QUANTIFICATION OF TRANSPORT OFFER LINKED TO A EUROPEAN HYPERLOOP NETWORK

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ABSTRACT

Hyperloop is the modern and environmentally friendly update of an idea that has been in people's head for more than 200 years, since Medhurst presented the first patents. When "Hyperloop Alpha" was published by Elon Musk in August 2013, the best trained labour force, the most capable financial capital and the bravest governments and institutions, moved forward to make it a reality.

Currently, there isn’t any scientific publications that address with enough detail, and without self-bias, the transport offer linked to specific networks of this new mode. This paper presents an approach to an operational plan in the exploitation phase for a specific Hyperloop network in Europe.

About the proposed network, with an extension over 12,000 kilometres, the authors will analyse its social and economic benefits based on GDP and the directly connected population, describe its design parameters (radii of curvature, acceleration, deceleration and constant speed zones), outline the demand using simple gravity models, propose an annual service calendar with schedules and frequencies differentiated by country, and present the main magnitudes associated with its operation.

In addition, the presentation will show the results of the research carried out on the main obstacle that the Hyperloop implementation will pose in the future: the number of tubes needed per direction vs. the transport capacity of each capsule or pod.

1. INTRODUCTION

Hyperloop is the update of an idea that has been in men's head for more than 200 years, from Medhurst's first patents related to the atmospheric train (Medhurst, 1810).

Launching a pressurised capsule, loaded with goods or people, through a tube whose inner pressure has been considerably reduced, is nothing but the next evolutionary step of magnetic levitation trains.

Since its inception, railway speed has been related to different aerodynamic designs of trains and different traction typologies. Since the first horse-drawn and guided carriages, rail transport has known first the steam traction, then diesel traction and later electric traction. It was with high-speed railways (first with electric traction and then with magnetic levitation) that the aerodynamic design of trains began to gain importance, reaching top speeds of 600 km/h, as in the case of the Maglev.

The physical barrier that has so far prevented the achievement of better high-speed rail speeds has always been air friction. That is why the next step to achieve higher limit-speeds is to necessarily reduce the atmospheric pressure around the train, as proposed by Hyperloop concept. To help better understand the process being described, note anecdotally that a tube without pressure inside, and whose temperature is close to absolute zero, is conceptually very close to the representation of a particle accelerator, where the speed of particles is close to the speed of light.

Taking this idea as a backbone, in August 2013, Elon Musk and his support teams at SpaceX and Tesla published 'Hyperloop Alpha' (Musk, 2013). A document that, with a modern and ecological format, brought to the present the original ideas of Medhurst and many others who came after him, such as Lamson (1908), Goddard (1924), Salter (1972) or Olster (2010-2015).

The challenges posed by this new mode of transport are very diverse. There are obvious physical risks, but also economic, financial, legal, regulatory, budgetary, and even socio-political risks, taking into consideration that Hyperloop will be able to "deform" the territory, turning countries into neighbourhoods.

Regardless of this, in just 8 years, Musk's initiative has sparked the birth of a very dynamic new industry. Despite its notable shortcomings, 'Hyperloop Alpha' has become the dragging engine capable of bringing together the best trained human force, the most capable financial capital and the boldest governments and institutions.

The prospect of a new mode of land transport with the huge potential to bring closer together regions separated by long travel times, has attracted the interest of governments such as India or United Arab Emirates, which have shown their interest in hosting this type of infrastructure. At the level of countries and supra-national entities under the influence of the OECD, receptiveness to the Hyperloop project has also been high, although the approach is taking place in a more cautious manner.

In order to analyse the financial viability of such an investment project and, where appropriate, the sustainability of the public accounts of the region in which it is located, it is necessary to have certainly about the amounts of capex and opex linked to it. In this sense, this document provides information on a plausible Hyperloop network serving the European

Union, using different methodologies to capture its design characteristics and the amount of transport it would provide annually if all its lines were put into service in the same year.

2. BIAS PROBLEMS IN THE FACE OF THE NECESSARY SOCIETAL ENDORSEMENT OF A NEW TECHNOLOGY

In September 2020, Gkoumas and Christou published ‘A Triple-Helix Approach for the Assessment of Hyperloop Potential in Europe’ (Gkoumas and Christou, 2020), a paper which referred to the relative abundance of research devoted to capsules and operations, but the paucity of research on safety issues. This document refers to other research advocating that the commercial potential and financial viability of Hyperloop has yet to be demonstrated (Walker , 2018). Gkoumas and Christou also index an inconclusive study published in 2016 by the US Department of Transportation (Taylor et al., 2016) on the commercial viability of Hyperloop, and a more recent research that questions the financial viability of the system in a potential deployment in the Great Lakes environment (USA) (Transportation Economics & Management Systems, Inc, 2019).

The main problem with financial feasibility studies for disruptive technologies such as Hyperloop, which are not based on concrete applications, is always the lack of detail. This matter is even more striking when feasibility studies carried out on specific infrastructures and with well-proven technologies are observed, duties that usually have the support of the developer industry itself.

The risk of self-serving bias in innovations of this scale is something that infrastructure planners and policy makers need to be aware of from the earliest stages. Assuming this, it is worth remembering that Hansen (2020) has already warned of the risks of polarising the opinion of the different interest groups that could benefit from a transport solution such as Hyperloop.

This is something that has already happened in the past, and it was a step prior to the failure of a project of similar characteristics as was ‘ARAMIS’. Referring to this event, in 1993 the French philosopher Bruno Latour published a book (Latour and Poter, 1996) in which he described how technological passion for a concept can have a double detriment: on the one hand it can blind some of the promoters to the technical feasibility of the project, and on the other hand it can make others irrational denialists.

During the 1970s, in Paris, ARAMIS was the latest attempt to create a rapid passenger transport system whose concept had emerged in the United States a decade earlier. The goal was to develop an automatic-guided public transport system, in which the transport elements would resemble the private car in size and comfort. These elements would be hooked to each other forming trains of variable length, as the ‘carriages’ would be temporarily attached until the destination turnout of each other was reached. The project never materialised.

In 1994, Latour, in an article derived from his book and entitled ‘Ethnography of a case of ‘high technology’: on Aramis’ (Latour, 1993) put the spotlight on the different currents that in his opinion caused the project to fail: “Aramis is technically ready for homologation”, ... , “Aramis was technically ready, but would have been so costly that it would have been unsalable politically”, ... , “the Aramis cabin was not technically ready because the RATP (Regional Transport Authority of Paris requested that Matra respect specifications completely unsuited to such an innovative experimental prototype”, ... , “nothing can be gained from the Aramis, it produced no technical or cultural results, it was a false innovation from the outset, an impracticable idea”, ... , “the question of the technical feasibility of the Aramis should not be raised”.

In this context, two milestones can make the difference between Hyperloop and ARAMIS:

- February 2020: CEN-CENELEC announced the launch of a new joint technical committee, CEN/CLC/JTC20. Its purpose is the standardisation of Hyperloop systems. As several European and international industries are investing in Hyperloop systems supported by the interest of public and private actors, European standardisation is crucial to achieve a coherent deployment of this new mobility tool (CEN-CENELEC, 2020).
- October 2020: Shift2Rail, a body of the European Commission, promotes the financing of a new project called Hypernex. Led by the Polytechnic University of Madrid (UPM), it tries to identify the main challenges facing Europe in terms of research, innovation, and infrastructures. The objective is to lead the development of this new means of transport and seek the most appropriate solutions (Universidad Politécnica de Madrid, 2020).

But regardless of the above, and although there is a broad consensus on the viability of this subsystem-level technology, it is clear that it will be necessary to carry out prognosis exercises in which all of them operate in a joint and coordinated manner. These exercises should be extremely detailed and applied to concrete realities.

Today, the simulation possibilities in multiple fields allow, for example, to emulate the design characteristics of transport networks using artificial intelligence algorithms. Through specific commercial software, it is also possible to emulate the annual operation of the rolling stock linked to these networks. And through sophisticated spreadsheets it is possible to simulate the commercial life of a vehicle company project. The information derived from such tasks, properly processed and integrated, would be the first step to advance in a solid understanding of the financial viability and future budgetary sustainability of a concept like Hyperloop.

With the design of a transport network for Europe, connecting the main cultural and economic nodes, from which detailed physical information can be extracted, and on which a reasonable plan of operations can be projected, it will be possible to calculate the capex and opex that allows to advance in the knowledge of the economic viability of the system as a whole.

As a tangential result, this document provides the necessary inputs to calculate the volume of investment in infrastructure of a hypothetical network. As the main result, this paper provides the quantification of the transport supply linked to it. The measurement of the transport offer is the necessary input to calculate the volume of investment in rolling stock, as well as to calculate most of the operating costs.

3. A PROGNOSTIC EXERCISE THROUGH THE PROPOSAL FOR A EUROPEAN HYPERLOOP NETWORK

The land deformation effect that the speed of certain modes of transport generates is behind the positive socio-economic effects that occur when these modes come into operation.

The figure below shows what a European Hyperloop Transport Network would look like. In addition to others, the fundamental design premise has been to connect the capitals of the states over which it is deployed, as directly as possible.

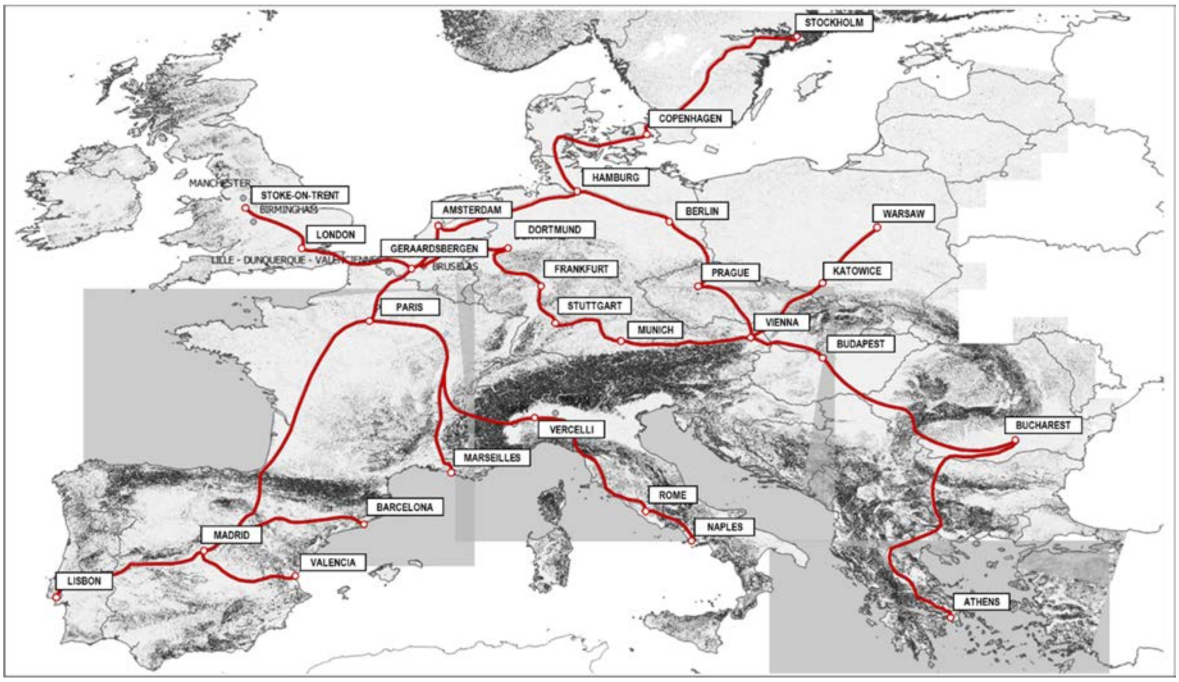


Figure 1: Lines of the proposed European Hyperloop Network

The name of the network lines and their length is shown in the table below.

Transport line name	Length [km]	Transport line name	Length [km]
01 LISBON - MADRID	537.66	15 MUNICH – STUTTGART	236.62
02 VALENCIA - MADRID	360.02	16 STUTTGART - FRANKFURT	169.32
03 MADRID - BARCELONA	544.65	17 FRANKFURT – DORTMUND	240.14
04 MADRID - PARIS	1,108.71	18 DORTMUND – GERAARDSBERGEN	274.62
05 MARSEILLE - PARIS	787.92	19 HAMBURG - COPENHAGEN	464.36
06 PARIS - GERAARDSBERGEN	247.53	20 COPENHAGEN – STOCKHOLM	595.13
07 GERAARDSBERGEN - LONDON	317.56	21 VIENNA – KATOWICE	304.38
08 LONDON - STOKE-ON-TRENT	238.33	22 KATOWICE - WARSAW	260.25
09 GERAADSBERGEN – AMSTERDAM	198.93	23 BUDAPEST – VIENNA	229.06
10 HAMBURG – AMSTERDAM	391.34	24 BUCHAREST – BUDAPEST	746.49
11 BERLIN – HAMBURG	262.40	25 ATHENS – BUCHAREST	1,079.47
12 PRAGUE – BERLIN	306.67	26 NAPLES – ROME	198.12
13 VIENNA – PRAGUE	280.89	27 ROME – VERCELLI	561.18
14 VIENNA – MUNICH	364.96	28 VERCELLI - PARIS	760.58

Table 1: Length between network nodes

The design of this network has been established within the framework of a research project linked to the University of the Basque Country.

3.1 Utility offered

In addition to the connection of state capitals, the European Hyperloop network includes the physical connection of European metropolitan regions with a census population of more than two million people.

The network thus consists of 28 lines with 28 nodes or stations (15 of which are located in state capitals). Three grouped nodes are suggested. The first of these would be in the Italian town of Vercelli, which would cover Milan and Turin. The second node would be located in Geraardsbergen, a Belgian town which would cover both Brussels and the Lille-Dunkerque-Valenciennes area. The third such node would be located in Stoke-on-Trent to cover both the Manchester and Birmingham agglomerations in the UK.

Starting from a Central European ring of 10 stations, the network extends to the rest of the continent via four branches. The northern branch would connect Hamburg with Stockholm. The southern branch would connect Geraardsbergen with the southern countries (Portugal, Spain, France and Italy). The eastern branch would connect Vienna with the peripheral countries of Poland, Romania and Greece. Finally, the north-west branch would also connect Geraardsbergen with the United Kingdom.

As an example, based on the latest available census data, the network would host seven super-nodes, defined as stations with the capacity to connect more than 15 million people (Geraardsbergen, Madrid, Paris, London, Stoke-on-Trent, Vienna and Marseille) through a single journey stage.

The proposed design would also allow direct access to the new high-speed mode of transport for 1/4 of the EU-28 population (120 million people), 1/3 of its GDP, 1/4 of its workforce, and 1/5 of all goods moved.

3.2 Methodology for the characterisation of the network layout.

Once the utility of the network has been described, the layout of the network should follow criteria that minimise the amount of investment required for its implementation. Following this premise, the layout process begins with the viewing of the slope map of Europe. Knowing the orography of a territory makes it possible to draw lines connecting cities through the flattest areas, and to use large radii of curvature.

After defining the layout of the network, the next step would be to determine its characteristics. In terms of capex, a linear infrastructure connecting two points through 15.45% of singular works (tunnels and viaducts) is not the same as another infrastructure with 18.76% of this type of works for the same connection.

3.3 Fundamentals of transport services operation

The stock of public capital allocated to transport services only achieves social utility when it is used to design a reasonable operational plan that makes it possible to present a specific transport offer to users. In order to determine the amount of transport that should be produced in a typical year in a network such as the one proposed, any planning office in the service of a public administration would have to go through a series of very well-defined phases.

3.3.1 About the radii of curvature

Firstly, the radii of curvature that apply on each section of each of the 28 lines must be known. This makes it possible to determine the maximum speed of the capsules on each of the aforementioned sections by means of equation (1), which is derived from ADIF's General Project Instruction IGP-3 (ADIF, 2011).

$$V = 6{,}4692 \times R^{0{,}4481} \tag{1}$$

In this equation, R refers to the applicable radius of curvature expressed in metres and V to the speed of the capsule expressed in km/hour.

Figure 2: Curvature radii for a European Hyperloop Network

The radii of curvature recorded in the design of the proposed lines range from the 2.64 km in the vicinity of Athens (line 25 linking this city to Bucharest) to the 260.74 km in line 24 (Bucharest - Budapest). According to equation (1), when the proposed radius is 60,000 metres, the curve speed is 895.24 km/hour.

3.3.2 About acceleration, deceleration, and maximum speed

Although Hyperloop's maximum speed is theoretically 1,220 km/hour, the operational plan described here puts this figure at 850 km/hour. A sufficiently high speed, which does not rigidify the physical-technical boundary conditions of the system as much. In the same way, the acceleration and deceleration of the capsules is maintained at all times at values of 0.1G, coinciding, for example, with the hypotheses used by HTT in its own studies (Transportation Economics & Management Systems, Inc., 2018), but far from the value of 0.5G shown in the ‘Hyperloop Alpha’. Under these conditions of movement, the time and space consumed by a capsule to reach a speed of 850 km/hour from 0 would be 240.766 seconds and 28,423.80 metres.

Adopting these assumptions, which could at some point be described as conservative, will allow the formulation of a reasonable financial viability analysis, which the industry could gradually beat with the introduction of more solid technical innovations.

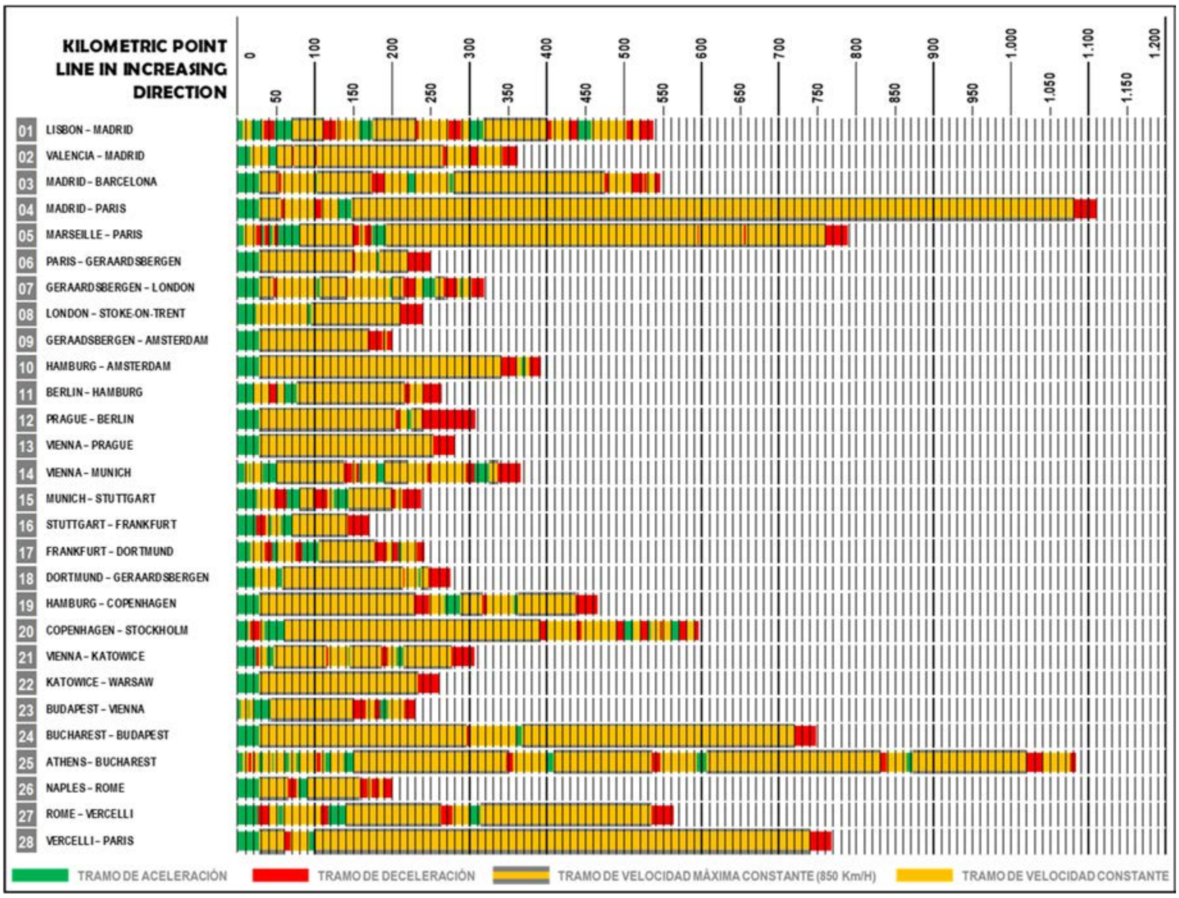


Figure 3: Overview of pod movement characteristics in the network

The figure above shows the acceleration, deceleration, constant speed and maximum constant speed zones, linked to each of the lines of the proposed European Hyperloop Network.

3.3.3 About time consumed in pre- and post-travel related tasks

A Hyperloop station or Hyperloop gateway will have many operational similarities to a high-speed rail station, but physically it will have two well distinct zones, as is the case in any airport. In this sense, while an airport differentiates between ‘land side’ and ‘air side’, a Hyperloop station will have to differentiate between an ‘atmospheric pressure side’ and a ‘low pressure side’.

Under these conditions, the process of transporting a person or a load between the origin and destination of any line in the network would be affected by certain unalterable milestones and fix time consumptions. This is due to the need for persons or objects under atmospheric pressure to transit to a state where they maintain atmospheric pressure inside a capsule, but which, when it enters the tube through a lock, must be under low pressure.

The table below shows in a schematic way what should be the orderly process of access of users to the transport capsules. It also shows how the capsules access to the tubular infrastructure, the process of arrival of the capsules at the stations, and finally the disembarkation process.

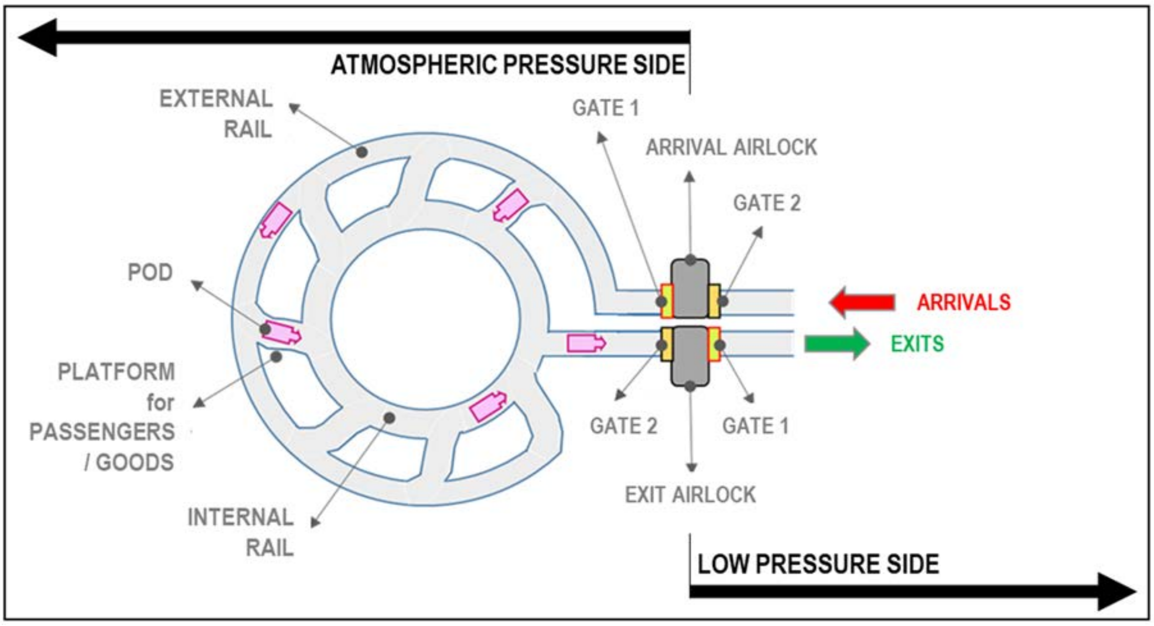


Figure 4: Approach to a Hyperloop station scheme

Milestone		Duration [min]
1	Pod transition from platform to entrance to exit airlock (gate 1)	3.50
2	Pod entrance at departure airlock	0.75
3	Gate 1 closing in the exit airlock	0.58
4	Air extraction in the exit airlock	2.50
5	Gate 2 opening of the exit airlock	0.83
6	Pod movement towards the propulsion zone in the tube	0.42
7	Gate 2 closing in the exit airlock	0.83
8	Pod movement inside the tube to its destination	VARIABLE
9	Gate 1 opening at arrivals airlock	0.83
10	Pod entry at the arrival airlock	0.75
11	Gate 1 closing at the entrance to the arrival’s airlock	0.83
12	Pressurisation of the arrival’s airlock	0.67
13	Gate 2 opening at arrivals airlock	0.58
14	Pod movement from the arrival’s airlock to the platform by external rail	3.50
15	Pod reposed on platform	0.33
16	Uncoupling operation of passenger / cargo	1.50
17	Pod doors opening and orderly departure of passengers/cargo from the capsule interior	2.00
18	Equipment for sanitisation rapid intervention / pod condition checking	4.00
19	Battery replacement (or partial recharging if necessary)	5.00
20	Pod on standby until passenger/cargo occupancy starts	VARIABLE
21	Passenger/cargo occupancy	2.50
22	Anchoring of passengers/cargo and approval by a supervisor	2.00
23	Pod closure and automatic safety check	1.50
24	Transition of pod from platform to entrance to exit airlock (gate 1)	MILESTONE 1 AGAIN

Table 2: Description of milestones in pre and post trip operations and times allocation

The sum of the times of the above milestones amounts to 35.42 minutes (0.5903 hours). This amount could be equated to the boarding and alighting times for passengers boarding and alighting high-speed rail services.

The above table refers to both passengers and cargo. In the case of cargo, with the right logistics, these times could be even shorter.

3.3.4 About the commercial speed of the transport system

According to the Royal Academy of Engineering of Spain, commercial speed is defined as the "average travel speed used by public transport vehicles to complete a full circle of a route, including all delays and waiting time at terminals" (Real Academia de Ingeniería, 2012).

Transport line name	**(a)** Length [km]	**(b)** Variable time [hours]	**(c)** Fixed time [hours]	Commercial speed [km/hour] **(a) / (b)**	Commercial speed [km/hour] **(a) / (b+c)**
01 LISBON – MADRID	537.66	0.8069	0.5903	666.33	384.81
02 VALENCIA – MADRID	360.02	0.5129	0.5903	701.93	326.34
03 MADRID – BARCELONA	544.65	0.7628	0.5903	714.01	402.52
04 MADRID – PARIS	1,108.71	1.4006	0.5903	791.6	556.89
05 MARSEILLE – PARIS	787.92	1.0856	0.5903	725.79	470.15
06 PARIS – GERAARDSBERGEN	247.53	0.3614	0.5903	684.92	260.09
07 GERAARDSBERGEN – LONDON	317.56	0.4700	0.5903	675.66	299.5
08 LONDON – STOKE-ON-TRENT	238.33	0.3561	0.5903	669.28	251.83
09 GERAADSBERGEN – AMSTERDAM	198.93	0.3032	0.5903	656.1	222.64
10 HAMBURG – AMSTERDAM	391.34	0.5447	0.5903	718.45	344.79
11 BERLIN – HAMBURG	262.40	0.3951	0.5903	664.14	266.29
12 PRAGUE – BERLIN	306.67	0.4303	0.5903	712.69	300.48
13 VIENNA – PRAGUE	280.89	0.3979	0.5903	705.93	284.24
14 VIENNA – MUNICH	364.96	0.5449	0.5903	669.77	321.49
15 MUNICH – STUTTGART	236.62	0.3770	0.5903	627.64	244.62
16 STUTTGART – FRANKFURT	169.32	0.2844	0.5903	595.36	193.57
17 FRANKFURT – DORTMUND	240.14	0.4236	0.5903	566.9	236.85
18 DORTMUND – GERAARDSBERGEN	274.62	0.3974	0.5903	691.04	278.04
19 HAMBURG – COPENHAGEN	464.36	0.6526	0.5903	711.55	373.61
20 COPENHAGEN – STOCKHOLM	595.13	0.9241	0.5903	644.01	392.98
21 VIENNA – KATOWICE	304.38	0.4342	0.5903	701.01	297.1
22 KATOWICE – WARSAW	260.25	0.3744	0.5903	695.11	269.77
23 BUDAPEST – VIENNA	229.06	0.3984	0.5903	574.95	231.68
24 BUCHAREST – BUDAPEST	746.49	0.9563	0.5903	780.6	482.67
25 ATHENS – BUCHAREST	1,079.47	1.5699	0.5903	687.6	499.71
26 NAPLES – ROME	198.12	0.3141	0.5903	630.75	219.06
27 ROME – VERCELLI	561.18	0.7936	0.5903	707.13	405.51
28 VERCELLI – PARIS	760.58	0.9775	0.5903	778.09	485.13

Table 3: Detail of commercial speed on each line of the network

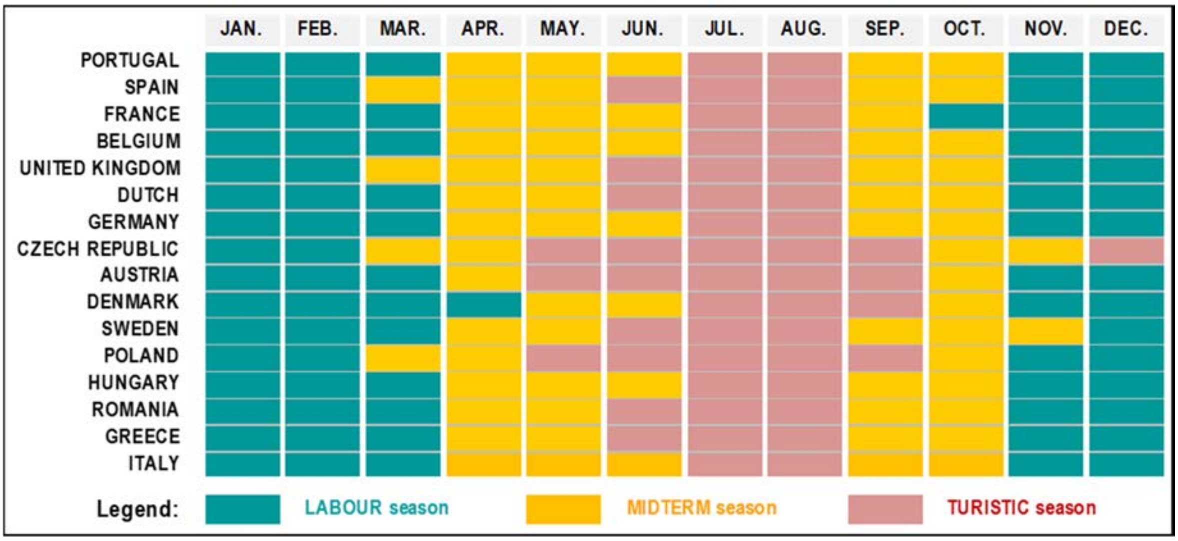
The table 3 shows the commercial speed that Hyperloop would offer on each of the lines of the proposed European network, taking into account both the time of the exclusive movement of the capsule on the so-called ‘low pressure side’ of the system (variable time), as the time resulting from the sum of the previous time and the fixed time defined in the previous section.

These data allow us to state that the commercial speed linked to the network would be 699.56 km/h when considering only the travel time of the capsules (variable time). If the predefined fixed time (0.5903 hours) is added to this time, the commercial speed would be 357.25 km/h.

3.3.5 About the monthly, weekly, and daily organisation of the transport services

The transport offer made available to users of the new European transport network should be designed according to values of frequency of departure of the capsules from the originating stations expressed in reasonable terms. The time that elapses at a station between the departure of one capsule and the next, may vary depending on the time of day, the day of the week, the season, and the country in which the station is located.

In view of this reality, it is proposed that there should be three annual seasons, quantifiable by months. During the so-called working season, the system's service offer will be mainly oriented to meet the demand generated from Monday to Friday. During the tourist season, the service offer will try to meet the demand generated on weekends. The so-called intermediate season is the period of time when the service supply transitions between the working and tourist season.

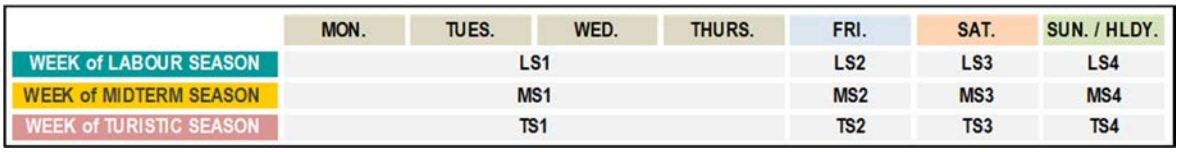


	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
PORTUGAL	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟩	🟩
SPAIN	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟩	🟩
FRANCE	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟩	🟩	🟩
BELGIUM	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟩	🟩
UNITED KINGDOM	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟩	🟩
DUTCH	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟩	🟩
GERMANY	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟩	🟩
CZECH REPUBLIC	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟥
AUSTRIA	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟩	🟩
DENMARK	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟨	🟩	🟩
SWEDEN	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟨	🟩
POLAND	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟥	🟥	🟨	🟩	🟩
HUNGARY	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟩	🟩
ROMANIA	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟩	🟩
GREECE	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟥	🟨	🟨	🟩	🟩
ITALY	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟥	🟨	🟨	🟩	🟩

Legend: 🟩 LABOUR season 🟨 MIDTERM season 🟥 TURISTIC season

Figure 5: Variation of transport offer by season and country type

Within each season, the transport offer will vary according to the country and each of the four standard days to be considered. This research has considered the existence of 15 standard days.



	MON.	TUES.	WED.	THURS.	FRI.	SAT.	SUN. / HLDY.
WEEK of LABOUR SEASON	LS1				LS2	LS3	LS4
WEEK of MIDTERM SEASON	MS1				MS2	MS3	MS4
WEEK of TURISTIC SEASON	TS1				TS2	TS3	TS4

Figure 6: Acronym for each standard day within the annual transport offer

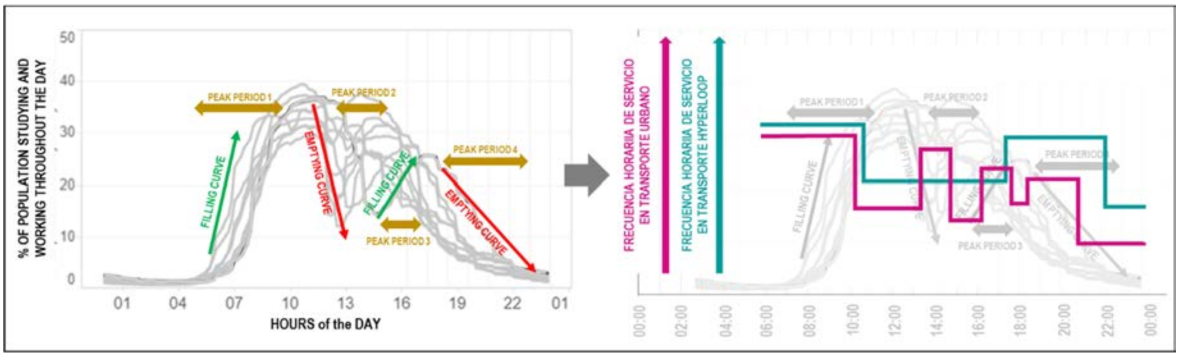


Figure 7: Transport service frequencies linked to people's time use on labour days

FREQUENCY TIMETABLE	PERIOD 1 [MIN] since ... until [MAX]	PERIOD 2 [MIN] since ... until [MAX]	PERIOD 3 [MIN] since ... until [MAX]	PERIOD 4 [MIN] since ... until [MAX]
on labour days	MIN: 5 am MAX: 11 am	MIN: 9 am MAX: 17 pm	MIN: 13 pm MAX: 22 pm	MIN: 18 pm MAX: 0 am
LS1	3 minutes	6 minutes	4 minutes	7 minutes
LS2	3 minutes	6 minutes	3 minutes	7 minutes
MS1	3 minutes	5 minutes	4 minutes	6 minutes
MS2	3 minutes	5 minutes	3 minutes	6 minutes
TS1	5 minutes	7 minutes	5 minutes	10 minutes
TS2	4 minutes	6 minutes	3 minutes	5 minutes
on Saturday day	MIN: 6 am MAX: 10 am	MIN: 9 am MAX: 22 pm	MIN: 21:00 MAX: 1 am	MEANING of the FREQUENCY POD 2 POD 1 X minutes
LS3	10 minutes	5 minutes	10 minutes	
MS3	8 minutes	5 minutes	8 minutes	
TS3	15 minutes	10 minutes	15 minutes	
on Sunday / Holiday day	MIN: 6 am MAX: 16 pm	MIN: 15 pm MAX: 22 pm	MIN: 21:00 MAX: 1 am	
LS4	8 minutes	4 minutes	6 minutes	
MS4	7 minutes	4 minutes	5 minutes	
TS4	6 minutes	3 minutes	4 minutes	

Figure 8: Pod frequency from stations (expressed in minutes between exits)

The idiosyncrasies of each country shape different patterns of how people spend their time. In the context of the working season, the number of people working and studying throughout the day in the different countries of the European Union tends to be distributed in a similar way, with two clearly differentiated peaks, especially on the days from Monday to Thursday. In terms of urban transport, the existence of these peaks leads to the existence of four peak periods of demand. One before and one after each peak.

There is a tendency to compare the utility of a Hyperloop network with the utility provided by any metro network in any urban agglomeration. Due to the very nature of the trips to be offered by this new transport system, this document will only consider the existence between Monday and Thursday of two peak periods when the frequency of the services offered should be higher.

The figure 7 shows, on the one hand, the time use curves of people on a working day in various European countries according to Eurostat (Madrid (Ediziones) - Europa Press, 2018), and on the other hand, the differentiated frequency periods that must be established within each day.

The figure 8 shows the time in minutes that should elapse in each period (of variable duration depending on the country) linked to each standard day between the departure, from the same station, of two consecutive capsules established in the operational plan. It is this information that defines the final transport offer made available to users of the network.

The amount of service offered for passenger transport ranges from a minimum of four capsule departures per hour and direction (15 minutes frequency) to a maximum of 20 capsule departures per hour and direction (3 minutes frequency).

It is proposed to provide a supplementary cargo service in addition to the passenger service, which will be provided on timetable sections of each standard day where the frequency is more than three minutes.

3.3.6 About inter-core travel, network usage demand and design demand for each line

Newton's gravity equation has served for many years as the basis for explaining the demand for travel between two distant points in the territory. This simple conceptual tool is based on the assumption that traffic between two population centres is proportional to the population of the two centres and inversely proportional to the square of the distance between them, i.e. a point is as attractive as its mass is important and vice versa.

Equation (2) allows the calculation of the displacements between two points i and j with population p_i and p_j and separated by a given physical distance.

$$\text{Total trips F}_{i,j} = K_F \times (p_{i\times} p_j)/(dF_{i,j}{}^2) \tag{2}$$

Equation (3) allows the calculation of the displacements between two points i and j with population p_i and p_j and separated by a given distance in time.

$$\text{Total trips T}_{i,j} = K_T \times p_{i\times} p_j)/(dT_{i,j}{}^2) \tag{3}$$

In both equations, K is a coefficient to be estimated that allows calibration. In this research, the calibration has been carried out considering the reality of population censuses, usage demands, and physical and temporal distances in the Iberian Peninsula, between the Madrid-Barcelona and Madrid-Valencia connections.

Proceeding in the manner described allows two types of displacements to be quantified. One comes from the consideration of an exclusively physical distance (kilometres) between two points, and the other comes from the consideration of an exclusively temporal distance (minutes).

The demand for use of the new system will come from the amount of journeys it is able to capture from other modes (air, rail, bus, car and motorbike), as well as the amount of journeys it is able to induce. Under these assumptions, it has been hypothesised here that 80% of any travel decision on the European Hyperloop network will be influenced by the time variable, while only 20% of that decision will be influenced by the physical distance variable.

Transport line name	Gravitational model total trips (TTGM) and demand for use of the European Hyperloop Network (DUEHN)					Demand for design in …	
	by distance criterion …				DEHN yearly 20% P + 80% T [000.000 pax]		
	… physical (P)		… temporal (T)				
	TTGM [000.000 pax]	DUEHN [000.000 pax]	TTGM [000.000 pax]	DUEHN [000.000 pax]		… average working day [pax]	… rush hour [pax]
01 LISBON – MADRID	5.40	4.67	4.94	4.27	4.35	15,032	2,029
02 VALENCIA – MADRID	2.95	2.14	7.08	6.13	5.33	18,404	2,485
03 MADRID – BARCELONA	10.22	8.84	10.22	8.84	8.84	30,525	4,121
04 MADRID – PARIS	5.49	4.75	10.51	9.09	8.22	28,407	3,835
05 MARSEILLE – PARIS	5.21	4.50	7.10	6.14	5.81	20,082	2,711
06 PARIS – GERAARDSBERGEN	23.86	16.12	15.16	10.99	12.02	41,499	5,602
07 GERAARDSBERGEN – LONDON	16.87	12.23	34.13	29.52	26.06	90,017	12,152
08 LONDON – STOKE-ON-TRENT	33.91	22.91	20.19	14.63	16.29	56,270	7,596
09 GERAADSBERGEN – AMSTERDAM	8.27	5.59	3.85	2.79	3.35	15,041	2,031
10 HAMBURG – AMSTERDAM	1.37	0.99	3.67	3.17	2.73	12,291	1,659
11 BERLIN – HAMBURG	5.81	3.92	3.87	2.80	3.02	13,591	1,835
12 PRAGUE – BERLIN	3.39	2.46	2.88	2.08	2.16	9,698	1,309
13 VIENNA – PRAGUE	2.18	1.47	1.66	1.20	1.25	5,637	761
14 VIENNA – MUNICH	1.42	1.03	3.31	2.87	2.50	11,221	1,515
15 MUNICH – STUTTGART	3.32	2.24	1.86	1.35	1.53	6,866	927
16 STUTTGART – FRANKFURT	6.01	4.06	2.11	1.53	2.04	9,154	1,236
17 FRANKFURT – DORTMUND	5.55	3.75	2.92	2.12	2.45	10,972	1,481
18 DORTMUND – GERAARDSBERGEN	8.14	5.50	5.91	4.28	4.52	20,319	2,743
19 HAMBURG – COPENHAGEN	2.62	2.27	2.26	1.95	2.01	6,962	940
20 COPENHAGEN – STOCKHOLM	1.10	0.95	1.05	0.91	0.92	3,172	428
21 VIENNA – KATOWICE	1.93	1.40	1.60	1.16	1.21	4,161	562
22 KATOWICE – WARSAW	3.16	2.13	2.16	1.56	1.67	5,796	782
23 BUDAPEST – VIENNA	3.76	2.54	1.90	1.37	1.60	5,551	749
24 BUCHAREST – BUDAPEST	1.05	0.91	1.51	1.31	1.23	4,247	573
25 ATHENS – BUCHAREST	0.63	0.55	0.98	0.84	0.78	2,711	366
26 NAPLES – ROME	8.06	5.45	3.63	2.63	3.19	11,037	1,490
27 ROME – VERCELLI	7.79	6.74	7.91	6.84	6.82	23,560	3,181
28 VERCELLI – PARIS	11.88	10.28	17.26	14.93	14.00	48,350	6,527

Table 4: Displacements according to different gravity model criteria. Demand for network use and design demand

Under the above assumptions, if the proposed network design had been fully implemented and operational in 2020, it would have registered an annual usage demand of 145.9 million passengers. Similarly, in the same year, the network would have served 530.6 thousand passengers on an average weekday, and 6,153.5 thousand passengers in a rush hour.

3.3.7 About the carrying capacity of each capsule

The proposed passenger transport demand should be satisfied by a transport supply that allows mobility without bottlenecks at the busiest time of the year (rush hour).

The existence of bottlenecks depends not only on the number of tubes in each direction on each line of the network, but also on the transport capacity of each capsule.

The first hypothesis on capsule capacity adopted by Musk's Alpha document was 28 people per transport unit. However, since 2013, the different studies that have been published have been raising this hypothetical capacity, and it is now beginning to be suggested in a very timid way that this figure, in the case of capsules intended for passenger transport, could even be as high as 200 passengers (European Hyperloop Week Mailbox, 2021). Notwithstanding the above, this document sets the limit for passenger capsules at 100 seats.

Under these conditions, as will be explained below, the new network will assign capsules with transport capacities of 40, 50, 60, 60, 80, 90 or 100 persons (in the case of passenger transport), and capsules with transport capacities of 5, 6.25, 7.5, 10, 11.25 or 12.5 tonnes (in the case of freight transport).

3.3.8 About the amount of tubular infrastructure per direction that will be necessary

The design demands on some of the lines in the proposed network can hardly be met with considerations of a maximum departure frequency of 3 minutes, a capsule capacity of 28 persons, and one tube per direction of travel.

This analysis was already carried out by Egea et al. (2016) when in a study entitled "Comparative analysis of the viability between Hyperloop and AVE means of transport in the Madrid-Barcelona corridor" (Egea et al., 2016), under the consideration of capsules with a capacity for 28 passengers, and operating conditions different from those proposed in this research, they already demonstrated the need for the existence of two Hyperloop tubes in each direction on a hypothetical Madrid - Barcelona route that would serve the current high-speed rail demand at rush hours in the corridor.

In this context, if the capsule capacity is brought to its maximum value of 100 seats, but the maximum frequency of passenger capsule departures from stations remains unchanged at 20, in the 2020 standard year, there will be two lines on the network that will need to have more than one tube per direction to meet the weekday design demand. Specifically, the

Geraardsbergen - London connection (line 7) will require three tubes in each direction, and the London - Stoke-on-Trent connection (line 8) will require two tubes in each direction.

Despite the above, the need for three tubes in each direction on line 7 results in unsatisfied demand at rush hour. This situation of unsatisfied demand at rush hour is repeated on three other lines in the network (line 3 Madrid - Barcelona, line 6 Paris - Geraardsbergen, and line 28 Vercelli - Paris), which quantify the number of tubes required in each direction at one. The existence of small bags of unsatisfied demand in some cases is justified by the rational need to ensure that there is no under-utilised stock of public capital at any point in the life cycle of any infrastructure.

3.3.9 About the relation between the transport capacity of each capsule and the amount of tubular infrastructure per way

The weekday and rush hour design demands provided for each line of the new network in section 3.3.6 are linked to the year 2020. There is a large body of research that attempts to link the annual growth in demand for any mode of transport to the evolution of the GDP of the countries in which it is generated. Thus, if no technical progress is made on the existence of capsules that overcome the self-imposed limitation of 100 seats, the need for more than one tube per direction will end up affecting more lines than initially enunciated.

The 2018 Ageing Report (European Commision, 2018), one of a series of reports regularly published by the European Commission, provides very long time series quantifying GDP growth by country. Similarly, through equation (4), which is the result of research led by Judith Fernández (2015) in the framework of the Optired project (Fernández Jáñez, J., 2012), it is possible to make prognoses on the growth of demand for a transport system according to the evolution of GDP linked to the territory that hosts them.

$$\%\triangle\ \text{Demand} = 0{,}11698 \times (\%\triangle GDP - 0{,}8817)^2 + 1{,}906 \times (\%\triangle GDP - 0{,}8817) \quad (4)$$

Transport line name	Need of tubes per direction in the pods operation …									
	100 pax.									200 pax.
	2020	2030	2040	2050	2060	2070	2080	2090	2098	2098
07 GERAARDSBERGEN – LONDON	3	3	4	5	5	6	7	8	9	4
08 LONDON – STOKE-ON-TRENT	2	2	2	3	3	4	4	5	6	3
06 PARIS – GERAARDSBERGEN	1	1	1	2	2	3	3	3	4	2
02 VALENCIA – MADRID	1	1	1	1	1	1	2	2	3	1
03 MADRID – BARCELONA	1	1	1	1	1	2	2	3	3	2
04 MADRID – PARIS	1	1	1	1	1	2	2	2	3	1
28 VERCELLI – PARIS	1	1	1	2	2	2	2	3	3	2
01 LISBON – MADRID	1	1	1	1	1	1	2	2	2	1
05 MARSEILLE – PARIS	1	1	1	1	1	1	2	2	2	1
09 GERAADSBERGEN – AMSTERDAM	1	1	1	1	1	1	2	2	2	1

Table 5: Evolution of the need for tubes by direction due to increases in demand in two pod capacity scenarios

Based on the approaches described above, table 5 is provided showing those lines which in the period 2020-2098 will gradually increase their need for tubes per direction by more than one. The table shows the values for the need for tubes both in the case where the capacity limit of the passenger capsules is 100 or 200 seats.

As an abacus, the figure below shows the results of a simulation relating the capacity of passenger capsules to the need for tubes per direction on five of the 28 lines in the network.

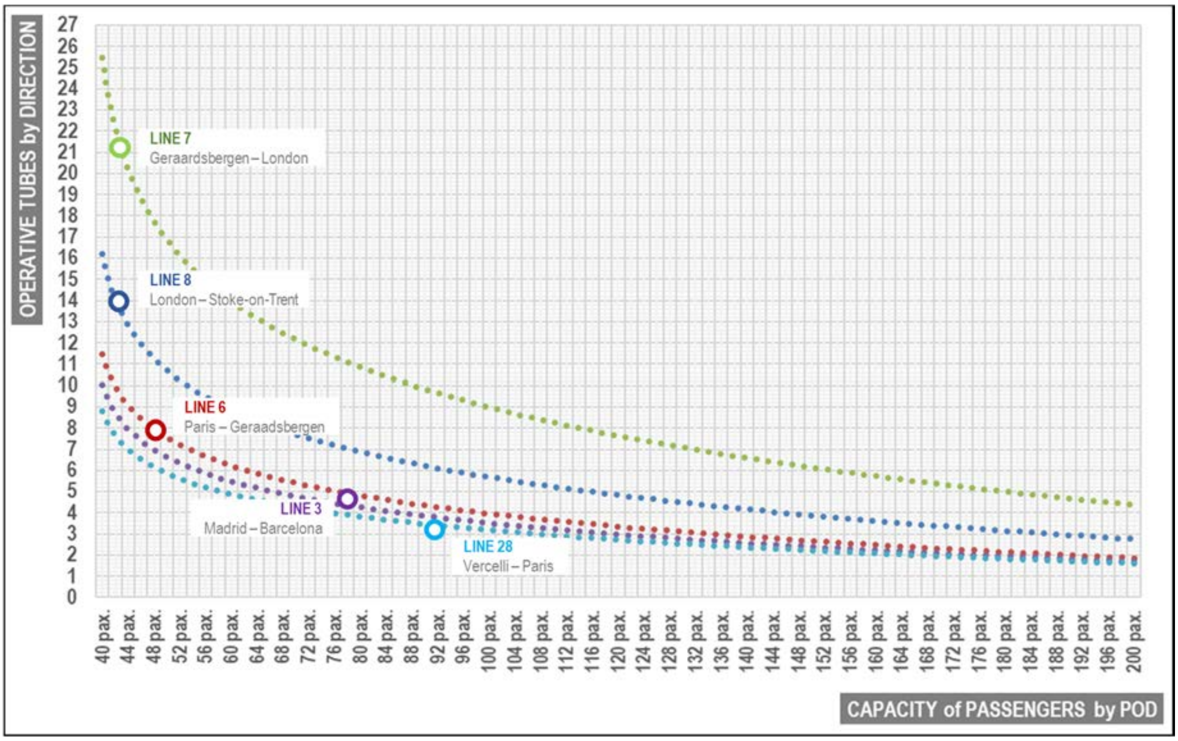


Figure 9: Relation between pod passenger capacity and the need to operate two tubes or more per direction

In any case, for reasons of space, the configuration of the line does not seem reasonable to exceed 3 operational tubes per direction and 1 additional tube as a backup. It is environmentally unacceptable to create tracks in the terrain that are more than 60 metres wide.

4. QUANTIFICATION OF THE TRANSPORT SUPPLY LINKED TO THE EUROPEAN HYPERLOOP NETWORK IN 2020

European Hyperloop Network		01 LISBON – MADRID	02 VALENCIA – MADRID	03 MADRID – BARCELONA	04 MADRID – PARIS	05 MARSEILLE – PARIS	06 PARIS – GERAARDSBERGEN	07 GERAARDSBERGEN – LONDON	08 LONDON – STOKE-ON-TRENT	09 GERAADSBERGEN – AMSTERDAM	10 HAMBURG – AMSTERDAM
Length	[Km]	537.66	360.02	544.65	1,108.71	787.92	247.53	317.56	238.33	198.93	391.34
Trip time	[Hours]	1,4	1,1	1,35	1,99	1,68	0,95	1,06	0,95	0,89	1,13
Qy. of tubes	Depart	1	1	1	1	1	1	3	2	1	1
	Spare	1	1	1	1	1	1	1	1	1	1
	Arrive	1	1	1	1	1	1	3	2	1	1
Seats pod		60	80	100	100	90	100	100	100	60	50
Qy. of pods	Pax.	62	52	62	88	76	44	150	84	40	52
	Freight	22	18	22	32	28	16	54	32	14	18
000 expeditions	Pax.	167	167	167	164	164	164	508	339	165	182
	Freight	28	28	28	32	32	32	114	76	34	32
000 trip hours	Pax.	259	210	258	360	310	180	579	349	163	223
	Freight	54	46	55	83	68	41	143	75	37	40
000,000 km travelled	Pax.	89.6	60.1	90.9	181.7	129.1	40.5	161.6	80.7	32.8	71.4
	Freight	14.9	9.9	15.0	35.5	25.2	7.8	35.8	18.0	6.8	12.3
Transport offer	000,000 seats	10.01	13.35	16.68	16.40	14.76	16.40	50.85	33.90	9.92	9.12
	000 tn.	206.76	275.68	344.60	399.10	359.19	399.10	1,421.28	947.52	256.35	197.09

European Hyperloop Network		11 BERLIN – HAMBURG	12 PRAGUE – BERLIN	13 VIENNA – PRAGUE	14 VIENNA – MUNICH	15 MUNICH – STUTTGART	16 STUTTGART – FRANKFURT	17 FRANKFURT – DORTMUND	18 DORTMUND – GERAARDSBERGEN	19 HAMBURG – COPENHAGEN	20 COPENHAGEN – STOCKHOLM
Length	[Km]	262.40	306.67	280.89	364.96	236.62	169.32	240.14	274.62	464.36	595.13
Trip time	[Hours]	0,99	1,02	0,99	1,14	0,97	0,87	1,01	0,99	1,24	1,51
Qy. of tubes	Depart	1	1	1	1	1	1	1	1	1	1
	Spare	1	1	1	1	1	1	1	1	1	1
	Arrive	1	1	1	1	1	1	1	1	1	1
Seats pod		60	40	40	50	40	40	50	90	40	40
Qy. of pods	Pax.	44	48	44	52	44	40	48	44	56	70
	Freight	16	16	16	18	16	14	16	16	20	26
000 expeditions	Pax.	182	182	171	182	182	182	182	182	182	170
	Freight	32	32	37	32	32	32	32	32	32	38
000 trip hours	Pax.	191	202	179	223	191	174	202	191	240	275
	Freight	36	37	42	40	36	31	37	36	44	66
000,000 km travelled	Pax.	47.8	55.8	47.9	66.4	43.1	30.9	43.7	50.1	84.6	100.9
	Freight	8.2	9.7	10.5	11.5	7.4	5.4	7.5	8.7	14.6	22.6
Transport offer	000,000 seats	10.94	7.29	6.83	9.12	7.29	7.29	9.12	16.40	7.29	6.79
	000 tn.	236.51	157.67	186.67	197.09	157.67	157.67	197.09	354.77	157.67	189.22

Table 7a: Quantification of the offer transport linked to a previously justified amount of infrastructure and pods

European Hyperloop Network		21 VIENNA – KATOWICE	22 KATOWICE – WARSAW	23 BUDAPEST – VIENNA	24 BUCHAREST – BUDAPEST	25 ATHENS – BUCHAREST	26 NAPLES – ROME	27 ROME – VERCELLI	28 VERCELLI – PARIS	TOTAL	
Length	[Km]	260.25	229.06	746.49	1,079.47	198.12	561.18	760.58	464.36	12,067	
Trip time	[Hours]	0,96	0,99	1,55	2,16	0,9	1,38	1,57	1,24	--	
Qy. of tubes	Depart	1	1	1	1	1	1	1	1	31	90
	Spare	1	1	1	1	1	1	1	1	28	
	Arrive	1	1	1	1	1	1	1	1	31	
Seats pod		40	40	40	40	40	50	100	100	--	
Qy. of pods	Pax.	44	44	70	98	42	62	72	56	1,68	52
	Freight	16	16	26	36	16	22	26	20	604	18
000 expeditions	Pax.	171	172	172	163	168	168	164	182	5,333	182
	Freight	37	34	34	32	30	30	32	32	1,027	32
000 trip hours	Pax.	178	184	288	392	171	258	288	240	6,907	223
	Freight	42	39	59	92	39	55	66	44	1,48	40
000,000 km travelled	Pax.	44.4	39.4	128.6	176.0	33.2	94.1	124.7	84.6	2,201.9	71.4
	Freight	8.2	9.7	10.5	11.5	7.4	5.4	7.5	8.7	423.6	
Transport offer	000,000 seats	10.94	7.29	6.83	9.12	7.29	7.29	9.12	16.40	355,3	
	000 tn.	236.51	157.67	186.67	197.09	157.67	157.67	197.09	354.77	8,631.76	

Table 7b: Quantification of the offer transport linked to a previously justified amount of infrastructure and pods.

5. CONCLUSIONS

The information set out in this document would already allow an approximation of the capex of network implementation and the opex linked to the operation of transport services. It will also make it possible to establish revenue scenarios based on assumptions of passenger and freight capsule occupancy for each of the proposed journeys.

Based on the above, it can be stated that the average length of a line in the network is 430.96 km, and the average journey time is 1.21 hours. 23% of the tubular infrastructure would correspond to backup tubes. This type of tube should have a pressure inside it such that, should it be necessary, due to an incident in the rest of the pipes, the service pressure would be reached in a short space of time.

The carrying capacity of the passenger capsules would range from 40 to 100 seats per trip. If each seat is assigned an equivalent payload of 125 kg, the carrying capacity of the cargo capsules would range from 5 to 12.5 tonnes. The cargo activity is envisaged as a complementary service to passenger transport and should be focused on high value-added and/or perishable cargo.

The need for passenger pods is quantified at 1,680 (73.5% of the total), and they would operate on a daily average of 8.70 journeys (4.35 journeys per direction). The average operating time of this type of capsule would be 4,111 hours per year (11.26 hours per day).

The average annual km travelled by each passenger capsule would be around 1.3 million (3,591 km per day).

The need for cargo capsules is quantified at 604, and they would operate on a daily average of 4.66 expeditions (2.33 expeditions per direction). The average operating time of this type of capsule would be 2,450 hours per year (6.71 hours per day). The average annual km travelled by each passenger pod would be around 0.70 million (1,921 km per day).

From the gravity demand models, a demand for the use of the network of 145.9 million passengers can be surmised for the year 2020. The calculation of this usage demand in a planning phase is particularly useful to obtain the design demands for an initial dimensioning of the number of tubes required in each direction.

The setting of operating timetables per line on each of the 14 predefined standard days, and of time slots within each day with differentiated service frequencies, would make it possible to offer a potential transport capacity of 355 million passengers per year and 8.7 million tonnes from 2020 onwards.

As a reference taken from Eurostat (2021), it is worth noting that in terms of air transport alone, the volume of passengers generated in 2019 by 47 European airports (providing a service equivalent to that provided by the 28 stations of the European Hyperloop Network) to any other airport in the European Union amounted to 256 million. These values show the possibility of growth in demand for use over a reasonable period of time during which it would not be necessary to undertake work to expand the capacity of the network.

6. NEXT STEPS

If the final decision on the part of governments is to provide this type of infrastructure through public-private partnership contracts, there must necessarily be Special Purpose Companies of a mercantile nature to make them a reality. In this sense, it is essential to determine the number of companies that will be necessary to carry out the investment projects, as well as to describe the corporate purpose of each.

In the process of technical, economic, financial, and legal structuring of this type of agreement between public and private agents, the amount of obligations to be met by the companies will emerge on the one hand, and the amount of rights on the other. The final balance resulting from the balancing of these rights and obligations will make it possible to quantify, where appropriate, the need for the contribution of public resources and their typology.

In this context, one of the most relevant obligations in the opex structure of the new operating companies will be electricity consumption.

As stated at the beginning of this paper, Hyperloop has been presented to the world as a new green mode of transport, and the existing proposals to date all advocate that the renewable energy source should be solar. Since 2009, the price of solar power generation has been gradually decreasing from USD 0.359 per kWh to USD 0.037 per kWh today. Similarly, in 2009 the cost of wind power generation was USD 0.135 per Kwh to USD 0.040 today (Schneider, 2021). Despite the relatively low prices on exhibit, and the technical availability of battery backup is becoming more and more feasible, there is still a problem of stable availability of this type of energy source.

It would therefore be worth exploring the possibility of linking Hyperloop with novel energy sources that are potentially more beneficial than solar and wind. In 2016, the European Patent Office approved the patent application for a Spanish invention called the Ionic Electric Power Station (Santana Ramirez, 2016), which, in addition to promising to generate electricity at a production cost of around USD 0.020 per kWh, has also been classified by the same body as a renewable energy source that mitigates climate change under the heading (Y02P20/133).

Keep going through further progress in the search for sustainable energy sources with more stable generation profiles will advance the financial viability of Hyperloop.

REFERENCES

ADIF (2011) Instrucción General de Proyectos IGP-3. URL (Last Access: Mar 2021)

CEN-CENELEC (2020) A Newcomer in the European Transport Standardization Family: JTC 20 on Hyperloop Systems. URL (Last Access: Mar 2021).

EGEA, P., GARCÍA, E., DE LA FUENTE, J.C. (2016) Análisis comparativo de la viabilidad entre los medios de transporte Hyperloop y AVE en el corredor Madrid- Barcelona.

ET3 GLOBAL ALLIANCE, INC. (2010-2015). URL (Last Access: Mar 2021).

EUROPEAN COMMISION (2018) The 2018 Ageing Report: Economic and Budgetary Projections for the EU Member States (2016-2070). URL (Last Access: Mar 2021).

EUROPEAN HYPERLOOP WEEK MAILBOX (2021) EHW - Partner Event. European Hyperloop Week Webinar. Youtube (minute: 26:35). URL (Last Access: Mar 2021).

EUROSTAT (2021) – International intra-EU air passenger transport by reporting country and EU partner country[avia_paincc] URL (Last Access: Mar 2021).

FERNÁNDEZ JÁÑEZ, J. (2012) Una visión actualizada de la competencia entre el tren de alta velocidad y el avión. URL (Last Access: Mar 2021).

GKOUMAS, K., CHRISTOU, M. (2020) A Triple-Helix Approach for the Assessment of Hyperloop Potential in Europe. Sustainability 12, no. 19: 7868. URL (Last Access: Mar 2021).

GODDARD, R. (1924) How my speed rocket can propel itself in vacuum. Popular Science. p. 38. URL (Last Access: Mar 2021).

HANSEN, I.A. (2020) Hyperloop transport technology assessment and system analysis, Transportation Planning and Technology, 43:8, 803-820 URL (Last Access: Mar 2021).

LATOUR, B. (1993) Ethnography of a high-tech case. About Aramis. URL (Last Access: Mar 2021).

LATOUR, B., PORTER, C. (1996) Aramis, or, The love of technology. URL (Last Access: Mar 2021).

LTD. LAMSON (1908) Improvements connected with Pneumatic Despatch Apparatus. URL (Last Access: Mar 2021).

MADRID (EDIZIONES) - EUROPA PRESS (2018) Así se compara el horario laboral español con el de otros países europeos. URL (Last Access: Mar 2021).

MEDHURST, G. (1810) A New method of conveying letters and goods with great certainty and rapidity by air. London. URL (Last Access: Mar 2021).

MUSK, E. (2013) HYPERLOOP ALPHA. SPACEX. URL (LAST ACCESS: MAR 2021)

REAL Academia de Ingeniería (2012) Diccionario. URL (Last Access: Mar 2021).

SALTER, R. M. (1972) The very high-speed transit system. URL (Last Access: Mar 2021).

SANTANA RAMIREZ, A.A. (2016) Central eléctrica iónica. URL (Last Access: Mar 2021).

SCHNEIDER, M. (2021) Every euro invested in nuclear power makes the climate crisis worse / Interviewed by Gero Rueter. Deutsche Welle (DW). URL (Last Access: Mar 2021).

TAYLOR, C.L., HYDE D.J., BARR, L.C. (2016) Hyperloop Commercial Feasibility Analysis: High Level Overview. URL (Last Access: Mar 2021).

TRANSPORTATION ECONOMICS & MANAGEMENT SYSTEMS, INC. (2018) Great Lakes Hyperloop Feasibility Study: Technical Memorandum #1.

TRANSPORTATION ECONOMICS & MANAGEMENT SYSTEMS, INC. (2019) Great lakes Hyperloop feasibility study. URL (Last Access: Mar 2021).

UNIVERSIDAD POLITÉCNICA DE MADRID (2020) HYPERNEX: Un paso más hacia el liderazgo europeo en la construcción del Hyperloop. URL (Last Access: Mar 2021).

WALKER, R. (2018) Hyperloop: Cutting through the hype. URL (Last Access: Mar 2021).