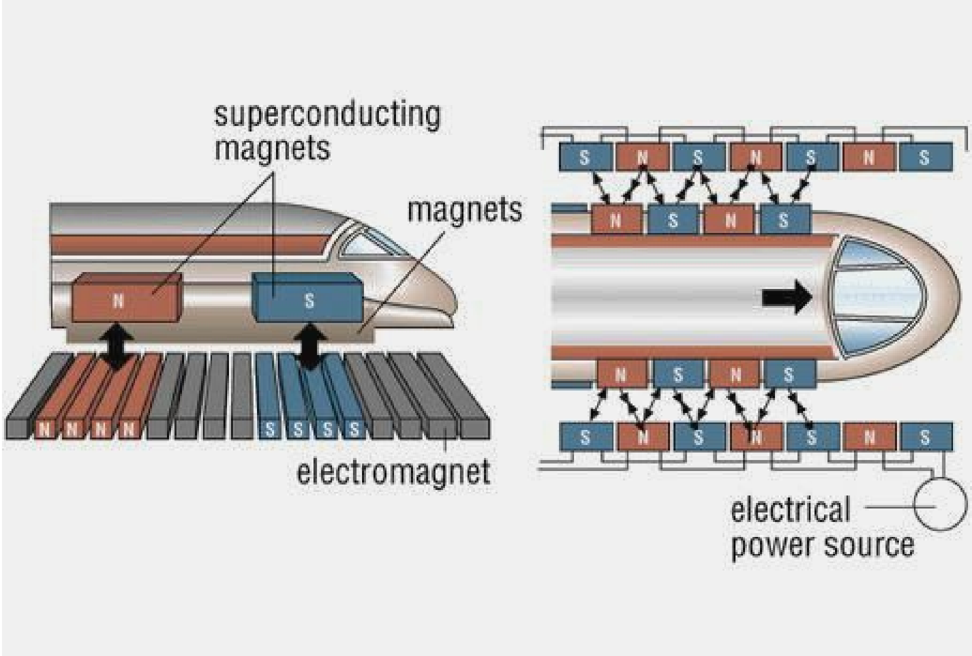
Conclusion

- Our propusion system must be capable of exerting force great enough to accellerate and decellerate the train at a rate of $0.25 \, m/s^2$ constantly
- The maximum velocity reached will be 150 m/s

How does Mag-lev Work?

There are two main types of maglev train that use magnetism in different ways. Electromagnetic suspension (EMS) uses C-shaped arms that wrap underneath the track. Electromagnets on the underside pull the train up by attracting the arms to the bottom of the track.

Electrodynamic suspension (EDS) uses the train's motion to induce magnetic eddy currents in the metal rail which creates a cushion of magnetic repulsion. The sides of the track have coils built in which create an overlapping pattern of alternating north and south magnetic fields. To accelerate, the train rapidly alternates the direction of its own supercooled magnetic coils to attract the train to the next coil along the rail.



How will we maintain a near vacuum?

Capsules will travel in a near vacuum because currently one of the greatest losses of kinetic energy in any automobile is drag. A near vacuum significantly reduces the collisions of air particles with the front face of the capsule, this reduces drag significantly. A system of valves and pumps will keep the air pressure at 100 pascals, this is one thousandth of normal air pressure at sea level. The gas in the tunnel can be nitrogen as an effective desiccant. This will help to increase the longevity of the rails and train as any moisture in the air can form metal oxide deposits and corrode metals. Yet another advantage of a near vacuum is that the ride would be more enjoyable than a usual train journey; smooth, silent and incredibly fast.

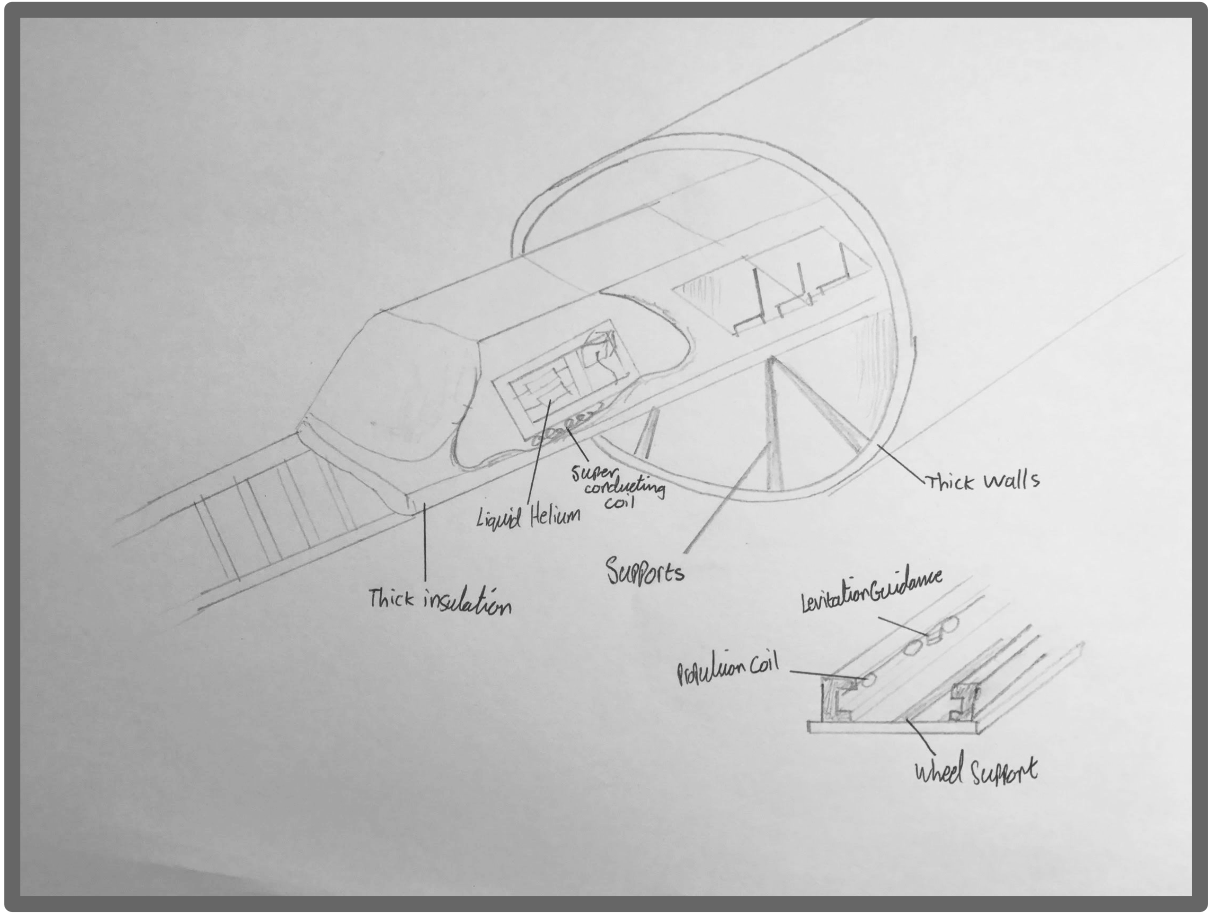
What sort of vacuum pump could be used?

For obvious reasons the pumps would have to be large, powerful and therefore expensive. Our 280km tunnel, diameter 4m would have a vast volume; $\pi \times 2^2 \times 280000 = 3.5 \times 10^6$ cubic meters.

Using an average vacuum pump with rate 20m^3/hour, the time taken to create a vacuum would be $3.5/20 \times 10^6$ = 175000 hours. (20 years).

Upon further research, we have found larger industrial vacuum pumps capable of drawing 2000m^3/hour, having one pump stationed every five kilometers of track, makes 56 in total; 112000 cubic meters per hour. Thus the total time taken to remove 95% of the air would take 29.7 hours.

Brief Design Sketch



Safety Systems

- A safety escape hatch would be a very difficult mechanism to implement into the A2A tube because it is under a vacuum, therefore the downforce on the hatch would be vast and too much for human operation. Besides this, a hatch would release the pressure in the entire line causing a backlog of problems to the other carriages.
- To avoid this, our track will be built with emergency run-off sections so if a passenger or sensor detects an emergency the train can change direction, enter an emergency run-off section and come to a stop. This small section of tube can then be sealed, brought back to atmospheric pressure and the doors can be opened. With today's technology the entire process could be achieved in seconds and emergency services automatically alerted.
- Doctors and medics are continually being replaced by simple google searches and online medical services.
- Within the next ten years we expect AI to have the capacity to give complex medical advice and will be available on board public services.
- Our trains will have an AI (Artificial intelligence) device built in to give instructions in an emergency, this will include instructions for resuscitation, defibrillation and other forms of emergency care.
- Journey times will however be extremely short and we don't expect medical emergencies to be a common occurrence.
- Due to the high acceleration of the A2A links, a doctor's consent will be required in order to attain a seasonal or long term pass on the trains. High G-force can reduce blood flow to the brain and cause blackouts if the passenger has a very weak heart or low blood pressure

Reliability

40%

The number of Southern Rail trains that arrived on time between january 2016 and February 2017 in the Southern Region.

Contingency Plans and Future Expansion

We recognise that there is a serious problem with the reliability of UK trains and this deters motorists from using the system as a means of transport.
Our rail system will remain close to 100% reliable and we will achieve this by having a near fully autonomous rail system. No drivers, Guards or Conductors. The lack of a driver will mean that we can circumvent any signalling problems and lack of staffing. Doors will close 60 seconds before departure, and there will be one member of staff there to ensure that everybody is on board.
Coaches will be chartered in a contingency against train failure which will go to and from each airport. This is of course a last resort and a malfunctioned carriage would ideally be removed through an exit point in the roof of the tube and repaired elsewhere to allow the normal function of the other carriages.
After breaking even within 20 years, we plan to add a second tube either directly above or to the side of the current one to double our transport capacity.
In the more distant future the system can be expanded to reach more distant UK airports and even connect up to the National Railway to allow seamless transport to any destination.
With more trains running every hour, as we expand so does the reliability of the company.

Cost and Schedule

General Upkeep

Maintenance is the general day-to-day upkeep of the railway such as looking after tracks, signals and power supplies. Railways are made up of complex mechanical and electrical systems and there are hundreds of thousands of moving parts. If a railway service is to be reliable, the equipment must be kept in good working order and regular maintenance is the essential ingredient to achieve this. A railway will not survive for long as a viable operation if it is allowed to deteriorate because of lack of maintenance. Although maintenance is expensive, it will become more expensive to replace the failing equipment early in its life because maintenance has been neglected. Therefore it is essential to have a plan to maintain a functioning track. The upside of using maglev technology is that it involves far fewer moving parts than a conventional locomotive. This will slash the cost of general maintenance.

Due to the high operating speeds of the magnetic levitation trains we use, we expect parts to wear down quickly over time due to higher temperatures and stresses in comparison to normal trains.
Qualified engineers and apprentices will be maintaining the track 24 hours per day, the parts they use in maintaining the track comes under running costs.
To employ a modest 100 engineers will cost in excess of £7000000. Of course the scheme will require many other types of staff such as security, but the aim is to minimise the running costs and thus minimise the staff. Our trains will not require a driver as we now have the technology to run driverless trains; a study in 2015 revealed that 36% of train accidents were down to human error.

Table of recently built and under construction rail projects

Railway	Date	Type of System	Cost per km	Distance/km	Comments
Madrid-Albacete	2010	High speed rail line	£8.39 million	304	
Seoul-Gimpo, Korea	2010	Airport line	£80.62 million	20.4	
Yichang-Wanzhou, China	2011	Main line	£7.48 million	377	Surface with 278 km in tunnel or bridges
Haikou-Sanya, China	2010	High speed rail line	£8.22 million	308	
Copenhagen	2011-2018	New metro line	£203.4 million	16	All underground

What Does this data suggest?

The data we gathered is only a small amount compared with the number of railway lines around the world but it gives us some insight into the costs involved with railway construction. The mean cost per km is £61.62 million. This figure is greatly affected by the Copenhagen line which is extremely expensive due to it being entirely underground. This information, coupled with the distance our line will cover has made it an obvious choice to chose an above - ground railway system. Using £203.4 million/km as a guideline, our route would cost £56 billion. Airport lines also appear relatively expensive, the most likely reason for this being their short length, meaning that they have proportionally more stations and other necessary expenses per kilometer

Implementation Programme

To have finished construction of the tube in five years, engineers would have to construct and weld together thousands of sections of tubing in a short space of time. 215 km in 5 years = 82.6m per week. This is certainly plausible if the entire process is happening at the same time, i.e the sections of tubing are created at the same time as their welding and implementation to the main line. If we can have the sections built in the UK then this would be far easier than transporting cargo overseas. If one section is approximately 42 m in length, we could use thermite welding to install 2 sections per week at different sections of track. The material for the tubing must be very strong. Silicon Carbide is extremely strong and this could be used for the exterior, the interior would need to be an insulator so as to avoid inducing a voltage in the conductive silicon carbide due to the electromagnetic fields. An alternative ceramic could be used for this.

The mass of the tubing will be enormous; 1 inch of silicon carbide for the 215 km track will have a volume of 68189 cubic meters. At a density of 3210 kg/m3 The mass will be $2.2 \text{ X } 10^8$ kg. And at a cost of £150/ton, the entire tube could cost £33 million in materials alone for the outer layer.

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