THE UNIVERSITY OF EDINBURGH

Observing The Complexity Of A Hyperloop: Beyond The Sphere Of A Technical Marvel

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ABSTRACT:

Upon observing already implemented large scale infrastructure projects such as the Channel Tunnel between England and France, it becomes apparent that while the advantages of large infrastructure projects are many and far-reaching, major issues related to them cannot be overlooked as they can cause major disruptions, delays and challenges that engineers have to face. It becomes obvious that the Hyperloop, as the technology that has never been implemented in full scale before, will likely have a substantial amount of issues that will require innovative solutions to build the envisioned, sustainable transport system.

The most salient of these issues include the cost of the project as with any first-time prototype implementation, cost overrun is a very real possibility. The role of sustainability is important as well. While the Hyperloop is unlikely to face competition on the technological front, the average consumer will have little incentive to switch away from traditional methods of transport if the cost of using it is prohibitive. The possibility of cargo transportation by the Hyperloop is another area that has yet to be fully explored.

We hope to shed light on the difficulties of integrating such cutting-edge technology into an already overstretched and ageing public transport system and implementing the technology in ways that provide a safe and reliable way of mobility for people and freight.

INTRODUCTION:

This paper will begin by describing the basics of a Hyperloop system. The following analysis will then employ a system dynamics model to assess the importance of a number of endogenous and exogenous factors affecting the viability of the Hyperloop, with a specific focus on sustainability, cost overruns, existing competition and cargo transportation possibilities as important areas of focus for future iterations of the ongoing research. This model is used to analyse changes in conditions over time while taking into account a number of key factors, which are identified a priori.[1] After using the model to show the intricacies of the factors affecting the Hyperloop, we will move onto the individual sections of the factors to analyse them in further detail. From our findings, we will try to give a brief overview of what the future of mobility could look like and identify the main challenges and aspects that require substantial future research.

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[1] Sterman, J (2001). "System Dynamics Modelling: Tools For Learning In A Complex World". *California Management Review.* 43(4): 11

THE HYPERLOOP:

We have so far been able to develop four main systems of transport. Transport by road is the most basic in which humans or goods are transported along a stretch of land that is used specifically for moving from point A to point B. Although convenient and cheap, this is quite slow and requires a large amount of petrol, diesel or electricity. In fact, petrol and diesel vehicles contribute to substantial greenhouse gas emissions. While electric vehicles are cleaner, they are still under development and cannot cover longer distances yet[2]. Similarly, transport by water, although able to connect countries together, is also quite slow and currently tends to be mainly used for cargo mobility or leisure. Rail transport is one of the cleanest ways of mobility and can provide relatively convenient and fast trips. Nevertheless, conventional railways often fail to meet constantly increasing demand and cater for the society's need for faster transport. High speed rail seems to offer a solution, however, speed improvements are unable to justify the massive costs required for infrastructure and decades of project development that can lead to the system becoming outdated by the time people finally use it. Air transport is by far the fastest option, however, it tends to be the most expensive way of mobility and together with road transport is the largest contributor to our overall transport carbon footprint.

On the other hand, a Hyperloop system is designed to be both inexpensive and quick. In many ways, it emulates transport by rail but is vastly different in the technology used. It consists of a tube with a very low pressure environment of approximately 100 Pa where capsules designed to hold either cargo or humans move through the length of the tube move at speeds up to 760 mph.[3] The acceleration occurs through a magnetic system and the resource used to power such a system would be an entirely green source of energy as suggested by Musk. However, how clean the energy actually is, depends on the electricity grid, therefore, the more renewable resources are used, the cleaner the Hyperloop is and it can achieve close to zero operational emissions if 100% of renewables are used to power it. In his Hyperloop Alpha paper (2013),[4] Musk's team further estimates that travelling between Los Angeles and California (563 km) with a Hyperloop system could bring journey time down to 35 minutes and carry 7.4 million people per year.

For the rest of this paper, we shall assume that we would have managed to build such a system. Our dynamic model will build a basic picture of our Hyperloop system interacting with a chosen variable and from there we will expand upon the relevant factors.

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[2] Gabbatiss, J (2018). "Transport Becomes Most Polluting UK Sector". https://www.independent.co.uk/environment/air-pollution-uk-transport-most-polluting-sector-greenhouse-gas-emissions-drop-carbon-dioxide-a8196866.html

[3] Musk, E (2013). "Hyperloop Alpha". https://www.spacex.com/sites/spacex/files/hyperloop_alpha.pdf

[4] Ibid. "Hyperloop Alpha".

SYSTEM DYNAMICS:

The Achilles heel of the traditional cost analysis model is the inability to cope with sustainability.[5] Sustainability is a continuous process and so it requires an adaptive approach. We need to consistently test and learn based on outcomes and so we opted for system dynamics. It involves a powerful, uncut process and finds its strength because it is able to adapt to problems that undergo change, such as sustainability and integration. It also has room to accommodate for traditional variables such as cost. Furthermore, it uses a visual approach that allows identifying loops or bottlenecks. Add to this the software that allows running simulations over time and we are then able to observe how successful a project could be, based on the variables and numbers that we input into the system. These simulations prove useful as we are able to obtain results before projects commence (or are inaugurated) and so if problems arise, they can rapidly be ironed out and with minimal expense.

Now, consider the progression over time of the population of the UK. Within the model, stock variables are those that are observed with respect to changes in the outcome. In this case, the stock variable is the estimated population of the United Kingdom in 2011, determined by the census carried out in March of that year.[6] Stock variables are affected by a number of flow variables fed into the model along with percentage weights. As the name suggests, a flow can either pass in or out of the model. Passing in can be seen as an addition to the system while passing out can be seen as a subtraction from the system. Flow variables that affect population may include the birth rate, death rate, life expectancy ratio, access to adequate healthcare facilities and so on. The model is then run to simulate the effects of the flow variables on the changes in the outcome (the changes in UK population). This same dynamic will be applied to the Hyperloop in the following.

[5] Hjorth, P. Bagheri, A. (2006). "Navigating Towards Sustainable Development: A System Dynamics Approach". *Futures*. Volume 38:1. pp 74-92

[6] Office For National Statistics (2011). https://www.ons.gov.uk/census/2011census/2011ukcensuses

{Figure 1.}

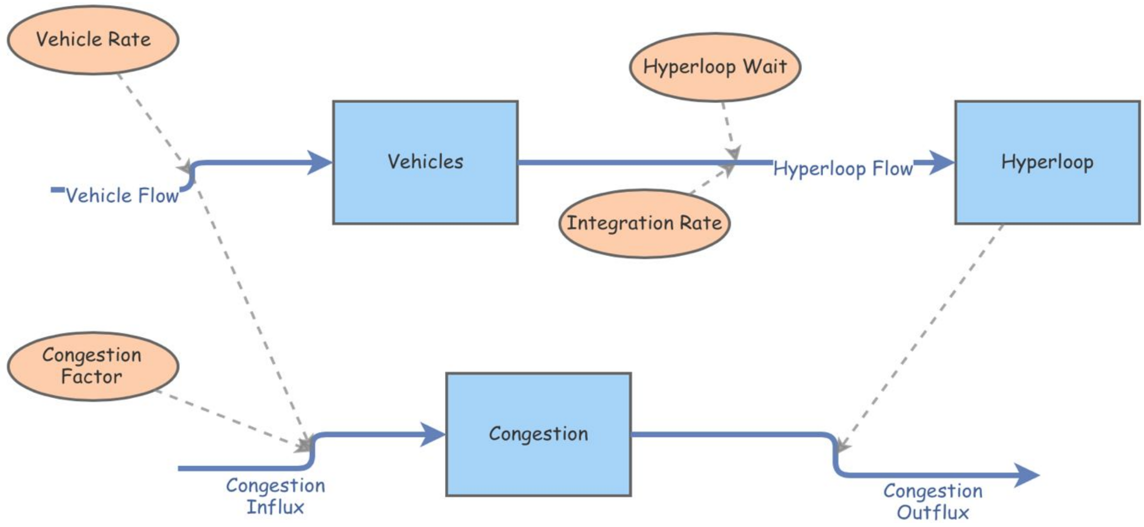


Figure 1 shows how the Hyperloop (stock) would interact with congestion (stock), in other words, how congestion would be affected over time by the introduction of the Hyperloop. We chose this stock as there is potential for large savings as it has cost the UK an estimated £7.9 billion in 2018.[7] Our chosen area was the M60 motorway within the Manchester traffic authority as it is observed to be one of the most congested roads in the UK.[8] Our base year is 2016.

Congestion is being measured as total hours spent stuck in traffic for everyone using the road. Congestion increases with Vehicle Flow which is the number of vehicles (assuming 1 person per vehicle) on the road multiplied by the Congestion Factor (variable) which is the average hours spent in traffic (44 minutes) by each vehicle.[9] Note that our original source, TomTom navigation, has recently removed 2016 data from their website so we used a different closely matching source. This then decreases with fewer vehicles on the road or with more people using the Hyperloop. These flows are called Congestion Influx and Congestion Outflux respectively.

To observe how many people would be using the Hyperloop we also need to build a system where we can observe the number of vehicles. We use a third stock which is Vehicles. The number of vehicles increases next year when our 2016 number is multiplied by the Vehicle Rate (0.023, variable) which is an average increase of the number of vehicles on the

[7] Barrie, J (2019). "Most Congested Roads In The UK Revealed". https://inews.co.uk/news/uk/most-congested-roads-uk-list-traffic-jams-cost-drivers-2018/

[8] BBC (2019). https://www.bbc.co.uk/news/uk-england-47175799

[9] Barlow, N (2016). https://aboutmanchester.co.uk/manchester-is-now-the-uks-3rd-most-congested-city/

road from 2012 to 2016.[10] This directly feeds the Congestion Influx, however, our aim is to observe the impact of a Hyperloop. So we monitor the number of people who would use a Hyperloop thereby decreasing the number of vehicles on the road. This decrease is brought about by the Hyperloop Flow which feeds the Hyperloop stock. In our model, we have used two factors which are the Hyperloop Wait and the Integration Rate. These are then multiplied with the Vehicle stock. The wait time is a much more conservative estimate (compared to Elon Musk's 2 minutes) of around 10 minutes (per journey) which is much closer to the average time we would have to wait for the London tube where the tube waiting time is around 13 minutes per month.[11] We must also observe the Integration Rate. This rate is the amount of people that would switch from using their vehicles to using the Hyperloop. The number we have used is 0.65 (or 65%) of people currently driving on the M60 would switch to the new system. This is calculated by the number of people willing to switch (we assume all personal vehicles owners would switch leaving only public and cargo vehicles) giving us a ratio of personal vehicles divided by all vehicles. This number is then multiplied by those willing to pay the cost. This is an optimistic estimate influenced by the Hyperloop Alpha paper.[12] Depending on how many people choose to integrate themselves within the new transport system, the waiting time becomes less of an issue with the time you would end up saving by using the system. Figure 2 below shows the simulated results of the above system starting from time 0 in 2016.

{Figure 2. rounded to the nearest unit}

Time (years)	Congestion (hours)	Hyperloop (#people)	Vehicles (#cars)
0	14076590	0	52590
1	14077477	5697	48102
2	14072591	10908	43998
3	14062425	15675	40243
4	14047429	20034	36809
5	14028015	24022	33668
6	14004561	27669	30795
7	13977411	31006	28167
8	13946881	34057	25764
9	13913258	36848	23565
10	13876808	39401	21554
11	13837770	41736	19715
12	13796367	43872	18033
13	13752799	45825	16494
14	13707252	47612	15086
15	13659894	49246	13799
16	13610881	50741	12621
17	13560352	52109	11544
18	13508438	53359	10559
19	13455257	54503	9658
20	13400917	55550	8834

[10] https://roadtrafficstats.uk/traffic-statistics-manchester-m60-manchester-75236#.XP05QaeZOfR

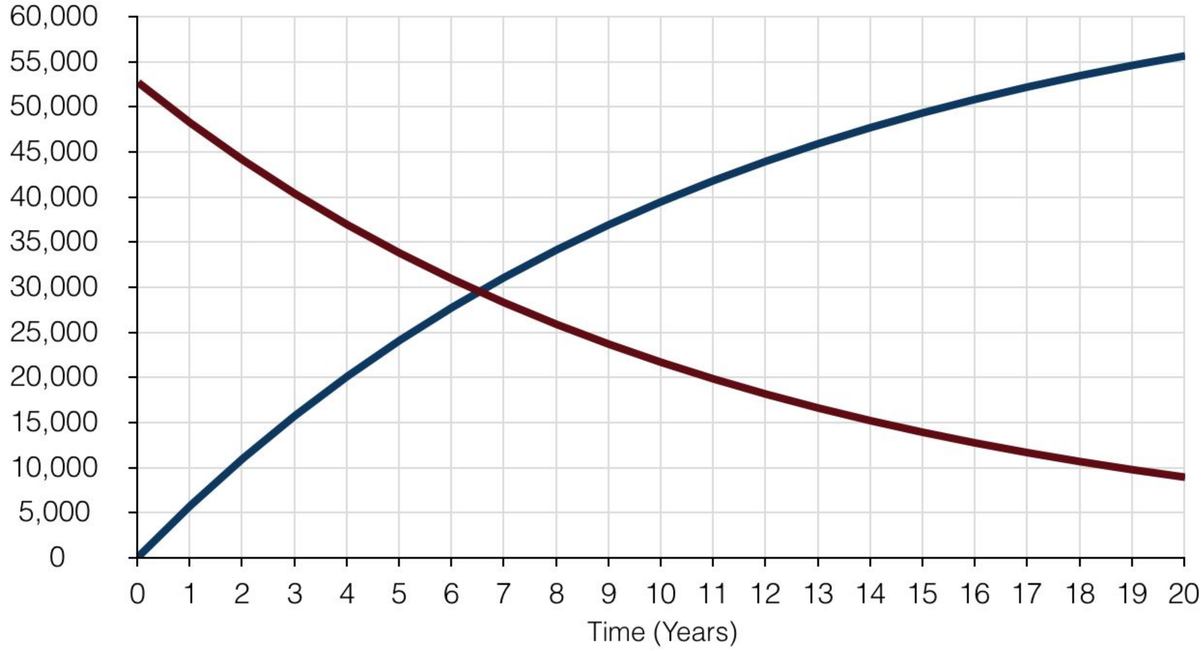
[11] https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index_United_Kingdom_London_and_South_East-2122

[12] Musk, E (2013). "Hyperloop Alpha". https://www.spacex.com/sites/spacex/files/hyperloop_alpha.pdf

Over a 10 year period, we see Congestion (total hours spent in congestion by everyone) and the number of Vehicles decreasing steadily while the usage of the Hyperloop is observed increasing. Since the Hyperloop is a clean energy system, the reduction in congestion will begin saving us time and directly lead to reductions in carbon emissions which will reduce the rate at which our ozone layer is depleted.

This relationship between the Hyperloop (blue) and Vehicles (red) can also be shown graphically as seen in Figure 3 below. The vertical axis shows usage by the number of people and the horizontal axis shows time in years. It would take approximately six and a half years from the time of commencement (or by 2022 in our model) for the Hyperloop to begin overtaking vehicles on usage numbers.

{Figure 3.}



From our results, the implementation of the Hyperloop will decrease congestion and the number of vehicles on our roads. This will not only be better for our environment but also save us large amounts of time over the years. However, these results are a direct outcome due to the values we used and the assumptions we made. We assumed that the Hyperloop has been built and implemented. To make our calculations uncomplicated we assumed each vehicle only had one person in them. In reality, we know this to be untrue as many people travel with their families or friends. We then further suppose an optimistic, year on year, integration rate of 65% where everyone who had a personal vehicle would stop using it. This would leave only cargo vehicles and other public transport on the road. Although these assumptions lead to us painting a very basic system dynamics model, the simplicity of the system is not to be disregarded as it can be used to highlight the true complexity of the Hyperloop beyond the technical innovation.

The following sections shall detail our analysis of the variables that should be included and why trying to obtain accurate numbers adds to the complexity of a Hyperloop system.

COST OVERRUN:

Any planned large infrastructure project is bound to face a gamut of hurdles including financial hurdles, social criticism, technical dead-ends and various uncertainties demanding attention. After research into the aspects of planning the Hyperloop and potential challenges that may arise, we find cost overrun to be a critical issue as it invokes a chain of uncertainties which lead into our other variables. This appears often with large transport projects, therefore, we will be using two high speed rail projects that are under development, the HS2 (High Speed 2) and the CaHSRA (California High Speed Rail). They will be used as a comparison since Hyperloop constitutes a major project itself. We will explore the causes and will subsequently propose a way of simulating and planning the project in order to avoid this (and additional) issues. Figure 4 shows a summary of the problems faced by the projects.

{Figure 4.}

Issue	HS2	CaHSRA	Hyperloop
Growth	Does high-speed rail help or hinder.[13]	Growth concentration in Fresno County.[14]	Unclear who benefits.[15]
Cost	Initially £32.7bn then a further £10bn investment.[16]	$25 billion in (1999). Now $63.3 bn – $98.1 bn.[17]	Estimate of $17 million per mile.[18]
Alternative Cost	The opportunity cost.[19]	Environmental impact.[20]	Obsolete when built.[21]

[13] https://www.bbc.co.uk/news/magazine-24159571

[14] https://transweb.sjsu.edu/sites/default/files/1627_Nixon-Measuring-Economic-Impact-California-High-Speed-Rail.pdf

[15] https://www.digitaltrends.com/cars/five-problems-with-elon-musks-hyperloop/

[16] https://transweb.sjsu.edu/sites/default/files/1627_Nixon-Measuring-Economic-Impact-California-High-Speed-Rail.pdf

[17] https://www.enotrans.org/article/timeline-california-high-speed-rail-cost-estimates/

[18] Hyperloop Commercial Feasibility Analysis - ROSA Phttps://rosap.ntl.bts.gov/view/dot/12308/dot_12308_DS1.pdf

[19] https://www.bbc.co.uk/news/magazine-24159571

[20] https://www.westernfarmpress.com/government/agricultural-working-group-addresses-high-speed-rail-issues

[21] https://www.newcivilengineer.com/tech-excellence/hyperloop-a-couple-of-decades-away/10025203.article

Before we even begin thinking about how much a project would cost to build, it is important to understand why it should be built in the first place. Who will it benefit? Who will be adversely affected? Will it boost our economy or will it bring budget deficits to an all-time high? Much is touted about the adaptation of new technologies. Take solar panels as an example. They were invented to decrease carbon emissions but they are expensive to install. The high participation cost will keep developing nations away from the benefits that the rest of the world would reap. Similarly, with the high speed trains HS2 and CaHSRA, the advantages are only available to the locations that are connected by them. It seems to be the case that only a small number of areas are connected via such systems, such as with CaHSRA (see figure 4). We must also ask the question of sustainability. What happens to areas that are bypassed by our transport systems? Suppose you have three areas A, B and C where you must pass through C to get to either A or B. If we now build a new transport system that directly connects A to B, what happens to the future prospects of C? It will surely lose out on a large portion of economic progress. Furthermore, in its current design, the Hyperloop is not easily accessible by those that need wheel-chair access or have issues with claustrophobia. This would potentially deter a fair amount of users and would not be in the Hyperloop's favour. It is clear, however, that the Hyperloop faces comparable criticism. It then becomes hard to argue for the need to build such systems as justifying the cost becomes difficult.

If we do manage to overcome the problem of growth, we must then deal with the large costs involved with these projects. Billions of dollars would need to be spent on these projects. HS2 and CaHSRA both had to revise their estimates making them much higher than the initial value due to time constraints, engineering, land rights and political motivations (see figure 4). $17 million per mile, then seems highly optimistic. Further, adding that the Hyperloop is still very much in the conceptual phase, this cost does not account for any uncertainty with operation and infrastructure costs. The higher the cost to build the project, the more likely it would be that this cost is passed on to consumers in the form of expensive tickets. If the cost of the tickets is too high then it could deter users. If the cost is too low then the economy's budget will most likely be seeing a large deficit unless it is made up for in other areas. Government subsidies could keep the ticket prices low, however, we then might face protests from other areas that also require large subsidies, such as agriculture. It might also be possible to cover the cost of the Hyperloop by transporting freight as well as humans. Drastically reducing delivery times across large distances could be an important motive for companies such as Amazon to invest in a Hyperloop system. Whichever way we look at it, the cost of materials must be supplemented by the cost of integration to achieve the true cost of a project.

Finally, we must also resolve alternative costs. These are costs not directly related to the project itself but still part of the discussion on cost analysis. Here we must note that all the alternative costs in Figure 4 can form the discussion for all the projects and not just their individual undertakings.

Opportunity cost constitutes a large part of this dialogue. Mainly whether there are better systems or projects to invest in? One could argue that it might be better to use the investment capital available to build more hospitals rather than reducing travel time between areas.

Impact of this transportation system is another part of the debate. How would other economies be influenced? For example, if we build a Hyperloop, how would that affect the agricultural economy? The transport business would see a surge in productivity, but what if the land used to build the transport system takes away from land that could have been used for farming? Furthermore, how would such a system affect the environment around the construction area? Would animal species be left displaced or (with great expense) relocated? Inadequate reports on such matters will no doubt spark protests and controversy,[22] spelling more trouble for the project and although this is an extreme case, it does highlight the importance of discussing impact.

Additionally, we also face the issue of obsoletion. HS2 and CaHSRA were already considered outdated even before construction started.[23] What then of the Hyperloop? Of course, travel is unavoidable but as technological innovation is making HS2 and CaHSRA obsolete, the same could be said for the Hyperloop. We might even find a way to make existing transportation greener, removing one big advantage of the system.

Our comparison between the three big projects shows that cost overrun is a major hurdle that needs to be cleared, however, it is not the only one.

CARGO:

The Hyperloop would likely be more deliverable in the UK as first a system focusing on the transportation of different types of freight/cargo, before focusing on the transport of passengers. Cargo requires less by way of safety measures that are required when transporting live passengers, and so could deliver much of the infrastructure of the Hyperloop system prior to adding in passengers. The 2018 Transport Systems Catapult offers insights into the ‘Hyperloop Lite’, a freight pipeline that offers a way to implement Hyperloop in the short term.[24]

[22]https://www.westernfarmpress.com/government/agricultural-working-group-addresses-high-speed-rail-issues

[23]https://www.yorkshirepost.co.uk/news/latest-news/hs2-will-be-obsolete-by-the-time-it-is-built-1-8262728

[24]https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2018/09/26144415/00601_Hyperloop-Report_Appendix_B.pdf

The focus on cargo before passengers has the advantage of tackling two issues. First, the cargo industry is carbon intensive by nature. This can be remedied by implementing the Hyperloop technology, an almost carbon neutral (in the long term, after the initial carbon cost of the building process) alternative to traditional trucking in the UK (see sustainability for more on this). Second, by using cargo, potential passengers will be able to see for themselves the Hyperloop at work. This will reassure people of the safety and reliability of the system, as the Hyperloop is likely to face critics (given that it is a near vacuum-sealed tube travelling at around 700 miles per hour, nearly ten times faster than traditional rail).

At current, the concept of using the Hyperloop system to transport cargo is notably being developed by Virgin Hyperloop One and DP Cargo World.[25] By utilising the Hyperloop technologies, the cargo industry (traditionally carbon intensive), can be transformed into a renewable, electricity-powered integrated system that allows both passenger and freight to be transported through the same network. With the rising demands and expectations of online commerce and for fast delivery services, the Hyperloop system offers a unique opportunity to harness the need for clean transport whilst simultaneously providing a more efficient delivery network with superior speed in global trade and supply logistics.[26]

First, this section will discuss preliminary ideas on how companies and industries that rely on the transport industry (such as Amazon), could benefit from the Hyperloop system and contribute to lowering the costs of implementation. Second, an example of the Hyperloop being used to reduce traffic in Liverpool, minimise HGVs on the road thereby reducing emissions and increasing efficiency between the expanding Port of Liverpool and Switch Island. This report was initially carried out by Touching Blue Limited, who consulted with Hyperloop Edinburgh (amongst others) to further develop the findings. Finally, the capabilities of the Hyperloop will be discussed in relation to cargo, providing a technical framework in which any given industry can work within.

Commercial Benefit Case Study: Amazon

Amazon is a unique case that can be used to assess the Hyperloop system in the future of global trade and supply. Amazon's 'Next Day' delivery

[25] https://www.dpworld.com/smart-trade/dp-world-cargospeed
[26] https://hyperloop-one.com/blog/new-cargo-brand-built-demand-world

service for Prime members, which was once the pinnacle of online delivery service, is rapidly becoming the norm across the industry.[27] New ways to accommodate such demands is crucial in order to meet the demands of the future. Boasting a rapidly expanding logistics network, including its own fleet of airplanes 'Amazon Air' and the innovative uses of drone technology, Amazon stands to benefit from the Hyperloop system, either in the UK or elsewhere.[28] Hyperloop offers an exciting opportunity to expand Amazon's already extensive catalogue of innovative delivery methods. The pioneering nature of Amazon is explicitly seen in the case of 'Amazon Prime Air', piloted in Cambridgeshire, UK, in 2016. Amazon Prime Air is an autonomous delivery service, using unmanned aerial drones to deliver goods (ones weighing under five pounds) in under thirty minutes.[29] In the USA, 'Amazon Air' utilises airplanes extensively to manage its growing demand for fast delivery.[30]

Accordingly, as Amazon expands alongside the size of the market for the rapid transportation of goods, the Hyperloop offers a new and revolutionary alternative to traditional forms of transport. The trend towards sustainable living and operations lends itself to the move away from reliance on heavy vehicles and towards a sustainable mode of transport that Hyperloop offers by travelling in the low-pressure tube, as opposed to existing modes of transport. By using the Hyperloop system, on-demand passenger or freight pods could be autonomously sent via the maglev operated system, through near vacuum, using only a small amount of electricity to power.[31]

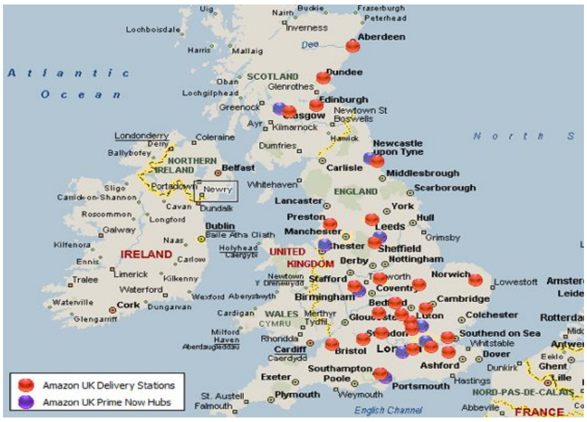
Fulfilment Centres: Connecting Amazon to the Hyperloop

Amazon currently possesses a UK workforce of 25,000 and over 40 delivery fulfilment centres across England, Scotland and Wales.[32] According to Amazon, their EU Operations network consists of more than 40 fulfilment centres, and in the UK, there are 17 fulfilment centres, meaning that UK customers can choose from millions of products stored in fulfilment centres across Europe.[33] Collaborative research with

[27] https://www.businessinsider.com/amazon-changes-prime-shipping-one-day-2019-4?r=US&IR=T
[28] https://www.ttnews.com/articles/rise-amazon-logistics
[29] https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011
[30] https://www.businessinsider.com/amazon-cargo-plane-fleet-grows-by-15-2019-6?r=US&IR=T;https://www.businessinsider.com/amazon-air-expanding-in-alaska-warning-shot-to-fedex-ups-2019-6?r=US&IR=T
[31] https://hyperloop-one.com
[32] https://www.aboutamazon.co.uk/working-at-amazon/about-our-fulfilment-centres
[33] https://www.aboutamazon.co.uk/working-at-amazon/about-our-fulfilment-centres

Amazon, with specific data from individual sites, could potentially highlight where a hyperloop system could bring both added benefits and problem-solving capabilities. As Amazon moves further towards a rapid time fulfilment (i.e. Amazon Prime's '2-hour promise', a more efficient system will be required. Moreover, rural areas are more problematic in terms of infrastructure and are yet to experience the same levels of integration. For example, the Highlands of Scotland (less integrated transport options, infrequent density rail, low density road networks) as opposed to the city of London where Amazon Prime Now operates one to two-hour delivery on thousands of products.[34] Prime Now Hubs, which have to operate in close proximity in order for a 'Prime Now area' to function, could be spread out further away. This could mean cheaper land alternatives meaning larger warehouse sizes, increased efficiency by organising fewer warehouses, generating more jobs in rural areas and expanded Amazon's fulfilment capabilities. For example, if Amazon Prime Now Hubs were stationed in Newcastle, orders could still be fulfilled in less than one hour into central London, and under two to the surrounding areas as the journey of one Hyperloop pod from Edinburgh to London takes 50 minutes.[35] By gathering more data from Amazon about each fulfilment station, the HYPED Research Team aims to build a case for Amazon being a beneficiary of the Hyperloop UK network. Figure 5 below shows a map of the Amazon hubs within the UK.

{Figure 5.}



Using Hyperloop to tackle an existing UK problem: Researching Touching Blue Limited's report on the Port of Liverpool

Hyperloop technologies can also be used both to enhance the UK's cargo industry and to remedy existing ailments. Touching Blue Limited began to research the potential for the system to be used in Liverpool, which will be continued next year by the HYPED cargo team. Touching Blue Limited are working towards solving the major road-based freight congestion in the main east-west corridor that links the Ports of

[34] https://www.aboutamazon.co.uk/innovation/prime-now
[35] https://hyp-ed.com

Liverpool and Hull, which also serves as part of the Ireland-Russia Trans European Transport Network corridor.[36] This impacts road traffic into the A5036 in Merseyside and the A63 in Hull. The main concerns are congestion, emissions, efficiency of the industries (i.e. drivers) and safety in the area.

Hyperloop is being considered as one of the possible answers to many of these problems, providing a long-term fix which can be extrapolated onto the wider industry across the UK. A rapid transport underground tunnel is being explored, whereby the Hyperloop cargo link would be created between the port and a new interchange (Switch Island), removing HGVs from the road, lowering emissions and rejuvenating the area which has suffered from severe congestion.[37] The concept is still in its research phase, but the Hyped Cargo Team are looking to continue research next year and look into extrapolating such innovative ideas and use of the Hyperloop across other areas of the UK cargo industry. All credit remains with Touching Blue Limited for the initial research.

The Pod

As the pod size would most likely remain the same for both passenger and cargo use (for consistency and the option to use the cargo pods for dual use passenger fares), the figures from the Hyperloop Alpha Paper Section 4.1.1 will be used. Accordingly, the dimensions inside the pod would have a maximum width of 4.43 ft (1.35 m) and a maximum height of 6.11 ft (1.10 m).[38] Based on the Alpha paper, at peak performance, a single pod/capsule is expected to depart from each lane every 30 seconds with an average of one every two minutes.[39] The payload of each pod/capsule is estimated at around 12,000 kilograms in a cargo-specific pod (no seats, safety equipment, passengers etc).[40]

Based on this, some goods that offer high Return on Investment (ROI) could include:

- Pharmaceuticals (low density, high value, time sensitive)
- Fresh food e.g. fruit and vegetables (low to medium density, low value, time sensitive, high demand)*

[36] Touching Blue Limited (2018). Transport Logistics, V1. Southport. p.4.
[37] Touching Blue Limited (2018). Transport Logistics, V1. Southport. p.11.
[38] https://www.spacex.com/sites/spacex/files/hyperloop_alpha-20130812.pdf
[39] Werner, M., Eissing, K., Langton, Sebastian. (2016) 'Shared Value Potential of Transporting Cargo via Hyperloop'. Frontiers in Built Environment 2. P.3.
[40] Werner, M., Eissing, K., Langton, Sebastian. (2016) 'Shared Value Potential of Transporting Cargo via Hyperloop'. Frontiers in Built Environment 2. P.3.

- Perishable foods (meat, milk) (low density, low to medium value, high demand, time sensitive)
- Frozen produce (medium density, medium value, time sensitive)
- Petroleum goods (high density, high value, high demand)
- Horticulture products (low density, medium value, time sensitive)

* Much of this currently passes through the Port of Felixstowe (south of England) which suffers from congestion. Problem solving measures are currently being researched by the team.

For reference, an exploratory investigation into the benefits of the Hyperloop in Germany found that Hyperloop NG's higher speeds create value worth €400 million yearly, whilst also reducing the number of accidents (less traffic from traditional cargo), €150 million yearly in shared value.[41]

Types of goods are potentially limited owing to the nature of the pod being in near vacuum. Highly explosive goods, such as petroleum or gas, would unlikely be deemed worth transporting in such an environment due to the risk to the public and to the transport infrastructure. Yet, they also offer high ROI and it is likely to be dependent on UK Government regulations. Hyperloop Cargo would be best suited to in terms of cost are high value, low density goods. The Hyperloop system can ship freight from ports to main business hubs, increasing the efficiency of the logistics chain. However, this early stage of development of the Hyperloop means it is difficult to monetise the real time benefits without actual costings of specific routes combined with actual costings data from existing transport routes.

SUSTAINABILITY:

Let us now turn our attention towards sustainability. Using the definition obtained from the 1992 Bruntland Report for the World Commision on Environment and Development, sustainability refers to "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable transport systems can therefore be defined as systems with "effective modal balancing, quality transport, future economic development, and environment & social wellbeing of society".[42]

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[41] Werner, M., Eissing, K., Langton, Sebastian. (2016) 'Shared Value Potential of Transporting Cargo via Hyperloop'. Frontiers in Built Environment 2. P.10.
[42] Anbanandam, R. and Kumar, A., 2019. Development of social sustainability index for freight transportation system, *Journal of Cleaner Production*, [e-journal] 210 pp 77-92.

In this section, we will focus on economic, environmental and social sustainability, looking into factors such as social inclusion and access to opportunities to improve the quality of life. These factors are related to specific Sustainable Development Goals (SDGs). The SDGs, as laid out by the United Nations (UN), presents an outline of what a sustainable and better future must hold. They address various global challenges and we have picked the ones that can be directly related to transport. If we are to build a system for the future then it must follow the blueprint for the new future. The goals we have chosen include good health and wellbeing (3), decent work and economic growth (8), reduced inequalities (10), sustainable cities and communities (11) and peace, justice and strong institutions (16).[43] These five factors together encompass the demands that a new transport system must fulfill to be considered as part of a sustainable future.

SDG's 8 and 11, which are decent work and economic growth and sustainable cities respectively, are the ones that require immediate attention. This is because with any project that is going to affect whole cities and countries, what happens to the economy is a question that persists since growth within a country's economy dictates how well it does. Additionally, our desire to build a transport hub for the future has the auxiliary requirement of being sustainable if we are to follow the UN's guide as mentioned previously.

Take, for example, three cities within the UK that are A, B and C. Geographically, city B is in between A and C thus connecting the two cities together via the road that passes through it. This is an ideal situation for B as due to this it sees a lot of business. People travelling between A to C must pass through B. They might have to refuel their cars there, possibly stop for food and travel supplies. Maybe stay overnight if B is a good tourist attraction as well. Furthermore, any cargo travelling between A and C must also pass through B. This gives B the potential to become a cargo hub attracting investment from companies due to its centralized location. Alternatively, just like with the casual travellers, truck drivers might use it as a pit stop to refuel. Whichever advantage you pick and choose for B, having that natural location is good for B and

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Available through Science Direct website <https://www-sciencedirect-com.ezproxy.is.ed.ac.uk/science/article/pii/S0959652618333900#bib60>

[43] UN, 2016. About the Sustainable Development Goals. [online] Available at: <https://www.un.org/sustainabledevelopment/sustainable-development-goals/> [Accessed 18 June 2019].

the country as a whole. There are many locations within the UK that are in a similar situation if not exactly the same. Think about any company that needs warehouses (example Amazon). They strategically open these warehouses in areas that have convenient locations for fulfilling customer demands. If we take Amazon's investment into Bristol as an illustration, it brought in 1000 new jobs to the city.[44] This kind of job availability attracts more people to the city, they get paid more wages which is then spent back into Bristol in the form of rent and necessities further boosting local business which then goes on to boost the UK economy. Additionally, this also adds to the sustainability of the area as it is seen as a place with good future prospects.

Now consider a big advantage of the Hyperloop. It's ability to connect cities to each other. Upon building the Hyperloop it could be the case that cities which relate to city B in our example might be left disconnected. With the Hyperloop there would no longer be a need to stop over in city B if we can get from A to C in a short amount of time. This would then lead to a growth of inequality between areas. A and C will see tremendous growth while B loses out as the factors that drive growth (investment and spending) no longer pass through B but directly get to A and C. Extrapolating further, if Hyperloop stations are only placed in the major city hubs then disparities between rural and urban areas will also increase. This could lead to eventual obsoletion of the area which is the direct opposite to our goal of sustainability. Furthermore, we must also be wary of political uncertainty (as is the current case with Brexit) and weak analysis. These either compound the incompleteness of information or are the result of it. This incompleteness can make any decision harder as we will not have complete knowledge before making a choice making the outcomes uncertain. It must be accounted for or reduced to build strong system dynamics. Therefore, it is important for transport planning for the Hyperloop to be integrated with other planning such as land use planning. It is not enough to know who, how and where to transport. We must also look at other ways in which that land could be used and how it might be affected if used for transport. It might be the case that city B is better suited as a tourist attraction and not a cargo hub and so there might be other ways to attract growth factors to it. Land use planning is a useful addition as it can help alleviate the negative effects of using land to build the Hyperloop and augment the efficient use of resources to curtail any detrimental impact on future

[44] https://www.reuters.com/article/amazon-britain-employment-idUSL8N1L21UY

generations.[45] It will allow us to place stations in strategic locations so as to be more inclusive and can fulfill our sustainability requirements.[46]

Let us now move onto health and wellbeing (SDG 3) and reduced inequality (SDG 10). Another benefit of the integration between land use and Hyperloop transport planning is the intentional development of the Hyperloop to be accessible to everyone regardless of disability, age, gender, sexual orientation and socio-economic status.[47] This will enable equal access to opportunities that improve the quality of life, for instance, enhancing access to a wider range of socio-economic activities such as jobs, educational institutions, health facilities, affordable housing and interaction with far away family and friends.

Finally we have peace, justice and strong institutions (SDG 5). For the Hyperloop to be socially sustainable, it will also need to contribute to good governance, through the involvement of citizens in Hyperloop development decisions that will affect their lives.[48] This is particularly important in the development of the Hyperloop in developing countries where a number of institutions do not offer citizens the power to influence key decisions. There is a possibility of implementation of the Hyperloop in developing countries due to less rigorous regulatory systems and fewer deeply rooted transport systems to integrate into.[49] Consequently, having citizens involved in the development process will be essential to ensure their wellbeing.

To enable the Hyperloop to be a socially sustainable transport system, we can use a system dynamics model that can track the complexities of the SDGs we have chosen. Considering cities A and B which are both urban, and city C which is rural and positioned between A and B, the model would take into account the current flow of wealth, accessibility across different groups, and the involvement of citizens in local transport decisions. It will then assess potential changes in the flow based on the implementation of the Hyperloop with stations placed at different

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[45] Randhir, T. <http://www.waterencyclopedia.com/La-Mi/Land-Use-Planning.html>
[46] Hyperloop Connected, 2018. *Societal Impact of the Hyperloop.* [online] Available at: <https://hyperloopconnected.org/2018/04/societal-impact-of-the-hyperloop/>
[47] Atkins, S., 2008. *Transport and Social Sustainability.* [online] Available at: <https://www.tsu.ox.ac.uk/events/ht08_seminars/satkins080117.pdf>
[48] Atkins, S., 2008. *Transport and Social Sustainability.* [online] Available at: <https://www.tsu.ox.ac.uk/events/ht08_seminars/satkins080117.pdf>
[49] Business Insider, 2015. *Why Elon Musk's Hyperloop may be built overseas before it comes to the US.* [online] Available at: <https://www.businessinsider.com/hyperloop-likely-to-be-built-in-developing-countries-first-2015-7?IR=T>

locations, and comparisons made. However, a key challenge to be dealt with is the fact that a lot of aspects within sustainability entail dealing with qualitative data and incomplete information. There will therefore be a need for further research on logic systems that take this into account.[50]

COMPETITION:

Our final variable is competition. Since the Hyperloop is a future transport option we shall discuss competition that is "unconventional". Conventional challengers come in the shape of your typical cars, trains and aeroplanes. It should be noted that there has not been any new mode of transport introduced for more than 100 years and current transport links very often prove to be outdated, incapable of meeting always increasing demand and contribute to greenhouse gas emissions significantly. The Hyperloop could offer a new dimension to tackling those issues. By introducing a faster and supposedly cleaner mode of transport, the long-lasting issues would be solved not by improving the existing modes of transport, but instead introducing another mode to encourage modal shift to faster and supposedly cleaner transport.

Unconventional opposition comes from technology that follows a similar path as the Hyperloop. It is transport technology that is futuristic, rapid and/or uses clean energy.

Transit by supercavitation is the first of these unorthodox technologies and it could revolutionize nautical transportation. The concept is to create a layer of gas bubbles around an object inside a liquid. Picture a submarine within a shroud of bubbles. The use of gas reduces friction to such an extent that it allows the vessel to travel at supersonic speeds – around 5800km/h – and theoretically complete a transatlantic cruise in under an hour.[51] The project was originally being worked on by the Defense Advanced Research Projects Agency (DARPA). It was called the "Underwater Express" but they faced a glaring issue that the craft had no way to steer itself at these super high speeds.[52] The project has now been overtaken by a Chinese company but it is still a long way from implementation. Although, it is to be noted that supercavitation is not a new idea. It has already seen plenty of naval applications in the past in

[50] Anbanandam, R. and Kumar, A., 2019. Development of social sustainability index for freight transportation system, *Journal of Cleaner Production*, [e-journal] 210 pp 77-92. Available through Science Direct website <https://www-sciencedirect-com.ezproxy.is.ed.ac.uk/science/article/pii/S0959652618333900>

[51] https://www.dailymail.co.uk/sciencetech/article-3664723/US-Navy-developing-supersonic-submarine-cut-ocean-speed-sound-using-bubble.html

[52] http://nymag.com/speed/2016/12/supersonic-underwater-travel-may-be-coming-soon.html

the form of torpedoes that are used for military action.[53] Familiarity with the application of supercavitation will no doubt prove useful when searching for a solution.

Skylon is another interesting future transportation method that promises fast and easy access to every location on earth in under 4 hours alongside space travel.[54] It uses a new Synergetic Air-Breathing Rocket Engine (SABRE) that is being developed by UK based Reaction Engines Limited (REL). This aircraft's goal is to travel five times faster than the speed of sound. This would, in theory, let the craft escape Earth's orbit and breach into space. This technology can also be used to replace the current cohort of aeroplanes thereby drastically reducing flight time. The promise of space travel and high speed travel around Earth could be enough to overcome the potential of the Hyperloop if REL are successfully able to test their engine in 2020.[55]

Turning our attention to more familiar territory, we must take heed of the electrical evolution occurring within our current fleet of cars and aeroplanes. The introduction of electric vehicles has been quite significant as large cities like London and countries like Scotland have set themselves a goal to reach zero emissions on their roads by 2050.[56] This is being done by phasing out new petrol cars and expanding on charging points available for these vehicles. Furthermore, these electric vehicles also have the technology to eventually become fully autonomous. Looking to 2025 and beyond, driverless cars will become increasingly integrated into a system that might have a passenger use their smartphone to hail an autonomous, fully-electric taxi that communicates with other vehicles and infrastructure managers in order to manage traffic flows and ensure safety.[57] Roads will then become safer. Traffic and fuel efficiency will improve. Congestion – a Hyperloop advantage – will decrease saving you time and increasing productivity.[58]

Moreover, why replace aeroplanes with Skylon, when we can improve them into electric and/or hybrid-electric planes? Rolls-Royce have been working with a team to build the world's first hybrid-electric passenger aircraft called the E-Fan X and have a demonstration due to launch in 2020.[59] Alongside them, Boeing and Airbus are also looking to electrify their shorter range aircraft. Working on these technologies now will place the full technology (short and long range travel) in a good position to be available by 2050 which is in line with the zero emission goal of

[53] http://supercavitation.net/index.htm
[54] https://futurism.com/skylon-plane-can-fly-anywhere-world-4-hours
[55] https://www.reactionengines.co.uk/about/story-so-far
[56]https://www.independent.co.uk/news/uk/politics/scotland-petrol-diesel-cars-phase-out-ban-2032-nicola-sturgeon-snp-environment-air-pollution-a7930781.html
[57] https://thefutureishere.economist.com/transportation/blogs-future-transportation.html
[58] http://uk.businessinsider.com/advantages-of-driverless-cars-2016-6?r=US&IR=T
[59]https://www.telegraph.co.uk/education/stem-awards/electrical/hybrid-electric-propulsion/

places like Scotland.[60] These improved planes would be much quieter for passengers and people who live near airports. Their computer-controlled, electrically driven propellers will make for smoother and more comfortable flights. Electric motors cost less to operate and maintain than fuel-powered aircraft engines thus spelling lower costs for airlines and perhaps cheaper airfares for passengers. It also goes without saying that electric and hybrid-electric airplanes would be friendlier towards the environment due to their energy source being greener.[61] Governments and industry leaders appear to have already decided to fully support the electric revolution. Why then would they spend billions of dollars on a new system, such as the Hyperloop, when they seemingly find improving on technology already in place a more efficient use of time?

Here it is important to note that all (or most) of these technologies will face similar issues as the Hyperloop and there are many more that we have not mentioned. Anyone of the competitors mentioned in this paper can be replaced with any others that are invented or heard about. All of them have the potential to be the solution to our transport problems and deserve enough attention and financing. However, the Hyperloop has already seen a significant amount of investment from many. Two main companies currently developing Hyperloop technology are Virgin Hyperloop One and Hyperloop Transportation Technologies (HTT) and both are competing to introduce the full-scale Hyperloop system. HTT is currently working on building a 10 km stretch of the Hyperloop track in Abu Dhabi for the 2020 Expo exhibition.[62] Their goal is to build a tube connecting Abu Dhabi and Dubai and become the first full-scale operating Hyperloop system suitable for passengers. Meanwhile, Virgin Hyperloop One is working towards building the first Hyperloop track in India, between the cities of Mumbai and Pune.[63]

One might begin to wonder whether any of these systems will prove successful. Looking into the future, many technologies have significant potential to improve our lives, including the Hyperloop, and it is likely that the Hyperloop will face competition if those technologies prove feasible and practical. It will likely have the potential to compete with conventional and unconventional modes of transport however, as the future is unpredictable, only time will tell which ones are viable. But if the investment in Hyperloop is anything to go by, there is a good chance that it just might be our solution.

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[60]https://interestingengineering.com/why-we-need-to-start-developing-electric-airplanes-right-now

[61]https://www.nbcnews.com/mach/science/electric-planes-promise-big-benefits-air-passengers-planet-ncna862001

62https://www.businessinsider.com/r-us-firm-to-start-building-hyperloop-track-in-abu-dhabi-next-year-2018-10?r=US&IR=T

63 https://hyperloop-one.com/route-estimator/mumbai-in/pune-in/travel-times

CONCLUSION:

The High-Speed Rail 2, which will eventually connect London and the North of England, is arguably a new implementation of old technology – the railway. At an estimated (and potentially upwardly revised) cost of £50.1 billion,[64] HS2 claims to be able to potentially travel at around 250km per hour, serving 25 stations and connecting the South and North of England.[65] Yet, the technological developments in the transport industry and in the wider community of professions related to transport are rapidly developing new, modern and sophisticated ways to enhance or completely redevelop the existing status quo, aided by the expanding power of artificial intelligence. Implementing old technology at a time of rapid change will likely lead to HS2 being outdated before it is even finished, at the expense of the long-term success of the UK.[66] *Thinking differently* is required, and the Hyperloop offers an opportunity to mould the UK into a truly future-focused, technology-driven centre of commerce and cargo transportation.

The Research Teams at Hyperloop Edinburgh will build on the findings of this report, aiming to remedy the issues of managing Cost Overrun, building a case for the Hyperloop using Cargo, building a feasible Sustainable transport system and staying ahead of the Competition. We hope to expand our research into the area of Integration as well, looking at factors such as disability access. Furthermore, we would like to expand on the system dynamics so that we can build a more robust understanding of the Hyperloop. As this is the first year that designated teams have been allocated specific roles, the preliminary stages of these findings will be built upon in the next year of research by the individual teams with the aim of a comprehensive body of research that can be taken forward to companies, industries, and individuals that are suited to benefit from the Hyperloop system being implemented. We are looking to work closely with companies, especially those similar to Amazon and the UK government. By accessing their data, HYPED plans to create highly detailed, real-time, data-driven models that can accurately map some of the potential benefits of a Hyperloop system in the UK.

[64] https://publications.parliament.uk/pa/ld201415/ldselect/ldeconaf/134/13406.htm
[65] https://www.hs2.org.uk/where/
[66] https://www.internationalbusinessfestival.com/blog/future-transport-hyperloop-or-high-speed-rail

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