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HYPERLOOP: An analysis of its fit in the European Union

A STUDY ON THE POTENTIAL REGULATORY FRAMEWORK AND A CASE STUDY IN EU TERRITORY

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INDEX

1. INTRODUCTION.. 2

1.1 History... 4

1.2 Hyperloop Alpha 6

2. STATE OF THE ART 9

2.1 Companies in the industry 10

2.2 External analysis on viability.. 22

3. RESEARCH APPROACH 28

4. RESEARCH 31

4.1 BACKGROUND 33

4.2 REGULATION SUMMARY... 35

4.3 REGULATION ANALYSIS AND APPLICABILITY TO HYPERLOOP 40

5. CASE STUDY: CONNECTION BETWEEN THE CITY CENTRE OF MARSEILLE AND MARSEILLE-PROVENCE AIRPORT 48

5.1 INTRODUCTION 48

5.2 CURRENT ACCESSIBILITY BETWEEN THE CENTRE OF MARSEILLE AND THE AIRPORT 49

5.3 IMPACT.. 64

6. CONCLUSIONS.. 72

7. BIBLIOGRAPHY 77

1. EXECUTIVE SUMMARY

This paper introduces and explores the concept of hyperloop, diving deep into the possible implications it may bring and how it will be affected by the current framework of society.

Firstly, a short introduction is done in which the concept of what hyperloop is is explained, as it is understood today. The concept of tube transportation is not new, so an exploration of how it became hyperloop is done. An exploration of the history of hyperloop is done, from the first attempts in the mid-nineteenth century New York, when the concept of pneumatic tubes was applied to a larger scale to more recent projects that never ended up being built like Swissmetro, which is a very similar idea to the current hyperloop, only underground.

After analysing the past, it makes sense to analyse the present, what is going on in nowadays with the concept of hyperloop, who is developing it and how. There are several companies that have been founded with the only objective of creating a functioning hyperloop, and all of them are advancing fast. The state of the art of hyperloop is embedded in these companies developing it, and there are varying levels of advancement. While some have been testing for over a year in their own test tracks, others have full-scale pod prototypes and others still juts bits and pieces of key technology and are working on the construction of test tracks. In general, these companies are formed by young entrepreneurs with support from big names from the technology world in their boards of directors.

Once the concept is introduced, explained and explored in depth, the analysis of the fit in the European Union is carried out. The way this is done is on two dimensions: legally and practically through a case study. Hyperloop is a mode of transportation very comparable to railway in the operational sense, which is why the current regulation of the European railway market is studied. Following the reasoning that if the modes are similar, their regulation will probably be as well, the new Fourth Railway Package, which opens up the domestic railway market, is studied in depth, considering the points that may be applicable to hyperloop and have a possibility of being part of the future hyperloop regulation.

After that, the practical fit in the European Union is considered through a case study of a hyperloop line between the city centre of Marseille and its airport. This is a real case one of the companies developing hyperloop, TransPod, is studying. This company provided support throughout the development of the case study. In it, the current situation is thoroughly analysed as is the impact of a potential hyperloop line in that area, with a calculation of the capacity of the system and the construction costs of the route.

Finally, some thought is given to the whole matter and concept of hyperloop, and the challenges companies may face when implementing it in the European Union.

1. INTRODUCTION

Hyperloop is set out to become the fifth mode of transportation, as a hybrid between air travel and rail: it can reach speeds in the order of magnitude and even superior than the former, but with a shape and with a cost more similar to the latter. All of this while being clean, environmentally speaking, since it is powered by electricity and not fossil fuels directly, and many projects include installing solar panels on the tubes to gather enough energy to be self-sufficient and even have an excess to provide to the network (1). The hope is that this fifth mode of transportation will be able to substitute short-haul flights covering distances between 500 and 1500 kilometres, which are, incidentally, the less energy-efficient (2).

Simply put, hyperloop consists in having a tube in which there is very little pressure and a vehicle, suspended in the air, travelling at a great speed through it. At the time a more precise description cannot be given, because the technology to achieve these characteristics varies depending on the company developing the system, and it is not fully established in most cases. However, the most extended resource used for the suspension of the vehicles is magnetic levitation in one form or other, and propulsion is achieved through linear induction motors in more than one case.

Although at first this new mode of transportation seemed little more than science fiction for some people, it has steadily been taken more seriously by the scientific community, investors and society in general. The value of the hyperloop market is estimated to reach over $1000 million by 2022 and keep growing at a tremendous rate of over 40% in the following five years. This makes investing in the technology attractive not only for business angels funding start-ups, but also for well-established tech companies, giants in the transportation sector, governments and other incumbents who may be afraid of being left behind.

Advocates of the technology affirm that it is more sustainable and could be faster than aviation and, of course, high-speed trains. The real revolution that hyperloop offers is having a mode of transportation reaching speeds close to the speed of sound and a frequency similar to that of a subway, changing completely how people travel medium to long distances. It is characteristics like this that are supposed to counterbalance some negative aspects such as the claustrophobia that travelling within a de-pressurised windowless tube might generate in some people. Another point in favour of hyperloop is it claims to be environmentally friendly, since many of the current designs include solar panels embedded in the infrastructure to generate the energy necessary to run the system. This, of course, raises the question of how will a system operate in places with little sunshine such as the Scandinavian countries in the winter, which means they will have to be connected to the general network, where one cannot choose the origin of the energy consumed.

The several companies working in the development of the system are rapidly advancing in achieving viable vehicles and quickly approaching the speeds promised in their flyers. At this point, no one doubts hyperloop is technologically viable. However, there is a great uncertainty when it comes to other more subtle issues of the market such as regulation, interoperability and related concerns. Many companies are aware of this, especially when considering opening a route in the European Union, where regulation is usually more complex and pervasive than in other territories. That is why some of the companies have reached an agreement between them to start tackling these matters at the same time the technology is being developed, to be prepared with a plan by the time the system is ready to operate. The European Union has formally become a part of this agreement and is contributing with a multi-million investment for a research and development facility in the Netherlands that all the signers of the agreement will be able to exploit.

1.1 History

The first time the word hyperloop was used in literature was when Elon Musk published his paper `Hyperloop Alpha’ in 2013 (1). However, the concept of high-speed transportation within a low-pressure tube first appeared in the mid-19th century (3), and it has evolved rather slowly until recently, after the publication of Musk’s paper, the interest and development of such a transportation mode skyrocketed.

The idea of moving things along low-pressure tubes is quite old, and was extensively used during the 19th century to send telegraphs quickly across cities, although the use of pneumatic tubes by postal services declined and finally disappeared with the growth of cities after WWI and the development of the trucking industry. The breakthrough was thinking about using a pneumatic system to transport people, which came into being during the second half of the 1800s in New York (4). In 1867 Alfred Ely Beach, who was an American editor, patent officer and inventor, presented his Beach Pneumatic Subway at the American Institute Fair in New York. With it, he wanted to find a solution to New York’s congested streets by introducing a subterranean train such as the one that already existed in London, becoming the current’s subway precursor. However, in this

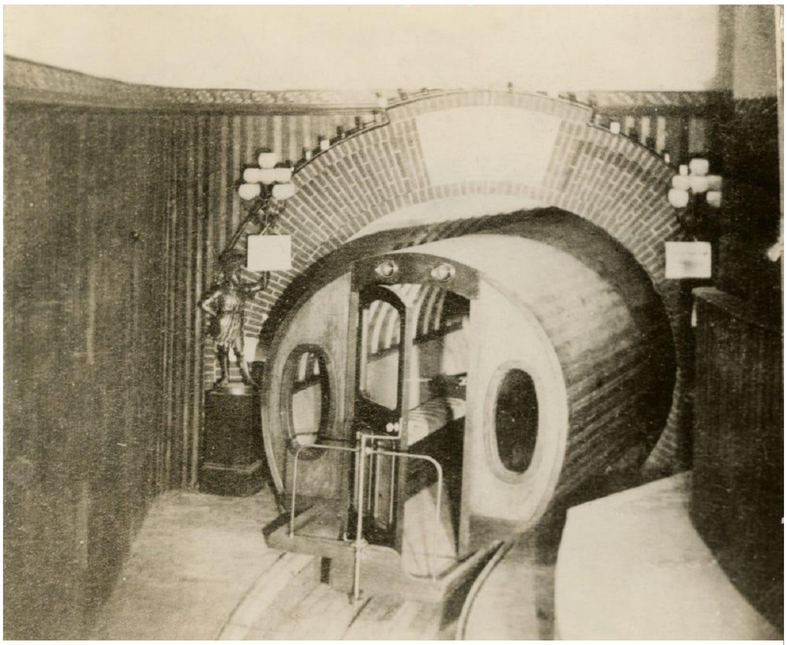

Figure 1: Beach Pneumatic Transit. Source: Business Insider

case instead of being powered by a steam engine, it was powered pneumatically. In 1870 Beach's system was installed: it consisted in a tube which had a diameter of a little under three metres and a length of 95 metres in which a single car moved to and forth, leaving very little space between itself and the tube walls. Within the tube a track was set on its floor, which guided the car, and a large fan called "Roots Patent Force Blast Blower" was located at one end. When this fan was turned on it pushed the car forward, reaching speeds close to 16 kilometres per hour. Close to the end of the tube, the car tripped a wire, which reversed the direction in which the fan rotated, "sucking" the car back to its initial position (3). This system was in operation for a year between 1871 and 1872, when it closed due to lack of funds.

One of the other main precursors of today's concept of hyperloop is the system proposed but never executed by Robert Goddard in 1909, which consisted in a transportation system that could connect New York with Boston in just 12 minutes. The basic concept was travel inside a steel vacuum tube in which a train was suspended, and propulsion fell to electromagnets, what we today call magnetic levitation (5), (6).

Fast forwarding to the 1970s, Robert M. Salter, as part of the RAND Corporation published several papers on "very high speed" transportation. The first of these publications was The Very High Speed Transit System (VHST), published in 1972. Its motivation was finding a clean transportation mode that could compete with airplanes, and the concept was the same as Goddard's: "electromagnetically levitated and propelled cars in an evacuated tunnel" (7). Besides the technical issues, this concept of transportation was meant to be integrated within the existing network, with terminals inserted in train or subway stations, becoming an early precursor of what we now call intermodality. In this paper, Salter proposed building a main line across the United States line between New York and Los Angeles, with two intermediate stops to make it more cost-effective in terms of both construction and operation. It would also include

Figure 2: The VHST network envisioned by Robert Salter. Source: RAND Corporation

several secondary lines which connected the main one with major cities such as San Francisco and Denver. This paper states that the speed of the vehicles in this transit system would be in the order of thousands of miles per hour, claiming that a non-stop trip between Los Angeles and New York would only take 21 minutes, which would imply an average speed of over 13 000 km/h. These speeds made the geometry of the lines very important in order to avoid reaching large accelerations, and so it implied building the whole system underground to guarantee straight routes. Evidently, the cost of such a pharaonic work was deemed too much, estimated at 1 trillion US dollars. That, added to the fact that the technology regarding magnetic levitation was not greatly developed in the country and Salter had proposed using steel wheels, made it impossible for this project to ever be anything else that research.

Some time later, in 1992, a company called Swissmetro was founded. Its objective was to create a network of high-speed trains running in underground evacuated tubes in Switzerland, connecting in very little time the main cities in the country. The whole project was promoted by Marcel Jufer, from the École Polytechnique Fédérale de Lausanne, and it consisted in using vehicles with a capacity for 200 passengers each, which would depart every 6 minutes from the different stations conforming the network and which would use magnetic levitation, thus obtaining low-energy consumption due to the little resistance encountered by a body which has no contact with any surface in a low-pressure tube (8). The company was dissolved in 2009 due to lack of support, since the economic viability of the system was not assured, and it is unlikely that it will be restarted.

Since then, the concept of high-speed transportation in closed environments has not experienced much interest or developments until Elon Musk's paper Hyperloop Alpha was published in 2012. This paper requires special attention because, although all of the projects described above have had an obvious influence in Musk's concept, it differed in key aspects such as the levitation technology and the location of the tubes.

1.2 Hyperloop Alpha

Elon Musk published Hyperloop Alpha in 2012. The document has two differentiated parts. The first one has an informative character, intended to be understood by anybody regardless of the technical background of the reader, while the second part is oriented precisely to people with that kind of training. The objective of this paper was to introduce the idea of a fifth mode of transportation and initiate research and development on the matter. It is important to note that the whole paper and idea revolves around a single line connecting two major cities in California (1).

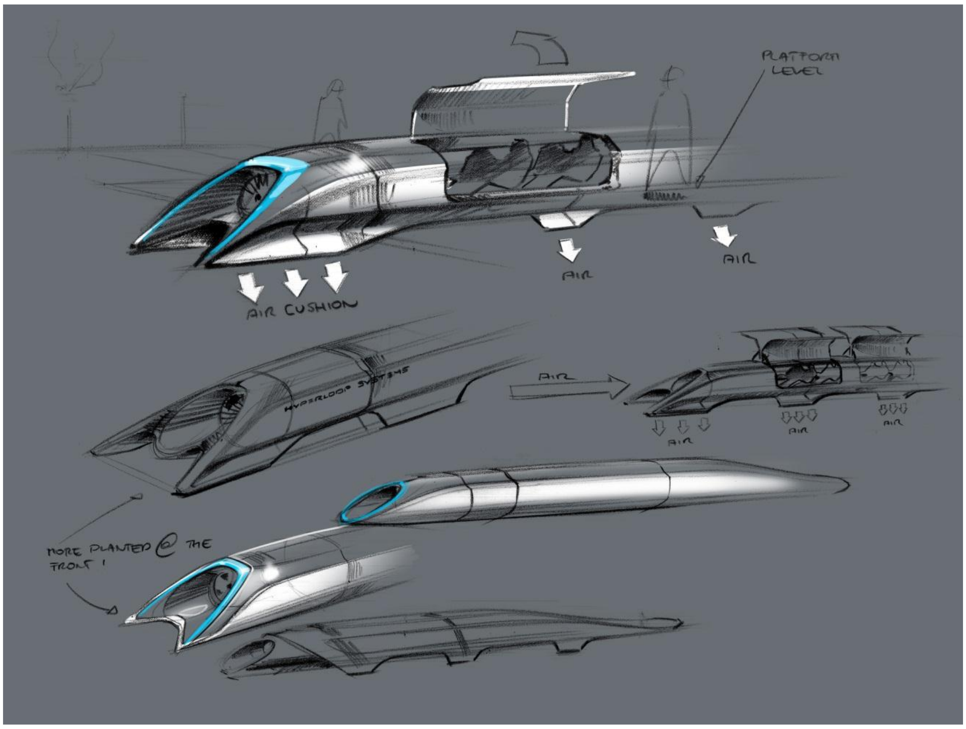

Figure 3: Hyperloop alpha conceptual design sketch. Source: Hyerploop Alpha

The trigger for this document was California's high-speed rail program, which wanted to build a line along the West coast of the US, basically connecting the cities of San Francisco and Los Angeles. The problem Musk saw in this was that the project suggested a bullet train that would have a great economic cost and a sub optimal speed: it would be slower and more expensive than a plane, thus it would inevitably remain unused by the public. He argues that if there is an alternative to be offered to the current options implying a "massive investment", the new option should be better than the existing ones, in aspects such as speed, safety, convenience and cost but that is also sustainable, immune to weather, resistant to earthquakes and non-disruptive. His proposition is developing a new mode of transportation that offers all of the mentioned advantages, Hyperloop, although he specifies it is an ideal solution only for very specific cases, two big cities with high volume traffic between them which are around 1500km apart (1).

So, what does Musk's solution actually consist in?

The first characteristic that differs from the described above solutions is that it considers neither atmospheric pressure nor a vacuum within the tube, but a low air pressure. While Goddard's system, with atmospheric pressure, would in theory be scalable in size and speed, air resistance increases greatly as the speed of the vehicle does, making it virtually impossible for this system to work. At the other end, a vacuum as described in Salter's idea, implies great difficulties in maintaining the conditions, avoiding leaks and so on, making it a very expensive and probably ineffective system. Musk's solution to this is introducing some air pressure, but keeping it very low to avoid high values of air resistance. However, as there is some presence of air, the Kantrowitz limit comes into play, which is a problem that the design of the system has to overcome. This limit is a ratio between the area of the tube and the one of the vehicle inside it, if it is too small then the vehicle has to push the whole column of air in front of it when moving, which creates evident problems. To solve this issue, Musk suggests installing a compressor fan at the head of the vehicle which would pump the high-pressure air in front of it to its rear end, which would be powered by a battery on board. The way of achieving very low friction is to have the vehicle suspended on air cushions, since wheels would create too much resistance in any case, and the air would come from the vehicles themselves and not from the platform in the tube, to limit the cost of the infrastructure. This is one of the main differences with the most widespread idea of today, which consists in using magnetic levitation to avoid friction. Regarding thrust, in order to accelerate the vehicle to cruise speed, the idea was using a round induction motor, not very different to the ones used in electric cars, integrated in the tubes (1).

Always referring to the same specific route between Los Angeles and San Francisco, regarding economics, Musk defends that even though his system is very expensive, it would not be as costly as the proposed high-speed railway line along USA's West coast. The difference in price is due mainly to the simplicity of the infrastructure, mainly prefabricated and built on pylons rather than a platform on the ground. In this paper, Musk also defends that his system is less intrusive, safer and more adaptable to earthquakes, which is an important issue in California, and taking into consideration this region's sunny weather, it could be fitted with solar panels that would produce enough energy to power the whole system without having to depend on the existing network (1).

The above is a short description of what Elon Musk proposed in 2013, without going deep into technical details since many have evolved with the further research and practical development carried out and because they are not relevant for this discussion. Since writing this paper, Musk was aware that his idea needed refining and further development, and that is why he proposed an open source design, inviting anyone who was interested to collaborate, even hosting a contest in 2016 to find the best ideas for the design of a functioning system. Since 2017, trials have been carried out on a test track in Nevada, and other companies also aiming at developing this fifth mode of transportation are in similar stages of development (9).

2. STATE OF THE ART

This section is the result of an investigation into the many companies that are or have been involved in the development of a hyperloop system. Since the concept was first introduced in 2013, it has created a technological hub around itself, with many start-ups arising to develop the whole system and many millions of euros being invested in it.

Since Elon Musk wanted to open source the development of the project, the amount of people and entities from universities to private companies is extremely high. However, the private companies developing hyperloop systems are not so keen on sharing their research and advances, and so the result is that the development of hyperloop has diverged into very similar concepts but using varying technology. In parallel, Elon Musk's SpaceX regularly holds contests to develop a working vehicle prototype which are populated by teams of universities from all over the world. The results from these contests are very impressive, recently achieving a speed of over 400 km/h.

From the first two companies that were founded just after the publication of Hyperloop Alpha to the over 7 currently existing, each and every one of them has received multi-million investments to develop their technology but are in different stags of development and testing. Some companies have already done extensive testing in test tracks, others are building this type of facility and others are still developing the concept and looking for more funding. What all of them have in common is an impressive support from investors, scientists and governments alike, with some very eminent names in the board of directors of several companies.

However, it is not just technology what has to be developed, it is also a regulatory framework, since this is a transportation system for goods and people, it will have to follow strict security rules and market procedures that comply with the regulatory scheme of the territory where it is installed. In this respect, several companies have reached an agreement with each other and with bodies within the European Union to develop this common framework and guarantee interoperability from the get-go.

In general, it looks like the technology has developed fast, not as fast as some predicted, but hyperloop is steadily nearing reality. With companies focusing on issues beyond technical and technological viability, and the involvement of governmental agencies, it is clear that not just the people directly involved in the development believe in it, and no one wants to be left behind.

2.1 Companies in the industry

Since Elon Musk published his paper Hyperloop Alpha, a small number of companies are working in developing the different technologies needed for this fifth mode of transportation to become a reality.

Although the general concept is the same, each company has a unique system design, and the differences between some of them are huge, from the propulsion system to the expected pressure within the tube. This section will explore the history and technology of the companies developing hyperloop systems, some of which, besides being dedicated to the advancement of the integral system, also focus on diverse, less tangible issues such as regulation (10).

2.1.1 SpaceX

SpaceX is an aerospace manufacturer and space transportation company founded by Elon Musk in 2002, with the ultimate goal of democratising space travel and even colonising Mars. Although the latter does not seem to be any closer, SpaceX has experienced major achievements in the space travelling industry, such as being the first private company to launch, orbit and recover a spacecraft and achieving and important partnership with NASA.

Although SpaceX does not formally develop any technology related to hyperloop, it does regularly host the hyperloop pod competition, which invites groups of students from all over the world to present their prototypes and test them in their facilities in California. This competition has proven to be a springboard for many young entrepreneurs which have ended up successfully founding their own companies and working in developing a functional hyperloop system. This competition is supported by another one of Musk's ventures, The Boring Company.

2.1.2 Virgin Hyperloop One

One of the largest companies, and the pioneer in surpassing critical milestones, working on hyperloop is called Virgin Hyperloop One, which since October 2017 is a joint venture between Virgin Group and the start-up Hyperloop One. This start up was created in June 2014 by Shervin Pishevar, an entrepreneur acquainted with Musk, Brogan Brambrogan and Josh Giegel, both former engineers at SpaceX, and it was initially named Hyperloop Technologies based in a garage in Los Angeles. By February 2015, Hyperloop Technologies had moved to LA's arts district and set up an innovation campus and raised $8.5 million in their latest investment round. As they get on with their work, they begin designing and testing different parts of the system, advancing towards the creation of a functioning hyperloop, with the development of unique testing systems. A major milestone takes place in December 2015, when Hyperloop Technologies establishes a site in Nevada to carry out propulsion open air tests and analyse their custom-made linear propulsion motor (11).

It is in May of the following year when several very important things happen. The Nevada site is fully operational and successful propulsion open air tests are carried out, validating the design of the motor and power electronics system. Also, at this time the company changes its name to Hyperloop One, to signify that they were the first company to start developing a full hyperloop system and announce their funding has reached $80 million. Finally, in order to "harness the most creative minds in making Hyperloop a reality", the Hyperloop One Global Challenge is announced, which consisted in an appeal for proposals of hyperloop routes connecting cities around the world. Out of the more than 2500 submissions, 10 were selected as winners, which meant Hyperloop One will pursue further research into them and possibly their construction.

Figure 4: Virgin Hyperloop One's testing tube. Source: Virgin Hyperloop One

Just a few months later, in the Summer of 2016 Hyperloop One has inaugurated the first hyperloop manufacturing plant and the construction of the first full scale 500-metre long hyperloop test track, both of them in Nevada. The construction of the test site, named Development Loop (DevLoop) is finished in March of the following year and in May the first successful test complete with power electronics, an autonomous pod, motor control and braking systems, levitation track, and guidance systems is carried out. The hovering of the pods is achieved through magnetic levitation.

By this time, the reality of hyperloop seems to be getting closer, and the leaders of the company realise that in order for a project of this magnitude cannot be put into motion single-handedly by them. A fifth mode of transportation is a radical innovation by its own merit, but this particular mode of transportation implies thousands of innovations in fields that go from thermodynamics to urbanism. Following this train of thought, and by making a comparison with the revolutionary entrance of the iPhone into modern society, the creation of ecosystems versus the traditional pipeline business model, Hyperloop One created the Partner Program. This promoted partnering with companies from different industries, fields and territories that would enable the ecosystem of hyperloop to take form and flourish, since it would be impossible for it to become a reality without collaboration from different parties of the transportation, manufacturing and engineering worlds. By promoting these partnerships, Hyperloop One benefits from being able to move further and faster and partners are able to be part of an innovative ecosystem and learn and adopt best practices experienced in the partnership, pioneer in expertise in the field, which will bring industry recognition and all of this translates into increased revenues. All in all, a very attractive idea for many companies such as construction companies, transportation services operators and providers. Their program made it easier for partnerships to be made, consolidating the innovative approach of open sourcing progress and development within the company.

Other developments within the company at this time includes the falling out of the founders, Pishevar and BamBrogan. The latter left the company and sued it for wrongful termination, defamation, financial misdeeds and assault, and went on to create another start up englobed in the hyperloop industry called Arrivo (12).

Tests continue in the Nevada site, the first vehicle that will be used for testing, called XP-1, is revealed and on July 2017 the second phase of testing is completed. In numbers, Hyperloop One's pod reached 310 km/h by using 300 m of stator for propulsion. With this data, the company claimed it could reach 1000 km/h by having an additional 2000 m of stator, which in a potential future hyperloop line is a very little percentage of the full length. Hyperloop One continues to pioneer in testing and development of this new mode of transportation, consolidating their spot as first movers in the industry, achieving a total of $245 million of funding by the end of the summer. One of the investors in the company is Richard Branson's Virgin, with which they team up in a strategic partnership, joining Hyperloop's One technology and innovation with Virgin's expertise and experience in operating passenger services. Another milestone in testing is hit when the pods reach 386 km/h.

Figure 5: Virgin Hyperloop's One XP-! vehicle being prepared for testing in Nevada. Source: Virgin Hyperloop One

Fast forwarding to April 2018, Virgin Hyperloop One partners up with global trade enabler and largest investor in the company DP World to create a subsidiary called DP World Cargospeed, which will take care of the transportation of palletised cargo in hyperloop.

In the summer of 2018, Virgin Hyperloop One signs an agreement to open their first development facility in Europe, in the south of Spain, which is set to be up and running by 2020. This facility would be used to develop, test and certify components and subsystems, going forward in improving the safety and reliability of the system. Throughout the year, Virgin Hyperloop One continues to gather support not only from the technology and start up world, but from the political world, testifying in the US Senate, receiving visits from government representatives and even hosting an event at Washington's Capitol Hill. This evidences the compromise of several stakeholders in the advancement of the project and makes it something very close to reality, not only on the technological side, but also on market, social and political dimensions, which are crucial in an enterprise of this scope.

Currently, Virgin Hyperloop One's design is centred upon their proprietary linear electric motor, which has the stator built within the tube and the rotor mounted on the pod. This, together with the very low pressure within the tube means the track doesn't require power along its whole route, only at some points. Regarding energy sources, Virgin Hyperloop One is open to using renewable sources, but it is not one of their "slogans", they will use energy from whichever source is available along the route at the points where it is needed.

2.1.3 Hyperloop Transportation Technologies

Hyperloop Transportation Technologies (HTT) was founded in August 2013, mere weeks after Musk published his white paper on hyperloop. It was created in an innovative way, by JumpStarter by using their crowdsourcing platform JumpStartFund, getting, in just one year, to 100 engineers coming from many of the most prestigious companies and institutions in the world in terms of transportation and technology such as Boeing, NASA and UCLA (13). At this stage, HTT was functioning in a very unconventional way, with no employees, but collaborators who were willing to spend their free time researching, suggesting and running simulations. These 100 professionals worked on the project carrying out studies concerning the technical and economic viability of hyperloop, which they released to the public in December of 2013, continuing with the same crowdsourcing philosophy of the company, as a "crowdstorm document" in order to receive feedback and input. The nature of this company, and their way of working makes it a less institutionalised organisation and it has been much more apprehensive of their developments than other companies in the industry, unwilling to publish advanced feasibility studies or reports on their progress.

In January 2015, HTT filed construction permits in California for "the world's first passenger ready Hyperloop system", to build a line as part of the Quay Valley project, a planned city just in between Los Angeles and California. This project would consist in 5 miles or 8 km track serve as a site for testing and demonstration. However, the Quay Valley project never started due to litigation issues and the test track was never built, for undisclosed reasons.

In May 2016 HTT licensed a passive magnetic levitation system, which they would use in their hyperloop infrastructure. This system in cheaper and safer than the usual active magnetiv levitation used in systems like MagLev, and it eliminates the need to set up power stations along the routes (14). Another technological innovation of this company was the Vibranium, a material made basically of carbon fibre with sensors embedded which send crucial information to the main computer such as temperature, stability and so on. The intention of HTT is to use it in their capsules as the outer layer, because besides the sensors, it is an extremely strong and light material, making it perfect to guarantee safety and reduce energy costs.

In January of 2017, HTT signed an agreement with the city of Toulouse to build a facility in what is known as the Aerospace Valley to develop and test hyperloop. In April 2018 the construction of the test tracks starts with the arrival of the first full-size tubes at Toulouse.

A major milestone for the company was hit on October 2017 when Munich Re, a major insurer, carried out a study of HTT design and considered it to be “feasible and insurable”. In a company where little information is disclosed and which at the time had no testing facilities in action, this was an important support.

In April 2018 HTT creates XO Square in Brazil, a facility that will host the company’s logistics research division, a fabrication lab and will serve as an ecosystem for local start-ups, universities and governments, fostering innovation in the company and the country, in the area of logistics. Other areas the company is researching are the hurdles regarding safety certifications and regulations. The company’s CEO even stated that at first, before a regulatory framework is established, passenger will have to sign an agreement before boarding to be insured.

In the summer of 2018, HTT partnered up with Tongren Transportation and Tourism Investment Group of the People’s Republic of China to build the first hyperloop in this country. The idea is that HTT provides the technology while Tongren takes care of certification, regulatory issues and construction. This is a major advance for HTT, since signing an agreement of this characteristics in a country like China, a huge country with over a billion potential passengers.

In October 2018, HTT revealed their first full-scale passenger capsule. It was built by one of the company’s partners, Airtificial, in their facilities in the south of Spain, from where it was sent to HTT’s facilities in Toulouse for testing. The capsule’s outer layer is mostly made out of the company’s material Vibranium, measures 32 metres and weighs approximately 5 tonnes (15).

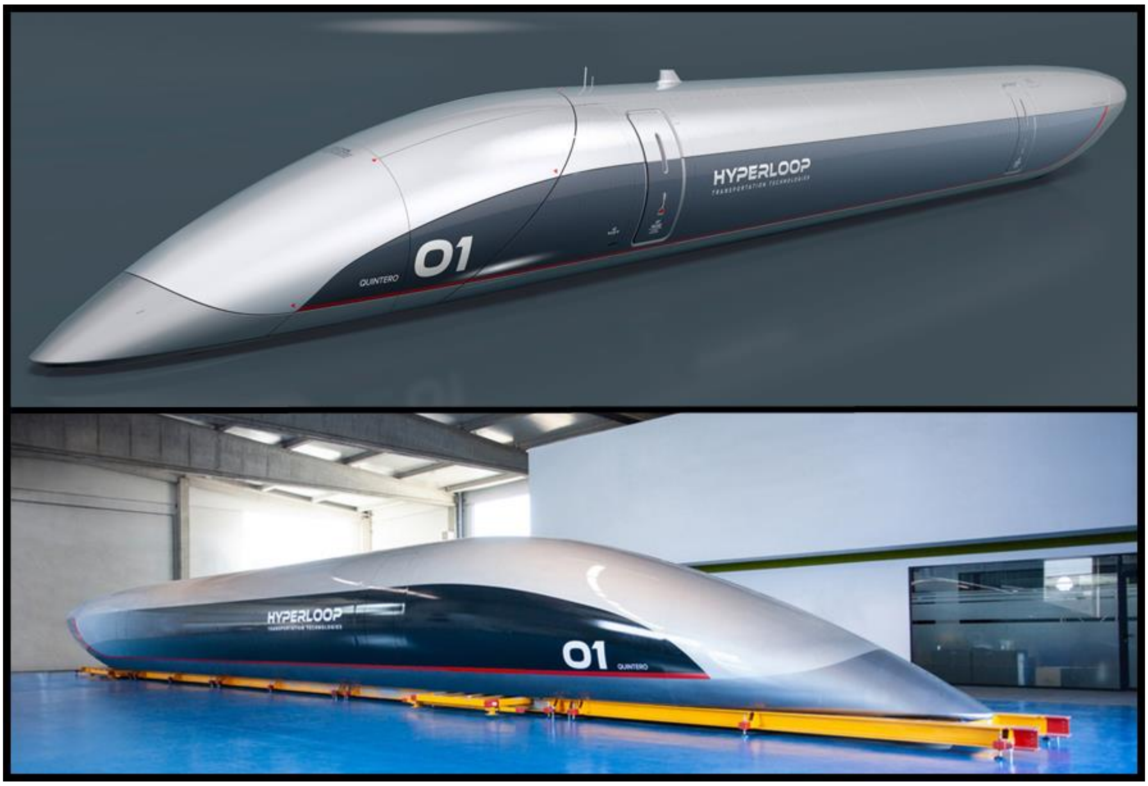

Figure 6: Comparison between HTT's vehicle render and the first prototype. Source: Own production from HTT's images

In May 2019, in partnership with TUV, a testing, certification and inspection firm, submitted generic guidelines to the European Commission to regulate hyperloop. According to the company's CEO: "It is important to create unified standards and procedures with Hyperloop TT's system along with other potential system providers". The document has not been disclosed.

HTT is one of the companies that has revealed less about the concrete technological details of their system, only stating that the system works with a linear induction motor, electromagnetic propulsion and embedded rechargeable batteries. Their levitation technology is called Indutrack, and it consists in arranging magnets in a Halbach array configuration to allow passive levitation over an unpowered but conductive track. By having a very low pressure within the tube, the energy needed is very small. The other major contribution of HTT is the previously mentioned Vibranium, a lighter but stronger than both steel and aluminium material, embedded with sensors that will be used for the pods. Other things regarding the system that HTT has published include enhanced virtual windows which show the scenery outside even in the tube is opaque.

2.1.4 Arrivo

Arrivo was founded early in 2017 by Brogan BamBrogan after he left Hyperloop One. The concept Arrivo wanted to sell differs from the mainstream concept of hyperloop, transportation of people in a pod within a low-pressure tube. Their idea was consisted in having platforms that could mount either cargo or a car, and these platforms would move along a track suspended through magnetic levitation at around 320 km/h.

In 2018 the company signed an agreement with the state of Colorado to build a test track outside of Denver, investing over $15 million in the facility. It was never constructed. Arrivo struck a deal with a Chinese company for $1 billion, this was not in direct funding, but a line of credit for Arrivo and its partners to use when building a whole transportation system. Late in 2018, when the company had about 30 employees, it had to shut down because it was unable to attract enough funding to continue (12).

Figure 7: Arrivo's concept render. Source: Arrivo

2.1.5 Hardt Hyperloop

In 2015, Elon Musk’s SpaceX announced the first Hyperloop Pod Competition, to encourage the development of functional prototypes and foster innovation by challenging students to design and build the best vehicle. The first competition was held in January of 2017, and the group of Delft University, in the Netherlands, won the award of “Best Overall Design”. Shortly after that, that same team, integrated by Mars Geuze, Sascha Lamme, Marinus van de Meijs and Tim Heuter, founded Hardt Hyperloop, one of the youngest companies working towards developing their own hyperloop system (16).

This company gained the trust of investors very early on, raising 600 000€ in their first investment round, and in just 6 months they built the first European test facility. They started setting it up in June 2017, when they built a 30m tube to test in it the systems that don’t require high-speed, such as levitation and propulsion (17). Just a few months later, Hardt Hyperloop among others, called for a 5 km test track to be built in the Netherlands, a proposal that was considered by the House of Representatives in that country, who is interested in supporting this project which may prove as a good investment for the future of the Netherlands, creating jobs and becoming the first experts in the industry. This test track could be used not only by Hardt Hyperloop but also by Hyperloop One. In December 2017 the House of Representatives approved a motion to investigate the financing of this test track.

Just one year after its foundation, Hardt hosted a second financing round in which they raised 12.5€ million from a diverse group of investors including sustainable energy companies and a football player. In May of 2018, Hardt had significantly increased the number of partners it had, adding some big names to the list such as Tata Steel and Royal IHC construction group, demonstrating the wide support it receives. Another major investment Hardt received came in December of that same year, when the group InnoEnergy invested 5 million euros in the company, as part of a larger consortium whose focus is starting the process of standardising and regulating the technology behind hyperloop.

In June 2018, Hardt Hyperloop along with other companies working in the development of hyperloop, signed an agreement to define, establish and standardise the methodology and framework to regulate hyperloop systems. The idea is to share know-how, best practices, and increase the pace in the road to achieve a real hyperloop system, guaranteeing interoperability from the start.

A year later, in June 2019, Hardt Hyperloop revealed the first European fully operating hyperloop system. The main innovation of this company is the lane switching technology, which enables vehicles to switch lanes without additional or moving components and without having to reduce speed. During the presentation of the system, the company announced the next steps of the company would include constructing the European Hyperloop Centre, equipped with a great R&D lab and a 3 km test track. In the last round of investment carried out last October, Hardt Hyperloop reached 10€ million in funding, getting closer to bringing hyperloop to Europe.

The main feature that differentiates Hardt from other companies is their lane switching technology, which, as mentioned earlier, allows switching lanes without having to slow down the vehicles, which reduces total travel time, and does not have any moving parts, which makes maintenance easy and cheap. Their levitation system consists in using two types of magnets, ones with a permanent magnetic field and electromagnets. The permanent ones have enough magnetic attraction and are stabilised by the electromagnets, making it an extremely energy efficient system, according to Hardt's website "the combination of the two types of magnets allows the technology to lift more than the weight of a car using only the amount of energy necessary to turn on a light bulb." The pod would be suspended just a few millimetres over the track, made out of steel, which makes the infrastructure not very expensive. The propulsion is made through a linear electric motor and when braking, the system restores a significant amount of energy which can be either stored or used to propel another vehicle. In their system, the pressure within the tube is also very low, and as of their last test, Hardt's vehicle does not have the aerodynamic shapes others do, although this does not mean that it will not eventually be that way.

Figure 8: Render depicting Hardt Hyperloop's vehicle used in their low speed tests. Source: Hardt Hyperloop

2.1.6 Zeleros

Zeleros is a start-up founded in Valencia, Spain, by a group of students, Daniel Orient, David Pistoni and Juan Vicén, of the Universidad Politécnica de Valencia (UPV) in November of 2016. Similarly to what happened with Hardt, the group of students and co-founders of Zeleros participated in SpaceX's design weekend in Texas and won two awards: Top Design Concept and Propulsion/Compression Subsystem Technical Excellence.

In their first year of existence, Zeleros built a 12 metre tube to carry out tests and built, in collaboration with the University of Purdue a prototype of the pod, which they presented to the August 2017 Hyperloop Pod competition and ended up within the global top 10 designs. In November 2017 they were given an award of 60.000 € from the Everis Foundation, which belongs to Everis, a Spanish consultancy company.

Consistently winning several start-up competitions and related awards, it is in 2018 when Zeleros receives major support from accelerators, venture capital companies and public funding programmes. In June of that year, Zeleros is one of the companies that signed with Hardt Hyperloop an agreement to collaborate between each other and other entities such as the European Union to define, establish and standardise the methodology and framework to regulate hyperloop systems. Regarding test tracks, in September 2018 Zeleros announced it would build theirs in Valencia, and it is expected to be finished in 2020.

As with other companies, Zeleros' pod is completely autonomous. Their technology and differentiation are based in achieving as much economic and ecologic savings as possible, with electric batteries to power the pods. Opposed to the traditional MagLev technology, which implies having electromagnets throughout the whole platform, their design consists in putting the magnets on the vehicles, so that they are attracted to the top of the tube, made of steel. This makes the pod more expensive, but it makes the overall cost per km of the infrastructure notably cheaper. However, the current estimated cost of a Zeleros Hyperloop line, calculated at 40 or 50 million euros per km, would be at least double what it costs to build a high-speed railway line in Spain, which averages at 20 million per km, so they are still working on reducing that number (18). Other initiatives to reduce cost and maximise energy savings are using aerodynamic propulsion systems, so that the system can operate in higher pressure levels which are already tested at commercial scale, and installing flexible solar panels on the tube.

Figure 9: Render of Zeleros' concept for their vehicles. Source: Zeleros

2.1.7 TransPod

TransPod was founded in October 2015 by Sebastian Gendron and Ryan Janzen in Toronto, Canada. In September 2016, TransPod presented their system at InnoTrans Rail exhibition, the largest trade show of the railway industry, in Berlin. At that fair, by unveiling the system, TransPod attracts several investors, and by November 2016 it earns $15 million in investment by Angelo, an Italian company specialised in high-tech developments for transportation systems. Other key partnerships occur in 2017 with Ikos, which will help in developing the general electrical system and safety engineering, and Liebherr Aerospace, which will help with the research, development and production of new cabin a vehicle thermal system. These partnerships build on the idea that hyperloop is a transportation mode that is a sort of hybrid between air and rail, having to accommodate technologies and standards from both industries.

By March 2017 TransPod has opened offices in France and Italy, becoming an international hyperloop company with offices in both North America and Europe. In July they publish an initial study to identify the preliminary capital costs for their hyperloop system infrastructure, not the vehicles or operating costs. The results in this study were inferred and developed from data of similar construction projects in collaboration with an architecture firm. This study claims that the infrastructure cost would be half of what the high-speed rail project estimates for a Toronto-Windsor line in Canada. A few months later, in September, TransPod released a “scientific peer-reviewed” publication at the EASD (European Association for Structural Dynamics) EURODYN conference, which presents the physics of the system.

In June 2018 TransPod was one of the companies that signed the agreement, together with Hardt and Zeleros, to advance in the development of a standard framework to regulate hyperloop in the European Union. The partnership is open to anyone who wants to join, industry executives, research institutes, regulatory bodies and governments who are willing to put in the time to discuss and develop a regulatory scheme with the pertinent authorities.

In January 2019 TransPod announced that it would be building a 3 km test track in France, where they created a subsidiary called TransPod France and moved their offices from Toulouse to Limoges. Testing is planned to start at the site in 2020. The construction of a prototype for the vehicle will be carried out in those same facilities after initial testing. This move has been supported by several new partnerships with companies such as ArcelorMittal and Electricite de France.

Figure 10: Render of TransPod's vehicle concept. Source: TransPod

The TransPod pods are built like an airline jet fuselage. They have an axial compressor at the front, to divert air flow towards the back of the vehicle, reducing air resistance. Propulsion is carried out by linear induction motors, fully electrical to reduce the fossil-fuel dependence of transportation nowadays, and uses magnetic levitation.

2.1.8 Others

Hyperloop is a very interesting project that attracts scientists, engineers and entrepreneurs from everywhere around the world. This is supported by the hundreds of people who participate every year in Elon Musk's pod contests. In fact, the teams and the universities they belong to participating in these events are a crucial component of the hyperloop ecosystem and are achieving very important milestones in pod design and speed. It is no coincidence that two of the companies explored above were founded by ex-members of teams which participated in Musk's pod competitions.

One team who has consistently won the award for fastest team is the one coming from TUM, in Munich. Last July, when the latest competition was held, their pod achieved a top speed of 463 km/h. Another university whose team has received in most competitions, including "Best Overall Design" in the last one is Delft. These universities, along with many others, play a crucial role in making hyperloop a reality.

There are other companies that are working in developing their own hyperloop system but that are still in a very early stage of the development process. One example of this is DGW Hyperloop, an Indian start-up founded in 2015, which is a subsidiary of Dinclix GroundWorks. For now, they have little more than a teaser and a proposal for a line between Mumbai and Delhi, but they are drafting and signing agreements with government agencies and private companies to carry out their research (19).

The final example is Hyper Poland, a polish company founded by yet another group of students who participated in Musk’s pod competition. They were also finalists in the global challenge proposed by Hyperloop One for possible routes, and is one of the companies who signed the agreement with Hardt, Zeleros and TransPod to work together in defining a common regulatory framework for hyperloop. They are currently building a 1:5 scale test track and expect to have a pilot project running by 2022. Hyper Poland’s project is slightly different from those described earlier; they have developed a technology for what they call “magrail system”: a passive magnetic levitation train operating on existing railway tracks. Vehicles on these tracks would reach about 400 km/h and it is a hybrid solution that allows exploiting existing infrastructure with innovative technology. However, this hybrid would evolve into a vacuum system, “hyperrail”, which would have a top speed of 600 km/h, still on the existing railway tracks. Eventually, Hyper Poland wants to develop the whole hyperloop system, including the new and necessary infrastructure for vehicles travelling at over 1000 km/h.

Besides these companies and university groups, there is a whole ecosystem growing around the concept of hyperloop, with well-established companies investing huge quantities in research and supporting these entrepreneurs. It is unlikely that all of the companies previously analysed will still exist in 15 years. However, many leaders in the aerospace and railway industries have got involved with them or are supplying companies with key materials and components for their hyperloop systems. Partners include engineering companies, manufacturers, consultancy companies, law firms, etc. There is a real and compact structure being built around a concept that does not fully exist yet, businesses are taking a huge risk, each one supporting a different hyperloop developer, betting they will win the race. It is this involvement from the part of deep-rooted incumbents that almost guarantees the success of a hyperloop system in the future.

2.2 External analysis on viability

From the analysis above it can be gathered that hyperloop is bringing up a lot of interest for the matter, that big and small companies alike are taking the risk of investing in it, as are all sorts of venture capitalists and even local and European government agencies. All of these players believe in the concept, believe that it will become a reality and that they will get a return on their investment. One of the main worries of investors and developers is that red tape may be the biggest hurdle to jump in the road to the full viability of the system. Politics, compromise and support from governments are the challenge companies must face now, more than technological issues. In fact, certification and regulation are now the main focus of some of the companies mentioned above, since the physics and technology seem to be advancing and working (20).

There are also sceptics on the matter who believe that hyperloop will never become a reality. Some of the concerns that are recurrently raised have to do with the acceleration experimented in the vehicles, which are close to the top tolerance of untrained humans, implying people who are frail may not be able to use the system, which would prove to be discriminatory (20). Accelerations within transportation systems are limited by regulation, and taking as a reference an acceleration of 1 metre per second squared, it would take 54 km of acceleration to reach the maximum speed announced by Elon Musk of 1200 km per hour, which means people would experiment that G-force for over 5 minutes, making it quite uncomfortable. These sort of considerations are refuted by representatives of the companies developing hyperloop, who affirm it will be perfectly safe for everyone, and that travelling within a tube makes it more comfortable stable than any other mode of transportation because it is not affected by weather or any kind of atmospheric conditions. Another concern is how will passengers be safely evacuated in case of emergency, to which no company has provided a full and satisfying answer for the critics. The near vacuum is also a creator of trouble for non-believers, the pressure on the tube would be very high, and a tiny crack could de-stabilise the whole structure, even causing an implosion. This also raises questions regarding safety from terrorist attacks, since such a long infrastructure would be very difficult to monitor completely. Finally, there is the question of cost, while several papers published by Musk or the companies developing the system defend a cost lower than that of a high-speed railway line, there are other, independent studies which say different, and claim the cost would be similar or even higher, such as the one published by the University of Queensland (21). Moreover, this only takes into account the construction costs, while operational costs are much more difficult to estimate with no actual experience of the system.

Carlo van de Weijer, head of the Strategic Area Smart Mobility at the Eindhoven University of Technology says that hyperloop is not flexible enough and that it does not fit into the existing transportation systems, so it will never become a reality. He states that the success of new concepts of transportation such as FlixBus or Uber lies in how well they fit into the current network: they don't need specific infrastructure to be built.

So, how viable is really this concept? How much time and money should society and private companies invest in hyperloop? Is it something that will become part of our daily lives in the near future or does it belong in science-fiction films? Many entities have tried and are still trying to provide some answers to these questions. One of these entities is SDA Bocconi School of Management, and their research centre, DEVO Lab, which offers the necessary competences and capabilities to support digital transformation through research and analysis of the most relevant subjects related to it. The objective is to help companies adapt to this trend and cope with the deep changes it implies within their organisation, processes and offering, for example by leveraging on digital technologies to simplify business strategy and operations and to reduce the time-to-market.

One relevant output of that analysis and research is the HIT Radar, a tool which allows the user to evaluate the business impact of digital technologies. It provides a clear framework to rationalise the complex technologies and their direct impact in the company for the world of decision making. It is a tool made to help in taking the decision of whether a company should invest or not in a technology, or in other words, it evaluates how likely it is for a technology to succeed in creating competitive advantage for those companies who pioneer with it.

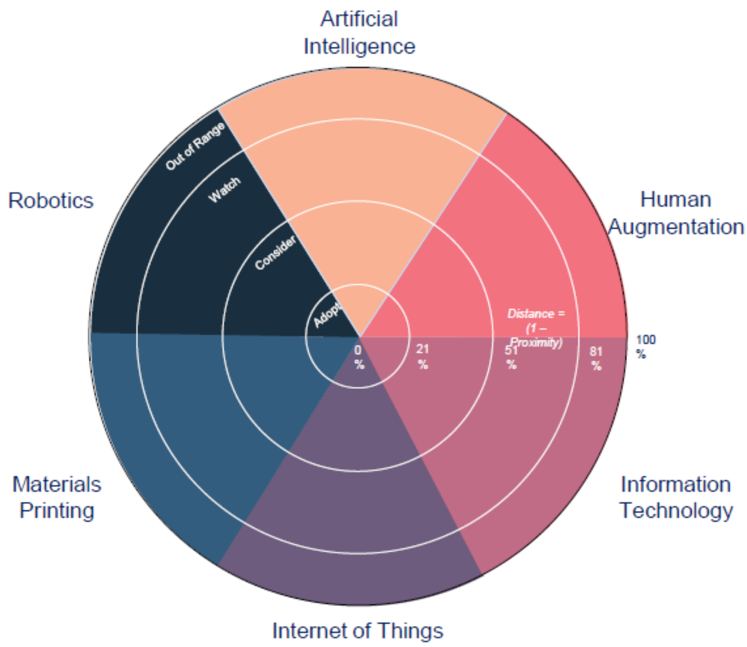

Figure 11: Radar for the technologies studied in the orginial HIT Radar study regarding digital transformation. (Source: Politecnico di Milano)

The model consists in assessing a new technology or product on three dimensions, each dimension has a series of attributes which are rated. The three dimensions and their corresponding attributes are:

- Impact: the actual impact that a given technology solution would currently have on a target profile organisation

    - Adoption: the current number of companies adopting a specific technology solution (1= innovators; 5= mainstream)
    - Economic impact: impact of a specific technology solution in terms of costs, revenues and company value (1= none; 5= disruptive)
    - Workforce: potential current impact on workforce employment following the organisational implementation of a specific technology solution (1= none; 5= radical)
    - Competitive advantage: potential impact of a specific technology solution on the company's long-term sustainability (1= none; 5= radical)
- Distance: the current ecosystem conditions that determine the feasible application of a given technology solution in the short term
    - Infrastructure Coherence: current level of fit between the context infrastructures and a specific technology solution (1= hostile; 5= perfect fit)
    - Business Model Coherence: current level of fit between the business organisation and a specific technology solution. (1= hostile; 5 = perfect fit)
    - Technology Maturity: Current market development state of a specific technology solution (1= experimental; 5= BETA Testing)
    - Skills and Knowledge: consistency of competences needed to manage properly a specific technology solution (1= no knowledge; 5 = master)
    - Regulation: current state of laws clearly regulating a specific technology solution (1= no reference; 4= well-defined regulation)
    - Legal Fit: current level of fit between existing regulations and the implementation of a given technology solution (1= hostile; 5= perfect fit)
- Dynamism: the current ecosystem dynamics that underline a future change of pace in the advancement of one or more of the impact attributes for a given technology solution.
    - Adoption Growth Rate: time span within which a given technology solution reaches the next level of the adoption life cycle (1= never; 5= 6 months)
    - Upstream Value Chain Support: trend of inputs feeding the upstream value chain of a given technology solution (1= no investment; 5= sustained development)
    - Changing regulation: current trends of change in the legislature's approach to a given technology solution (1= no change; 5= ongoing reforms)
    - Accessibility to Specialised Education: ease of access to formative opportunities to build and consolidate the skills and knowledge needed to master a given technology solution (1= none; 5= diffused knowledge)
    - Infrastructure Trends: current trends of change in the infrastructure's adequacy to host a given technology solution (1= no change; 5= sustained advancement)

- Business Model Knowledge: ease of access to information and knowledge on how to elaborate a proper business model to host a deploy a given technology solution (1 = none; 5= diffused knowledge)

After giving a score every attribute, each dimension provides a different characteristic of the result that will be plotted in the radar. Each technology is plotted with a rhomboidal icon, the score in the impact dimension determines its size (the higher the score, the bigger the icon), the distance dimension the distance to the centre of the radar (the higher the score, the closer to the centre) and the dynamism dimension the colour of the icon (red to green scale, the higher the score, the greener the icon). The coloured triangle in which the icon is positioned corresponds to the technology cluster to which each analysed new product or technology belongs to.

Applying this model to hyperloop we can analyse in an objective way how convenient it would be for a company to invest in it. This analysis is merely academic, and the scores have been given with current knowledge and intuition and they have not been contrasted with official sources.

For the impact dimension, adoption and economic impact are given a score of 1 because there is a very small number of companies currently working on developing hyperloop. However, for workforce and competitive advantage it reaches a score of 5, the maximum. This is because hyperloop is a construction-intensive technology, since it is infrastructure, and it would create many jobs both direct and indirect during the whole construction phase, which could last years. Furthermore, if the technology succeeds, it will revolutionise the world of transportation and it will prove as a source of competitive advantage to any company that adopts it or has participated in developing it. This gives hyperloop a total score of 12 out of 20 in the impact dimension, which is equivalent to a high impact, and the biggest size of icon.

Going on to the distance dimension, infrastructure coherence is given a 1, or "hostile" situation, as is the legal fit, because there is no existing infrastructure for hyperloop since it is a completely new mode of transportation and no current regulation that considers it. For the regulation attribute, the score given is "no reference", although there is some debate in this instance because many of the standards and regulations can be adapted from those of other modes of transportation (rail or plane depending on the standard), so it is possible that this attribute could be scored a 3 out of 4 for "By analogy". The skills and knowledge necessary to manage hyperloop properly are high given the complex technical mechanical characteristics of the system itself but also of the information technology that comes with it such as completely automated vehicles. Finally, the technology is in BETA testing phase, with some testing circuits built and others under construction, production of prototypes and so on. The final score for the distance attribute is 12 out of a maximum of 28. This locates hyperloop in the second most outer ring of the radar, under the tag "watch". This means that the technology has the potential to have a big impact but maybe not just yet, so it must be kept under watch so that the company is ready once the attributes for distance get a higher score.

Finally, for the attributes corresponding to the dimension of dynamism, it is considered that the next level of adoption, which would correspond to early adopters, will take place no sooner than in two years but no later than in five, which is coherent with the BETA testing phase taking into account the complexity of the technology. The upstream value chain support can be considered high, since the companies that are developing hyperloop all count with a large group of investors and companies of different industries that support the development of the technology both technically and in terms of management and regulation, which is why it receives a score of 2 in the changing regulations and infrastructure trends attributes. One of the reasons for this score is the existence of an EU Observatory for the development of hyperloop-related technologies, reports, etc. The accessibility to specialised education is rated as formalised knowledge and finally the business model knowledge as diffused knowledge because the business model that hyperloop proposes is not revolutionary, it is the one of any transportation service. The total dynamism score is 19 out of a maximum of 27, which makes hyperloop's icon completely green, according to a dynamism profile of "swoop", meaning the technology is developing quickly.

The following table summarises the scoring of each attribute and dimension.

ATTRIBUTE	**SCORE**				
Adoption	**Innovators**	Early Adopters	Early Majority	Diffusedly Adopted	Mainstream Adoption
Economic Impact	**None**	Marginal	Moderate	High	Disruptive
Workforce	None	Marginal	Moderate	High	**Radical**
Competitive Advantage	None	Marginal	Moderate	High	**Radical**
TOTAL IMPACT	**12/20**				
Infras. Coherence	**Hostile**	Unfavourable	Neutral	Enabling	Perfect Fit
BM Coherence	Hostile	Unfavourable	**Neutral**	Enabling	Perfect Fit
Technology Maturtity	Experimental	**BETA Testing**	General Availability	Mature	
Skills & Knowledge	No Knowledge	Basics	Practitioner	**Professional**	Master
Regulation	**No Reference**	Incomplete Regulation	"By Analogy"	Well-Defined Regulation	
Legal Fit	**Hostile**	Unfavourable	Neutral	Enabling	Perfect Fit
TOTAL DISTANCE	**12/28**				
Adoption Growth Rate	Never	**5 years**	2 years	1 year	6 monts
Upsteram Value Chain Support	No investment	Maintenance	Incremental Development	**Sustained Development**	
Changing Regulations	No change	**Thoughts**	Debate	Ongoing Reforms	
Accessibility to Specialised Education	None	Non-formalised knowledge	Best Practices	**Formalised Knowledge**	Diffused Knowledge
Infrastructure Trends	No change	**Debate**	Limited Advancement	Sustained Advancement	

Business Model Knowledge	None	Non-formalised knowledge	Best Practices	Formalised Knowledge	**Diffused Knowledge**
TOTAL DYNAMISM	**19/27**				

Figure 12: Scoring of attributes in the HIT radar for hyperloop. (Source: own production)

After scoring each attribute, hyperloop can be located under a cluster corresponding to technologies related to infrastructure, with a large icon due to the large impact it is expected to have in society; coloured in green due to the fast development of the system, both in technology and other issues surrounding it; and located in the outer shell of the watch category because the legal framework that will regulate the system is still non-existent and its form and extent is still unknown and fairly unpredictable.

The image below represents the results of this analysis in the graphic form established by this method, imitating a radar.

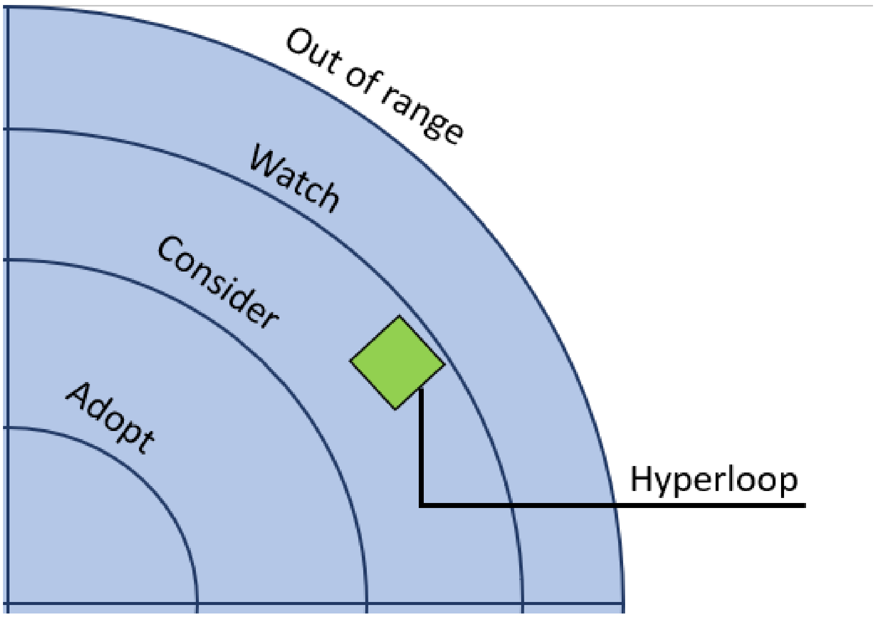

Figure 13: Positioning of hyperloop in the HIT Radar. Source: Own production

These results contrast with the reality of the amount of money being invested in this technology and also with harsh critics' position that it will never succeed. It is more aligned with cautious believers who think it will eventually happen but that it is still in a very early phase of development. It is important to note that the aspect that drives hyperloop towards the outer layer of the circle is how frail, if not completely inexistent, the regulatory and legal framework is. What this shows is that the output of this analysis concurs with the expert opinion of the people in charge of the development of hyperloop that red tape is the biggest problem the system faces.

3. RESEARCH APPROACH

The concept of hyperloop is a conglomerate of complex physical, technological, economic and regulatory characteristics. The current development of the system shows that there has been a lot of time and effort put in studying the first two, and that many advances have been made in that regard. An example of this are the over ninety patents registered to just two of the previously analysed companies, all of which are related to the technology or operability of the system.

However, it has become clear that there is another growing concern in the world of hyperloop, precisely because it is becoming clear that it is physically and technologically viable, which is building a regulatory framework that will allow exploiting the system commercially for freight, and, especially, passengers. Several companies have signed an agreement with the European Union to study this matter, and other are working independently on certification.

Hyperloop is a revolutionary concept, and it will surely have to have specific regulation drafted to administer and control it, especially when it comes to technical specifications. Nevertheless, it is also a mode of mass transportation, and therefore should be subject to certain rules that every other mode is also under regarding market characteristics, which is the subject under study in this thesis. Hyperloop has been described by Elon Musk as a “cross between a Concorde and a railgun and a hockey table” (22), the last part referring to his original design of having the vehicles suspended on air cushions, which has been dismissed by all of the companies developing the system in favour of magnetic levitation. However, the other two components of the comparison do concur with the current idea of what hyperloop is: a guided system travelling in a low-pressure environment at velocities close to the speed of sound. In short: hyperloop is a hybrid between air and rail travel.

Given this premise, it makes sense to assume that the regulatory framework for hyperloop will also be a hybrid between the one for air and the one for rail travel. It is reasonable to presume that the people in charge of drafting this regulation will use the existing documents regarding those two modes of transportation as inspiration and to make sure it is consistent with the existing rules. The rules and directives regulating hyperloop will be analogous to those of air transportation regarding the characteristics which are similar between both modes, and the same goes for rail. Not in all countries the laws regulating air and rail market characteristics are different, for example in the US and Canada there is only one standard for both. However, in the European Union (EU), which is the focus of this paper, there are different laws regarding air and rail, mainly because air travel became an open market much earlier than rail did, which is still a state-owned monopoly in several Member States.

Firstly, lets analyse which are the characteristics of hyperloop that make it similar to air travel: those would be the speed of the vehicles and the low-pressure environment. This suggests that the air transportation regulation will inspire safety and technical rules for hyperloop, for example regarding protocols in case of de-pressurisation of the cabin or the g-force experimented by passengers. These matters fall under physical and technical issues which are not the focus of this paper.

Secondly, the characteristics which make hyperloop similar to rail travel are the fact that it is a guided mode of transportation which needs specific infrastructure along the whole route it covers, the way passengers use (board, travel and disembark) it and its general appearance. Moreover, it is important to note that hyperloop was set out to substitute high-speed rail from its conception. All of these matters, especially the way it is intended to be used by passengers, suggest that the laws regulating market characteristics will be drawn out from the ones that nowadays govern the railways. Therefore, studying the current railway regulation in the EU will shed some light on the characteristics of the future hyperloop one, which will likely have many analogue articles in it. This assumption is even more firmly upheld by the fact that EU regulation regarding railways recently changed to transition towards a full open market and achieve a Single European Railway Area, where interoperability is pervasive, and competition promoted. All of the hyperloop stakeholders assume and want this kind of market for hyperloop in the EU, proven by the agreement between different companies and the investment made by the European Commission in research facilities in the Netherlands (23).

Given this hypothesis, analysing railway regulation can be very useful for hyperloop developers, to be ready and close to full compliance with the law by the time it comes into force. It can also be very useful for partners such as construction companies looking to build infrastructure, service companies looking to offer operational assistance and local governments looking to manage and attract investment in a hyperloop route in the area. The research approach is to analyse the current railway market regulation and extract those issues that are directly applicable to a potential hyperloop market in the future given what it known today of the technology and operational characteristics, described in the State of the Art section of this document.

Summarising, one of the main tests that hyperloop faces nowadays is no longer related to technological challenges, but with the fit within society and the market, more specifically, building an effective regulatory framework to support it. Not only developing it, but doing so at the same time as mechanical tests and advancements are made so that when the system is technically operational, the legal and market structure is ready to accommodate it too. Since hyperloop can be described as a hybrid between air and rail travel, it only makes sense to expect that its regulation will have similarities.

Regarding market characteristics, hyperloop is more comparable to rail than air for several reasons. The first one is how passengers use the system, not only because the appearance is similar and passengers board a train-like vehicle at a station, also because it is designed to be used for distances between 500 and 1500 km, where high-speed rail is the preferred mode of mass transportation when available. Secondly, since they are both guided systems, hyperloop and rail require specific infrastructure to be built along the whole route, from the platform to electrical substations to signalling systems, all of which are equally important and manufactured and operated by different players. This is directly connected with the third point, which is that precisely because of the aforementioned characteristics, the operational intricacies of both systems are similar. Finally, all hyperloop companies envisage their systems completely inserted in the existing transport network, introducing terminals in intermodal stations, promoting connections with other modes of transportation from air to metro, which is analogue to how railways work and are integrated in the network. Moreover, the EU is considering hyperloop routes to support and complete the TEN-T network, substituting high-speed rail (23).

All of this backs up the idea of analysing current EU railway market regulation in order to surmise how hyperloop will be regulated in the future. Specifically, the documents that will be studied are the ones dubbed “Fourth Railway Package”, published in 2016, which set the general rules in the European Union for an open railway market.

4. RESEARCH

The Fourth Railway Package is a set of six directives and regulations emitted in 2016 by the European Commission with the ultimate goal of opening the rail market to competition in every country of the European Union and creating the Single European Railway Area. It is made up of 6 texts, divided in two groups of three or 'pillars'; the first one deals with the technical aspects of infrastructure and rolling stock and the second pillar tackles the market side of the issue.

To reach a Single European Railway Area, the technical pillar deals with standardisation and safety certification issues. The market pillar deals with the entrance of new players and the obligation of offering passenger service contracts through tenders. This implies the access of entrants to infrastructure and a greater control in the governance and funding of their managers.

Figure 14: The Fourth Railway Package. Source: Own production

The Fourth Railway Package has four main aims, according to the European Commission.

Firstly, setting "standards and approvals that work". This is related to reducing the administrative tasks and therefore costs for rail companies and to make it easier for new operators to enter the market. This will be achieved by creating a European Railway Agency, a one-stop-shop for vehicle authorisations and safety certificates valid across the whole EU territory, instead of having to get one form each country the operator works in (24).

Secondly, having a "structure that delivers". The changes from the previous regulation further separates the roles of infrastructure managers and train operators, extending the role of the former, reinforcing the operational and financial independence from the latter. Some new responsibilities for the infrastructure managers include planning, timetabling and managing daily operations and maintenance (24).

Thirdly, “opening domestic passenger markets”. Up until the publishing of the fourth railway package, domestic routes were not necessarily open to competition. With these directives, all public rail service contracts will have to be offered through competitive tendering in all of EU territory. Besides this, from December 2019 onwards, new entrants may offer competing services and bid for public contracts (24).

Finally, “maintaining a skilled rail workforce”. The package also considers the importance of having skilled workers and proposes measures to protect those workers when public service contracts change to a new company (24).

Member States have to transpose these documents into national law, and were given until June 2019 to do so, with the possibility of asking for an extension of one year if necessary.

4.1 BACKGROUND

The European Union has issued directives establishing general rules for the rail markets in the whole territory and Member States specifically since the early years of the Union, but it is not until the first railway package of 2001 when the term "single European railway area" makes an appearance. This first package enabled operators to have access to the trans-European network on a non-discriminatory basis, opening up the market for competition, since in many Member States the whole rail system was still a monopoly at the time. Focused on freight transportation, it proposes setting up freeways by establishing a new tariff structure and reducing the time spent at borders. To achieve this, the Commission makes a list of the actions necessary to achieve it. Five years after the implementation of this package, the European Commission conducted an assessment to gather if its effects were positive, as expected, and discovered that that was the case. The fall in railway usage had been staunched, the safety level had been improved in many cases and the reduction in the number of jobs due to competition had been offset by the ones created by new entrants. Moreover, the performance of the freight railway sector had improved overall, but significantly more in those countries that had adopted the regulation earlier and even more in those that had new railway undertakings operating as leaders in the market (25).

Just three years after the first railway package, in 2004 the European Commission proposed a new set of measures which they called the second railway package, which had the objective of revitalising the railways through the swift construction of an integrated European railway area. The measures follow the same line as the first package of achieving higher safety and interoperability levels, as well as fully opening the freight market to competition. It is in this package when the first mention to a European Railway Agency is made, which would be in charge of providing technical support. This package achieves the full opening of the rail freight market to competition, in effect since January 2007 and creates the European Railway Agency, which establishes common procedures in matters of accidents investigation and creates Safety Authorities in each Member State.

The next step was taken three years later, in 2007, with the publication of the third railway package, which again aimed at revitalising the railways and advancing in opening the market to competition. This package launched open access rights for international rail passenger services, the first step towards the whole liberalisation of the market. Moreover, it created a European driver licence which allowed train drivers to operate trains across the whole territory, another step towards having a single European railway area.

It is not until almost ten years later, in 2016, when the fourth railway package in presented by the European Commission, which foresees the complete opening of the railway market, not only for freight or international services, but also for domestic ones inside each Member State.

Figure 15: Timeline of the liberalisation of the EU rail market. Source: Own production

Before the entry into force of the Fourth Railway Package, the European rail network was very fragmented, in the sense that each Member State had different standards in everything from rail width to safety to signalling systems. This meant, firstly, that cross-border services were very complex to get running, not only because of the technical challenges but also because of red tape and secondly, that it was very difficult for new entrants to penetrate the market. The different rail packages published by the European Commission have tried to gradually eliminate the barriers, until this last one, which means to achieve the establishment of a single rail area. Besides this, it also promotes a more competitive rail sector, which will be more attractive for passengers. By increasing the number of passengers which choose rail instead of road or air travel, the emissions created by the transportation sector will be reduced, which is aligned with the EU's compromise outlined in the 2011 Transport White Paper, along with other objectives such as developing the TEN-T network or increasing energy efficiency Union-wide.

4.2 REGULATION SUMMARY

4.2.1 Technical pillar

The first three documents of the 4th Railway Package are the ones in the so-called technical pillar. The first of these three documents deals with the European Union Agency for Railways, the second with interoperability of the railway system within the European Union and the final one with railway safety. Its objective is, as with the rest of the package, to make it easier for players to operate in the European Union as if in one country, thus achieving the Single European Railway Area. It deals mainly with interoperability through the application of a standardised signalling system throughout the member states and it widens the responsibility and tasks assigned to the European Railway Agency. This legislation states that the European Railway Agency will be the body in charge of issuing safety certifications for railway operators and authorisation for rolling stock manufacturers when either of them intend to operate in more than one member state instead of having to go through the same process in each country. This will mean savings for operators, manufacturers and member states in terms of money and time.

Altogether, the technical pillar aims at easing cross border traffic and harmonising the Member States' networks by remarkably reducing the number of national rules and laws, which are over 10,000 and which the European Commission thinks are one of the main hurdles in the road to complete interoperability.

The first document, Regulation 2016/796, makes the European Union Agency for Railways the only responsible entity in charge of issuing authorisations for railway vehicles, certificates for train operators and authorisations for trackside systems (control-command and signalling), instead of having one per country, becoming the coordinator in the development of ERTMS. This reduces the number of procedures needed to operate in the EU, which induces also a decrease in costs for operators, undertakings and the administration. This Agency also has the role of supervisor of the National Safety Authorities of each Member State and of the rules and laws installed in them. These changes are quite deep and require work to transition to the new paradigm, which has been carried out in the last three years in all Member States, with conversations between governments, agencies and other stakeholders (26). As an example, it was as soon as June 2017 when the Implementing Act for the Single European Safety Certificate was approved. One of the key issues of the new system of the Single European Railway Area (SERA) is the one-stop shop for all safety certificates and vehicle authorisations, which is an online portal which manages all of such applications, which is working since June 2019. The executive directive of the European Railway Agency stated that "In the short-term, the transition clearly requires investment from all actors, but in the long-term, everyone benefits from a process that is simpler, faster, and consistent throughout Europe" (26).

The new paradigm means every player in the ecosystem will have to undergo changes and adapt and go through a period of uncertainty while the dust settles, especially since only nine out of the twenty-six countries have transposed the legislation by now, and the rest will do it by June 2020. The only document that did not need transposition to national legislation in the regulation expanding the role of the European Union Agency for Railways, explained above. This means that for the period of a year, there are some Member States that are not fully integrated in the SERA, while others are (27). Another important issue is that there is a huge variety in stakeholder preparedness, since some of them have been part of the railway ecosystem for decades while other smaller ones have little experience and notion of how much the market will change when the Fourth Railway Package comes into effect.

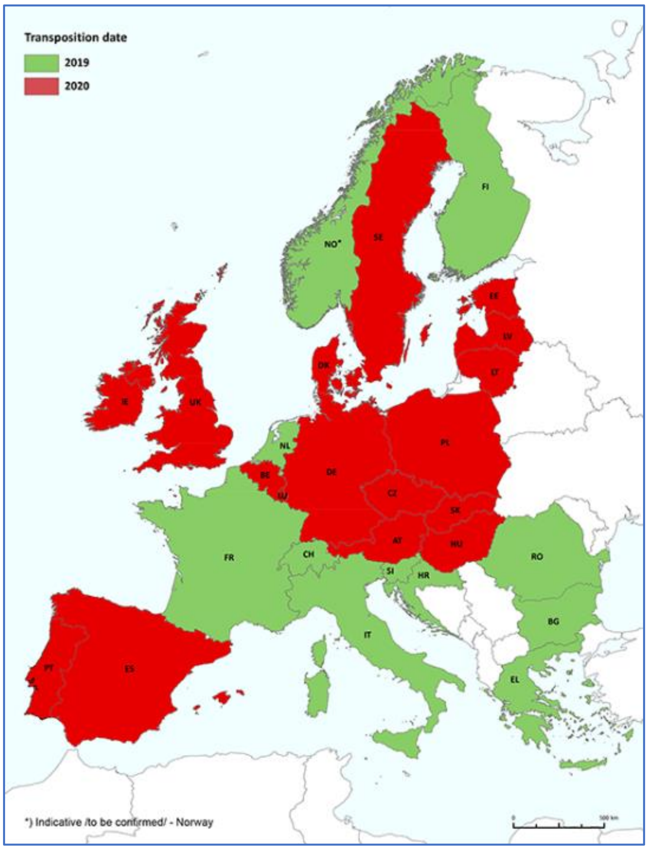

Figure 16: EU countries according to the transposition date. Souce: Rail Sistem

The second document in the technical pillar, Regulation 2016/797, deals with interoperability. One of the main novelties is the authorisation of ERTMS trackside equipment by the agency, a totally new procedure. This means, again, many changes have had to be implemented and a lot of work put into developing the certification process. All changes that have been implemented have implied a cost in developing processes, establishing new agencies and protocols. However, in the medium term, this investment will mean lower costs for all stakeholders.

This part of the package was adopted officially in April 2016, and preview implementation in a maximum of three years, with an extension of one in exceptional cases, which means it should be the current rule in most of EU territory.

4.2.2 Market Pillar

The second pillar, dealing with the market dimension of the package, is also made of three documents, two amendments of previous regulation and one repeal. The first concerns the opening of the market for domestic passenger transport services by rail, the second one deals with the establishment of a single European railway area and the final one repeals regulation regarding the common rules for the normalisation of the accounts of railway undertakings. The overarching goal of this regulation is to liberalise domestic railway markets in all of the European Union because the Commission believes competition brings "substantial benefits for passengers, railway undertakings and taxpayers alike: more quality of service, greater choice, innovation, cost-effectiveness and customer-orientation" (26).

The first document of the market pillar, which concerns the award of public service contracts for domestic passenger transport services by rail, was written to allow some flexibility for Member States on how to proceed when assigning public service obligation contracts. The European Commission will still allow direct awards under certain circumstances and with very strict service quality, frequency and capacity requirements. However, there will be a 10-year transition period for the entry into force of the new rules in on contracts awarded before December 2022. Regarding new entrants, they will be able to compete with the incumbent service operator from December 2020, after considering the economic impact on public service obligations.

While the technical pillar included many conversations, it was not nearly as controversial as the market pillar, which induced a lot of debate between the European Commission and the Member States, especially over the second document of the pillar, which deals with the opening of the market and the governance of the railway infrastructure. One of the main conflicts that arose was that the European Commission wanted to make the unbundling of incumbent train operators and infrastructure managers compulsory, and even took 13 Member States in 2010 to court for not fully complying. However, the court found that this separation was sufficient even if both entities are under the same holding company. This ruling has greatly influenced the Fourth Railway Package, which allows a great degree of flexibility in the choice of governance model, including the integrated holding company one. This part of the regulation causes concern among would-be new entrants, since it makes it more difficult for them to succeed, they believe that if the incumbent will be favoured over new entrants if the infrastructure manager is in the same holding company as the former and that may even be enough to discard the opportunity of entering a new market entirely. The origin of this conflict is in the fact that many important railway markets in European Union still worked as a state-owned monopoly, and since the unbundling allowed having infrastructure managers and operators to belong to the same holding company, it could clearly imply the manager has reason to favour the incumbent operator.

However, the package includes many provisions that guarantees new entrants will have the same opportunities and will receive the same treatment as the incumbents do, even if the infrastructure manager and the service operator belong to the same holding company. In fact, Article 56 of the directive (Functions of the regulatory body) states that applicants (potential new operators) have the right to appeal to the regulatory body if they believe there is any discrimination against them and that the regulatory body has the power to audit the competitive situation of the domestic railway markets, and "shall verify compliance…on its own initiative and with a view to preventing discrimination against applicants. It shall, in particular, check whether the network statement contains discriminatory clauses or creates discretionary powers for the infrastructure manager that may be used to discriminate applicants". (28)

Therefore, the key issue is that the regulatory bodies have in place mechanisms to monitor and guarantee fair play for all applicants, which they have been doing from the start, having issued several fines to Member States who were failing to comply with EU competition law. The responsibility for this control falls to the European Commission's Directorate for Competition, which deals with all issues regarding competition in any area. Liberalising the rail sector has been and still is a very complicated matter, which is encountering many problems along the way, reducing the power of incumbents has proved to be more than challenging, and especially with the holding company structure allowed, there needs to be other levers beside regulation to fully achieve the opening of the rail market.

The Fourth Railway package counts with complementary documents that complete the legislative framework and ease the transition to the new paradigm, they build on articles of the regulation to provide specific policies on how to carry out the provisions in the law. One of these documents eases the access of new entrants to Service Facilities, ensuring they do so in a fair and non-discriminatory way; the second one deals with the allocation process, timetables, scheduling and capacity restrictions, allowing infrastructure managers and customers to have a closer coordination; the final document is an act on the Economic Equilibrium Test (EET), which defines the conditions under which Member States can restrain access to infrastructure if it considers that imposing an open-access service may be detrimental for the economic balance of a public service obligation contract.

This last act has raised concerns among potential new entrants, they believe it opens a door for Member States to block the entry of competition in their domestic markets, especially in cases where the level of service the public service obligation contact offers is very high. This means that new entrants may decide not to even try to enter the market, which would make all the effort made to open it useless. However, the use of EET to award public service contacts will only be allowed until 2034 (26).

The great debate, arising from how differently the different players view the package and their opposing interests, shows how difficult it is to create a legislative framework that everyone considers fair. The regulation of the market and the system has a great impact on how it works, and therefore on all the stakeholders within it, from government agencies to manufacturers to private operators. In case of the rail market, this comes on top of the fact that there was already an existing system that has been built over the last one hundred and fifty years, and this is one of the most radical changes it will endure. Incumbents in many countries have managed infrastructure and operated services since the rail started functioning in their territory, and the strict separation between those to entities is going to take time, effort and willingness from parties which are, by definition, against the new paradigm.

This conflict is just another shape of the same dilemma of efficiency and innovation against tradition and bureaucracy. While the former are good for profitability of new entrants and dynamism of the market, without the latter there is a risk of losing control and worsening of the service offered, besides the fact that the incumbents are part of the establishment and have huge power. The key is to achieve an equilibrium and find a governance model that will not limit the capacity of new entrants to thrive and achieve an efficient and innovative railway market in all EU territory.

Another very important issue which arises with the change of regulation is passenger rights, which have also been amended to adapt to the new situation. Customers have to be protected from abusive practices while maintaining a good situation for train operators as well. With the system prior to the Fourth Railway Package, the European Commission considered that passengers could not exercise their rights to their full extent and that many provisions were obsolete, especially those regarding persons with reduced mobility, as well as different issues with through-ticketing. The new regulation, however, has a clause which allows operators not to compensate passengers due to delays in case of natural disasters or extreme weather, which until now was included in the law. New Article 13a states that by 2022 a through ticketing service will have to be operational, and there are provisions in the law which make it compulsory for Member States to have a system which allows passengers to buy tickets from any operator on the same platform in a fair and non-discriminatory way. The new directive also considers that the ticketing systems should promote door-to-door mobility through intermodality. If the open market is to work and succeed, it is essential that it has a well-functioning ticketing system and that all operators have representation in it. To achieve this, there has to be coordination between infrastructure managers, governments and operators.

From 2019 onwards, the European Commission intends to continue its work to improve and achieve total interoperability and digitalisation of services and networks, for example by further developing and implementing ERTMS. When all Member States have transposed and are under the Fourth Railway Package in its entirety, the Single European Railway Area will exist formally and in time, an array of public and private companies will shape a borderless system.

4.3 REGULATION ANALYSIS AND APPLICABILITY TO HYPERLOOP

All hyperloop initiatives are eminently private, but the service they mean to offer will likely be considered of general interest for the public and therefore a public service. This means it has to follow certain standards and is subject to laws which go further than those regulating a normal private company. Following the reasoning made in the Research Approach section of this document, it is interesting to analyse this regulation more deeply, stopping at certain articles and provisions which can be applied to a homologous regulation of a similar functioning system. Since the hyperloop market will start from zero in today's world, it is safe to assume that it will be an open market from the start, so all of the provisions that deal with the transition from the earlier model do not apply. However, those that control the doings of the liberalised one do. Although this regulation has a very important component of changing an existing system, which had public companies controlling infrastructure with a monopoly in operating them in many cases and a potential future infrastructure will likely be built as a private infrastructure, in order to be as profitable as possible, it is likely that the companies operating in the European Union will offer their infrastructure to other operators. This statement is supported by the fact that there is already a group of companies working together with the European Commission to set common standards and ensure interoperability.

The following will be an analysis of each of these documents, with a focus on novelties and on the components that, with the appropriate modifications, can be considered likely shape a potential future regulation on a *Single European Hyperloop Area.*

Regulation (EU) 2016/2337

This regulation is a very short document, which is just published to repeal Regulation (EEC) No 1192/69 on common rules for the normalisation of the accounts of railway undertakings. The regulation that is repealed allowed "Member States to compensate 40 enumerated railway undertakings for the payment of obligations which undertakings of other transport modes do not have to support." Basically, it meant that Member States could give aid to these undertakings without proper notification. By annulling this regulation, the market is more transparent and fair, since those 40 undertakings have no privilege whatsoever over other companies.

As regards the applicability to hyperloop, the only relevance could be that developing the kind of market that is being banished will probably not be a possibility and that a purely competitive market is the most likely future scenario.

Regulation (EU) 2016/2338

The second document of the market pillar of the fourth railway package is Regulation (EU) 2016/2338 of the European Parliament and the Council, which amends Regulation (EC) No 1370/2007 concerning the opening of the market for domestic passenger transport services by rail. The amended regulation deals with public passenger transport services by rail and by road, so it is not unthinkable that it may be amended in the future to include a new mode of transportation: hyperloop.

One of the motivations for the recast of the directive is stated in the amendment: "Rail transport…sustainable transport and mobility system, creating new investment opportunities and jobs." Hyperloop is all of those things, which implies that if the European Commission is to be consistent, it should support the development of this new mode of transportation, and companies can lever on that. One of the main objectives of this regulation is to "enhance the quality, transparency, efficiency and performance of public passenger transport services by rail", which means that the standards set in it will probably be the ones applicable to hyperloop as well. This document deals with the award of public service contracts, which may eventually be relevant for a hyperloop system. This regulation establishes that public service contracts should be awarded through a competitive tendering procedure open to all operators and has the objective of increasing competition in the railway market.

Firstly, it is important to clarify that a hyperloop service can qualify for a public service contract, should the competent authority consider it a service of general interest to the public and require it to have higher standards that those the private company is willing to provide without incentives. The second article of the regulation defines public passenger transport as "passenger transport services of general economic interest provided to the public on a non-discriminatory and continuous basis", which does not exclude hyperloop at all (29). When a specific service is considered of general economic interest, it is the competent authority the one who specifies the obligations of the public service, which should "be consistent with the policy objectives stated in public transport policy documents".

This regulation sets the rules that Member States have to follow when offering a public service contract to an operator, the information that has to be communicated and clearly states that the whole process should be transparent and non-discriminatory. Article 5 explains in detail the procedure of awarding a public contract, which includes competent authorities communicating their intent of offering such a contract and providing the necessary information for applicants to draft a proposal, the timeline of the whole process and so on. It also provides information on the cases when the contract is awarded directly, under which circumstances it is acceptable and for how long. This is defined very finely so that the cases which allow direct award are clearly outlined and this option cannot be overexploited by competent authorities, since the objective of this regulation is to promote competition.

An article which has been added in this package is Article 5a, which states that, to ensure a fair and non-discriminatory treatment of all applicants to a public contract, access to suitable rolling-stock should be ensured, and defines how that can be done. This can be relevant because in case a hyperloop service is ever under these conditions, the case will probably be the same regarding pods.

Of course, all public service contracts are compensated by the competent authorities, and the manner and amount of compensation is determined when the public contract is offered and maybe during negotiations in the tendering procedure. The rules for compensation are specified in the annex, which has a formula to calculate it, basically costs incurred in the provision of the service minus any positive financial effect generated within the network, minus receipts from tariff or other revenues generated plus a reasonable profit. Reasonable profit is defined as “a rate of return on capital that is normal for the sector in a given Member State and that takes account of the risk, or absence of risk, incurred by the public service operator by virtue of public authority intervention.” Should any competent authority every offer a public service contract for a hyperloop line, this is the likely compensation scheme it will have.

The final part of the document deals with the transition from the previous way of working to this one, which is irrelevant since hyperloop will start from zero and therefore will not have a transition period.

It has interest for hyperloop developers if their objective is to offer services of general interest, such as commutes between city centres and airports, which include several projects under study including the case study in this paper.

Directive 2016/2370

The last document of the market pillar of the fourth railway package is Directive 2016/2370 of the European Parliament and the Council, which amends Directive 2012/34 as regards the opening of the market for domestic passenger transport services by rail and the governance of the railway infrastructure. It was emitted to achieve a complete opening of the railway market.

The 2012 directive establishes a set of “common rules on the governance of railway undertakings and infrastructure managers, on infrastructure financing and charging, on conditions of access to railway infrastructure and services and on regulatory oversight of the rail market” (28) but didn’t consider domestic passenger services, which were not liberalised until later, when the amendment was published. This document is extremely interesting because many of those rules and standards are very generic and are easily transposable to a different mode of transportation, especially when talking about a guided system which requires specific and exclusive infrastructure.

The preamble sets a few issues that must be taken for granted when applying the articles within the directives. One of the first is number 5, which states that while a “line is in operation, the infrastructure manager should ensure in particular that the infrastructure is suitable for its designated use”. This may seem obvious, but it is important to note that the infrastructure manager is in charge of the infrastructure, whether the entity commissioned or oversaw its construction or not. In fact, just two paragraphs later, the following is stated “This Directive introduces further requirements to ensure the independence of the infrastructure manager”, from service operators mainly, and that all infrastructure managers are “subject to appropriate safeguards to ensure the impartiality of the infrastructure manager as regards the essential functions, traffic management and maintenance planning”. Another very relevant phrase in the preamble regarding this issue is the following: “Decision-making by infrastructure managers with respect to train path allocation and decision-making with respect to infrastructure charging are essential functions that are vital for ensuring equitable and non-discriminatory access to rail infrastructure". This is critical for a future hyperloop infrastructure and service since it is unlikely that the EU will allow a single company to manage the infrastructure and operate it on its own, every company building infrastructure will likely be forced by European competition regulation to 'rent it' to other operators. All of this is supported by the fact that the recast directive has the definition of 'infrastructure manager' changed in point 2 of Article 3, the key variation being that an infrastructure is responsible for operating and maintaining it, as well as participating in developing it, but not for establishing it anymore.

A relevant provision in this directive that also has to do with the collaboration and relationship between different operators and infrastructure managers has to do with ticketing. In the Fourth Railway Package, as it has been explained earlier, it is considered of utmost importance to have an effective through-ticketing system so that passengers can choose whichever service they prefer and in which operators have a fair and non-discriminatory treatment. What this implies is a need for communication between all interested parties and also the need to ensure confidentiality of commercial information.

Finally, some provisions that can be directly applied to a future hyperloop infrastructure even though they refer to rail in this case are the ones regarding certification of staff, machinery, vehicles, incident reporting and so on. This is not only because it is a transportation service, but because of its similarity to rail in needing specific infrastructure and trained staff to manage and operate it.

Once within the articles, dismissing the first three which deal with subject matter, scope and definitions, it is not until Article 5 when there are interesting statements laid out, in the sense that they could be transferred to a hyperloop situation. This article states that "railway undertakings shall be managed according to the principles which apply to commercial companies", which is important because it implies that a commercial company such as the ones developing hyperloop can operate passenger services under this regulation. This article establishes a wide freedom for undertakings to manage themselves operationally and financially and lets them "control the supply and marketing of services and fix the pricing thereof".

The next section of the directive, comprising Articles 6 and 7 is very interesting in that it regulates the Separation of infrastructure management and transport operations and of different types of transport operations. If it is assumed that hyperloop will be regulated by an analogous set of directives, this is one of the key points for developers to understand since it is potentially very beneficial for them and for the success of the system. By taking advantage of this framework, different hyperloop companies can develop synergies with each other and take advantage of each other's infrastructure. Article 6 says "Member states shall ensure that separate profit and loss accounts and balance sheets are kept and published, on the one hand, for business relating to the provision of services by railway undertakings, and on the other, for business relating to the management of railway infrastructure." This is quite straight forward and implies that companies will have to have a structural separation between the provider of services and the infrastructure manager, even if they are under the same holding company, which is allowed, as has been mentioned in the earlier section of this document. Article 7 exposes different measures and rules companies have to follow to guarantee the separation between managers and operators, in their internal structure and in particular decision making situations such as traffic management and maintenance planning as well as financially, in cases when they are part of separate companies and also in case of vertically integrated infrastructure managers. It is likely that a future hyperloop network will count with both cases. An addition that the Fourth Railway Package does to Article 7 concerns the European Network of Infrastructure Managers, an association meant to incentivise cooperation between infrastructure managers within the EU to support the development of infrastructure, share best practices, benchmark performance and tackle issues such as cross-border bottlenecks. It is interesting that something of the sort is already in play with hyperloop, in the shape of an agreement between the European Commission and several European and non-European hyperloop companies.

The following section of the directive deals with financing, and while the current European rail network relies heavily on State funds, a hyperloop one will not because of the nature of the system and how it is being developed. Therefore, there is little information of interest in this section.

Section four deals with access to railway infrastructure and services and contains two of the most changed articles of the recast directive, which regulate the conditions and limitation of access to railway infrastructure by service operators. This is of course of importance for a hyperloop network if their future regulation follows these guidelines. The first two paragraphs of Article 10 state that "railway undertakings shall be granted, under equitable, non-discriminatory and transparent conditions, the right of access to railway infrastructure in all Member States for the purpose of operating rail freight/passenger services". This is very clear and straight-forward and implies that once the infrastructure is built and operative, it can be accessed by any operator. Article 11 states the cases when access to infrastructure can be limited, which as explained earlier can be done for a limited amount of years if it can be justified that the access of a new entrant to the infrastructure can compromise "the economic equilibrium of a public service contract". It is not assured that this kind of provisions will be part of a future hyperloop regulatory framework, but it is likely that it will be, so that the European Commission remains consistent and because the general trend of any market is towards competitiveness. As it has happened in the case of rail, it will likely be the cause of many disagreements between the regulatory bodies and the infrastructure and service developers. The conditions on the access to services is regulated by Article 13 of the directive and it basically ensures the fair and non-discriminatory access to infrastructure in order to supply a service. It sets rules on the services which infrastructure managers have to offer to railway undertakings when the latter is going to offer a service on their infrastructure, which services have to be offered, how to ask for them and so on. The services to be supplied are listed in Annex II of the directive and they include basic provisions such as "handling of requests for railway infrastructure capacity", "the right to use the capacity which is granted" and others more elaborate such as "tailor-made contracts for control of transport of passenger goods". It is relevant to mention this article because future infrastructure managers have the opportunity to prepare for the compliance to it even before the infrastructure is built, which gives the hyperloop ecosystem a huge advantage in terms of administrative costs and time spent in negotiation. An addition of the Fourth Railway Package to this article deals with ticketing systems and how undertakings should "participate in a common information and integrated ticketing scheme for the supply of tickets, through-ticketing and reservations." Again, taking into account articles such as this can give hyperloop developers an idea of how the future system will be regulated and gives them the chance to develop an information system which is likely to be compliant with a regulation that does not exist yet, avoiding having to change it radically or develop it in a very short timeline once the actual rules are published.

Earlier in the document, the power of the European Commission in controlling passenger services was mentioned, and one of the embodiments of this lies in Article 15, which outlines the scope of the market monitoring done by it. This scope includes the monitoring of the development of the railway sector and its use (infrastructure charging, capacity allocation, etc.) in order to be able to propose new regulation, implement barriers and other actions with the goal of having a better network in every sense. It is extremely likely that something of the sort will be applied to hyperloop as well.

The next set of articles deals with the licensing of railway undertakings, which is very relevant for hyperloop as well, as any company will have to be licensed by the competent authority to operate any kind of service but especially passenger ones. The directive states that the authority which issues the licenses "shall not provide rail transport services itself and shall be independent of firms or entities that do so.", which will be the case with hyperloop as well. The main points to be taken out from this section are that licences don't entitle the holder to access the infrastructure, but to ask for that access and that there are conditions that have to be met in order to be granted a licence relating to good repute, financial fitness, professional competence and cover for civil liability. As in the earlier cases, being aware of such provisions can be very useful for companies developing hyperloop in order to prepare to comply with them early. Licences are valid in the whole territory for rail, and it is likely that this will be the case with hyperloop (at least partially) and are subject to regular revision in order to check if the licensee keeps fulfilling the obligations required to obtain it. This section also describes the procedure for granting licences, which will very likely be homologous to the one for hyperloop in the future.

The next chapter of the directive is very interesting in the case that hyperloop infrastructure will be accessed by more than one operator because it deals with the levying of charged for the use of railway infrastructure and allocation of capacity. Firstly, in order to offer the use of infrastructure, the manager will have to publish a network statement which sets out the nature of the infrastructure being offered and containing information “setting out the conditions for access to service facilities”. Infrastructure managers and service operators will then have to sign an agreement. The charging framework for the use of the infrastructure will be determined by Member States, but it will be the infrastructure managers the ones running the collection of the charges and applying the scheme in a fair and non-discriminatory way. Member States will encourage an efficient use of the infrastructure as well as projects to improve the quality of the infrastructure. The charges imposed to the undertakings depend on the cost of providing access to the infrastructure “plus a reasonable profit” and there can also be charges for environmental cost. This last issue can be a lever for hyperloop when negotiating with the competent authorities drafting the regulation. Infrastructure managers can also increment their charges when they have specific future investment projects that will increase the efficiency and cost-effectiveness of the infrastructure and services provided that will otherwise be impossible to make. Article 34 can be interesting for hyperloop if there is an equivalent one in their regulatory framework, and it states that there will be a compensation scheme when railway infrastructure instead of competing modes of transportation because of the environmental and accident costs avoided. Hyperloop claims to be cleaner than rail, so if there is such an article in their regulation, it could prove to be very beneficial for service operators.

The other half of the chapter deals with capacity allocation, and sets rules for how infrastructure managers have to distribute the capacity of the infrastructure, always in a fair and non-discriminatory manner. The European Commission is aware of the common principles and practices used for the allocation and the corresponding regulatory body needs to have access to the necessary information in order to perform their supervision. With regard to the power infrastructure managers have, besides allocating the capacity among applicants, they can set requirements these applicants have to meet in order to ensure sufficient revenue and draft framework agreements with applicants that last more than a “working timetable period”. These agreements are a sort of contract between an infrastructure manager and a service operator that last longer than regular capacity allocations and therefore are subject to more control by the regulatory body to guarantee the non-discrimination of other applicants.

The rest of the chapter deals with the scheduling, coordination to meet as many requests as possible, congested infrastructure and similar matters, which are directly applicable to another mode of transportation, should it be regulated by a similar set of directives.

The final articles of the directive deal with the establishment of a regulatory body in each Member State in charge of the railway sector. It is defined as follows: “this body shall be a stand-alone authority which is, in organisational, functional, hierarchical and decision-making terms, legally distinct and independent from any other public or private entity.” It also specifies that the same regulatory body can oversee different sectors, which leaves an open door for hyperloop not to have a specific regulatory body. The functions of the regulatory body are to guarantee every player plays according to the rules set in this and other directives. All of the last articles are applicable to a future hyperloop market, since in this accord, railways and hyperloop are homologous.

Finally, the annexes also hold important information, but the interesting issue in not that information per se, but what it implies. For example, Annex V deals with the principles and parameters of contractual agreements between competent authorities and infrastructure managers and sets that the performance indicators are to be user-oriented. This implies a modern view on how to measure accomplishments and that the main goal is to achieve a good service for customers. Being centred in that will not only be good for business in hyperloop, it will also make a shift of mode and investment more attractive for regulatory bodies such as the European Commision.

5. CASE STUDY: CONNECTION BETWEEN THE CITY CENTRE OF MARSEILLE AND MARSEILLE-PROVENCE AIRPORT

5.1 INTRODUCTION

Among the many studies that have been carried out analysing potential hyperloop lines, there are longer and shorter routes, ranging from several thousands of kilometres long to just a couple dozen. It makes sense that before building the long lines, some shorter ones are constructed and operated so that the investment can begin giving return as soon as possible.

This case study was done in collaboration with TransPod, one of the companies working in the development of a hyperloop system, which supplied data and support through the whole process. It is a short line between the city centre and the airport of the city of Marseille, in the South of France. It has been chosen because it is a city of medium size with low use of public transportation to access the airport, a busy airport in a very important area of the European Union which is witness to a big volume of passenger and freight traffic every year. The final idea is that this small line will be a part of a larger network that does not just connect city centres, but airports, with the objective of promoting intermodality for long distance travels.

The study of this line is challenging because between the city centre and the airport there is a stretch of mountains which make the tracing of the route complex, implies having an elevated percentage of it underground, which makes the construction more expensive, and does not allow for big speed to be achieved due to the shortness of the line and its geometry. This line, as a standalone project does not represent the real alternatives hyperloop offers as a new mode of transportation and has an elevated cost per km in comparison to other projects, but it is still cheaper than high speed rail.

The method followed to study this case is firstly carrying out an in-depth analysis of the current accessibility to Marseille's airport from its city centre. Researching and analysing every mode of transportation and option available, calculation of travel times and cost of each. After that, a study on how the new solution would change the current situation and the impact it would have on the city and its inhabitants, with a calculation of the capacity of this line, as a function of the velocity of the vehicles, which given the state of development of the technology is still unknown. Finally, with data provided by TransPod, a calculation of the construction costs has been made, which depends on the portion of the line underground.

5.2 CURRENT ACCESSIBILITY BETWEEN THE CENTRE OF MARSEILLE AND THE AIRPORT

In this section the current accessibility of Marseille-Provence Airport will be studied, and an in-depth analysis of the available transportation methods between that point and the city centre will be carried out, pointing out key characteristics of each.

Accessibility

The concept of accessibility, although intuitive, is very difficult to measure because it considers a large number of variables which vary in each case study and which themselves are not easily measurable, like the easiness to travel or the attractiveness of the offers, and implicates a sum of all the variables for all the available options. There is a subjective component to the choice and therefore it is more complex to quantify the impact of the value of some variables. Airport accessibility is particular to each airport and is relative to the geographical area it is located in, and to the characteristics of the territory, in economic, environmental and demographical terms. The main variables used in this study to measure accessibility are the duration of the journey and its cost, although other considerations are taken, such as frequency and reliability (29).

Accessibility can be described a means of measuring how easy it is for passengers to reach a specific point, the airport of Marseille in this case. Passengers choose from the available alternatives based on a series of subjective preferences and on the nature of the journey (business vs. leisure, national vs. international, etc.). The most important variables when making the choice are usually cost in terms of time and money, but also comfortableness, frequency, safety and reliability (30). It is important to note that not all passengers have access to all alternatives, since some require a pre-existing condition like owning a car, or the destination point may not have access through a particular mode of transportation. Accessibility is a key factor in airport choice, since an increase in 1% in accessibility can mean a 2% increase in passenger traffic for the airport (31). The factors influencing the airport choice can be subdivided in two categories: air and land. The air category deals with the flights offered at the airport (destination, fares, frequency, etc.) and the land one covers accessibility, and will be the focus of this section.

Marseille-Provence Airport (AMP) is connected to the city of Marseille by road and rail, which already gives this airport a high accessibility, since not all airports are connected by both modes of transportation. Out of the 30 largest airports in Europe, 23 have rail connection of some sort (metro, short, medium or long-distance trains) (30). The road connection is excellent the airport is located next to the A-7, one of the main roads of the country, which connects Marseille and Lyon, and also close to the A-55, a regional highway which connects the city of Martigues with Marseille. By rail, several lines cover the distance between the centre of the city and the airport. It is relevant to note that while accessibility in general is very high, when talking specifically about accessibility by public collective transportation, the case changes. When compared to other airports in Europe, the average percentage of travellers reaching the airport by private transportation or taxi is much higher (32). While in Paris, 43% and 35% reach Charles de

Gaulle Airport and Orly Airport respectively by collective public transportation, only 16,2% currently use it to reach AMP (33).

Today, AMP can be accessed from Marseille by three modes of transportation: car, bus and train. Since this study concentrates on the connection between Gare St Charles and AMP, all the data regarding time of travel and distances will refer to the connection between those two points.

The distance between Gare St Charles and AMP is:

- 19, 9 km in a straight line
- 25,8 km by road
- 22,2 km by rail (distance between St Charles and Vitrolles-Aéroport-Mars)

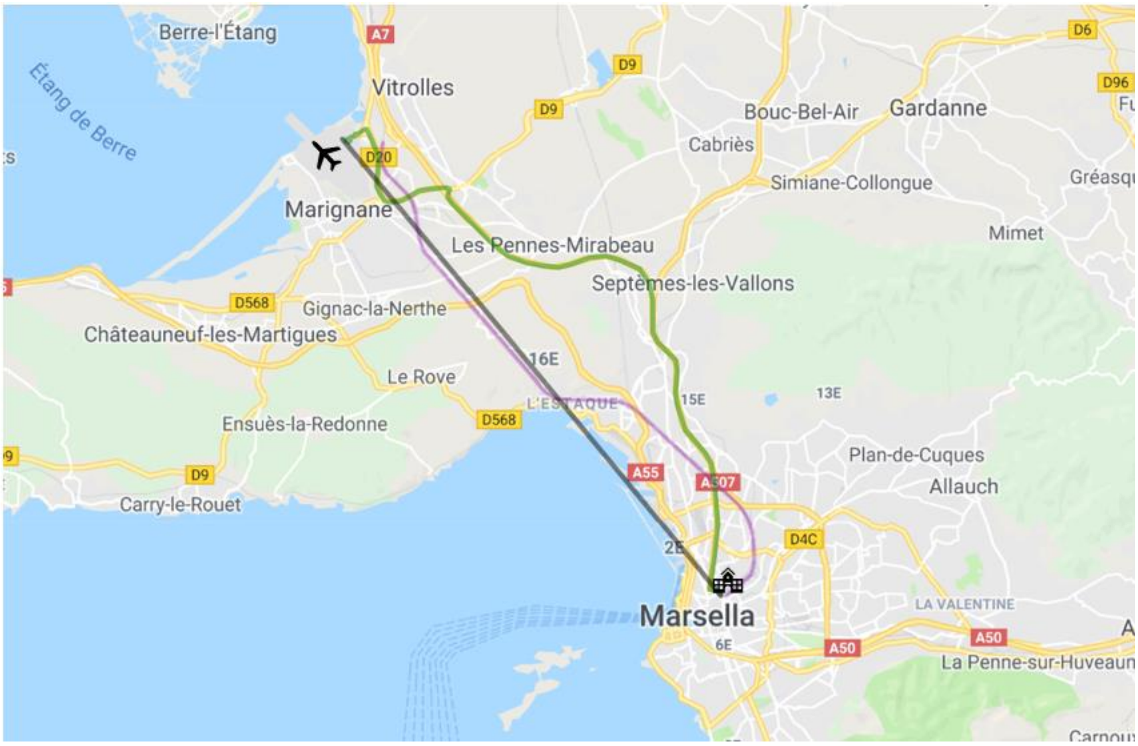

Figure 17: Distance between Gare St Charles and AMP. (Source: Goolzoom)

All the available connections will be described and analysed, and this study will be separated by mode of transportation.

Railway

France has close to 30.000km of railways, which connect great cities and small towns alike. There is only one company offering transport services by train, SNCF, owned by the state. Within SNCF, there are several sub-organisations that specialise in different kinds of specific services, such as TGV which are the high-speed trains, Intercités connecting cities around the country, TER for regional journeys, Transilien to travel within the region of Île-de-France, and more.

AMP does not have a railway station inside its facilities, but there is one very close by, 2,8 km away, called Vitrolles-Aéroport-Mars (VAM). The distance between there and AMP can be covered by travellers on foot, taking approximately 35 minutes, or by bus, with a free shuttle service provided by the airport. This shuttle bus, according to AMP's website, has a frequency of 10-15 minutes and takes passengers from the train station to the airport and vice-versa in approximately 6 minutes. This service however is about to be discontinued, and there is an on going study to build a cable car that covers this distance.

The service between Gare St Charles and VAMP is offered by SNCF TER (the regional service), Intervilles (long distance regional trains with first and second-class seats) and Intercités (SNCF classic trains linking large cities).

In 2018, the traffic between the stations of St Charles and VAM was of 132.000 people, and of 128.000 in the opposite direction.

The price of a single ticket between Gare St Charles and VAM is 5,2€, and since the shuttle bus between the VAM and AMP is free, this is the total cost of the trip.

Regarding frequency and duration of the journey between both stations, there is great inconsistency. The smallest interval between two consecutive trains is 4 minutes (8.18 – 8.22), the largest one is 2 hours and 10 minutes (21.18 – 22.37). However, the average interval is 31 minutes. It is worth noting that the interval between trains does not follow any pattern, there can be two trains 6 minutes apart and the next one 60 minutes after.

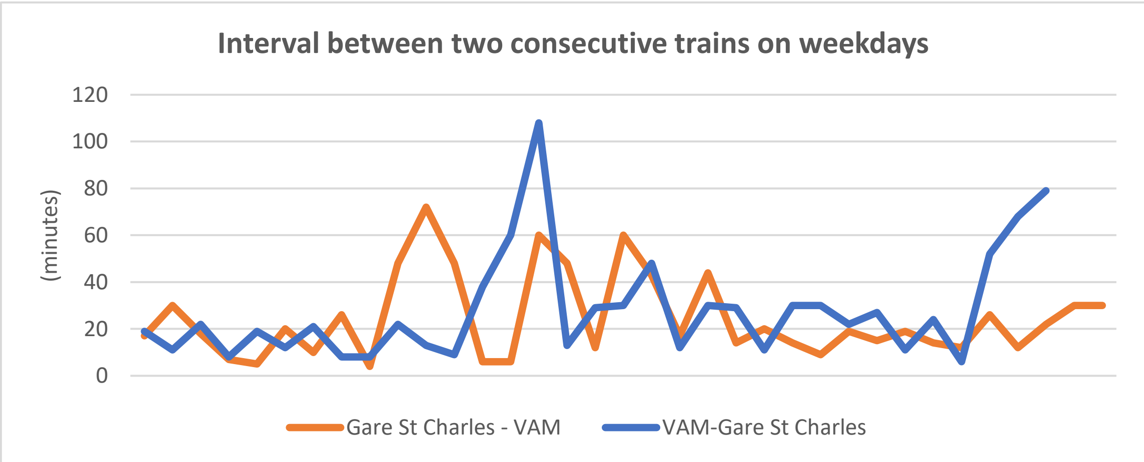

Figure 18: Interval between two consecutive trains on weekdays. (Source: own production)

Figures 18 and 19 illustrate this variation of the intervals between consecutive trains during the day.

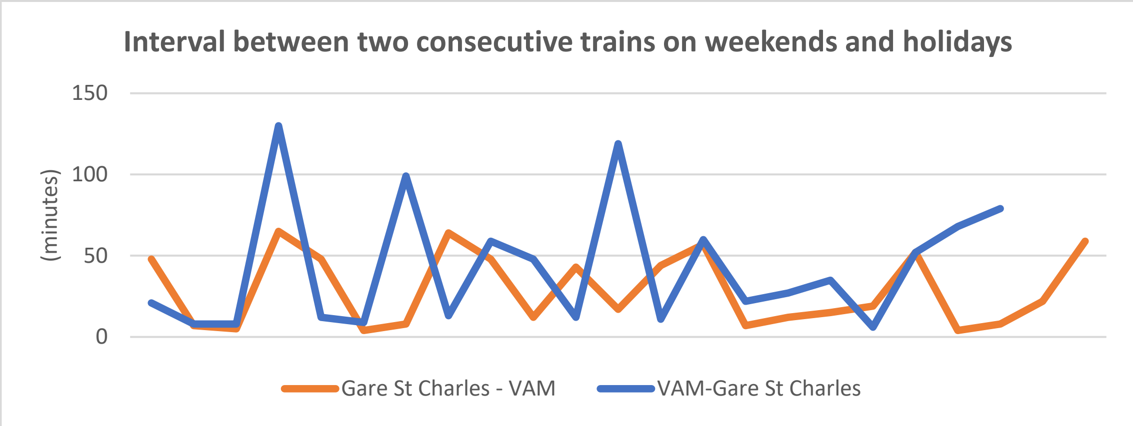

Figure 19: Interval between two consecutive trains osn weekends and holidays. (Source: own production)

It is also worth noting that there is no seasonality in the services, meaning that there are no extra services during specific periods within the year.

This data hints at the fact that the service covering the arrival at the airport is slightly better than the one on the opposite direction. These intervals are slightly higher for the trains heading towards the city in both cases, although the difference is more starkly pronounced on weekends and holidays, and the maximum value of the interval between two consecutive trains always corresponds to that direction, peaking at 2 hours and 10 minutes. Furthermore, there are two more trains a day that go from St Charles Station to VAM, 36 on weekdays and 24 on weekends and holidays than the ones that do the opposite route. The connection between Gare St Charles and VAMP is always part of a longer line that has one end at St Charles but usually the other one is quite far from the airport. This difference in service supports the demand data presented above, where the number of people that use the train to go to the city is slightly lower than those leaving the city. The reason may lie in the further connections it provides. The following table evidences the differences described above.

		St Charles - VAMP		VAMP - St Charles	
		MON-FRI	SAT-SUN	MON-FRI	SAT-SUN
Interval between two consecutive trains (mins)	Average	**24,5**	**29,0**	**28,2**	**42,8**
	Max value	72	65	108	130
	Min value	4	4	6	6
Duration of the journey (mins)	Average	**18,7**	**18,4**	**18,4**	**17,8**
	Max value	22	25	28	28
	Min value	15	15	13	13

Figure 20: Comparison of intervals between two consecutive trains. (Source: own production)

With this information, the calculation of the time it takes for a passenger to get from Gare St Charles to AMP follows.

The minimum time it takes, corresponding to 0 minutes of waiting time and optimal traffic conditions between the train station and the airport, is:

15 minutes of train travel
\+ 5 minutes to get off the train and walk to the bus stop

+ 6 minutes of bus travel

26 minutes

The maximum value, calculated with a reasonable maximum waiting time at St Charles of 20 minutes[1] and the worst traffic conditions between the train station and the airport, is:

20 minutes of waiting at St Charles
+ 25 minutes of train travel
+ 5 minutes to get off the train and walk to the bus stop
+ 15 minutes of waiting for the shuttle at VAMP
+ 8 minutes of bus travel

73 minutes

The reverse travel times, from AMP to St Charles are calculated next:

The minimum time it takes, corresponding to 0 minutes of waiting time and optimal traffic conditions between the train station and the airport, is:

13 minutes of train travel
+ 5 minutes to get off the train and walk to the bus stop
+ 6 minutes of bus travel

24 minutes

The maximum value, calculated with a reasonable maximum waiting time at VAM of 20 minutes and the worst traffic conditions between the train station and the airport, is:

15 minutes of waiting for the shuttle at AMP
+ 8 minutes of bus travel
+ 5 minutes to get off the train and walk to the bus stop
+ 20 minutes of waiting at VAM
+ 25 minutes of train travel

76 minutes

The maximum duration of the journey is over 3 times the minimum duration, which in a trip which is so time sensitive, probably acts as a deterrent for potential travellers. This is added to the intrinsic uncertainty of having to change modes of transportation in a single trip.

Road

There are several means of transportation that can use the road to go from the city centre of Marseille to the airport, namely: buses, private cars, taxis, etc. All of these have particularities that make them very different, but they all share the infrastructure they travel on and therefore the route they follow and the traffic on it. Hence, before

[1] Given the time sensitivity of this journey and that there is a bus leaving from St Charles station to the airport with a frequency of 10-20 minutes for most of the day, it is not reasonable to suppose that people would wait for longer than that for a train.

studying each one separately, the analysis on the time it takes to cover the distance will be done, as it is common for all vehicles.

To carry out the study on the duration of the journey by road, the route chosen between Gare St Charles and AMP is taking the motorway A7, which starts 700m away from the station, exiting it 18 km later on exit 30b, then following roads D9 and D20 for approximately 6,5 km until the airport. This is the route followed by bus 91 and the most commonly used by cars, since it is the most direct way, though it is not the only one. However, for the sake of simplicity, this analysis has been done only for this option.

To cover the distance between Gare St Charles and the airport, the minimum time spent is 18 minutes, corresponding to a traffic-less situation, while the maximum is 45 minutes, corresponding to heavy traffic situations like rush hour during weekdays or Sunday evenings, when the flow into the city is higher than usual. The following graphs represent the duration of the journey, in both directions, during weekdays, Saturdays and Sundays. This separation is done because data is consistent from Monday to Friday and Saturdays and Sundays present different traffic characteristics. Each graph shows a best and worst case scenarios, since traffic conditions, even though they show a pattern, also show variations. The average duration of the trip by road is 22,5 minutes from St Charles to AMP and 23,5 in the opposite direction.

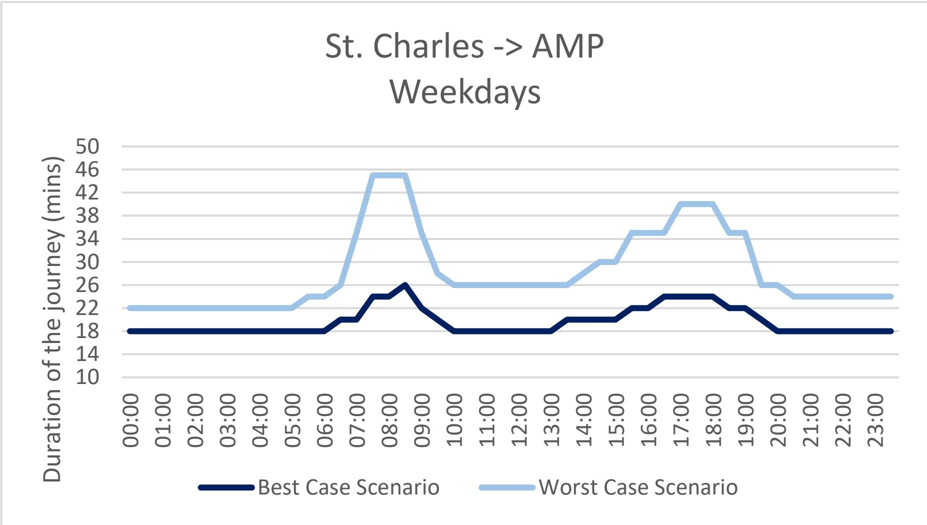

Figure 23: Duration of the journey between St Charles and AMP throughout the day on weekdays. (Source: own production)

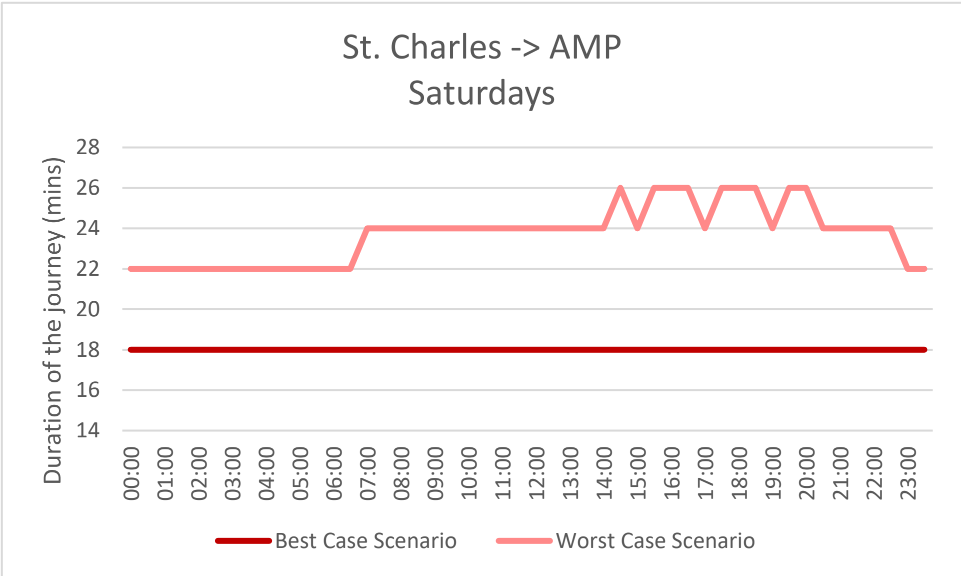

Figure 21: Duration of the journey between St Charles and AMP throughout the day on Saturdays. (Source: own production)

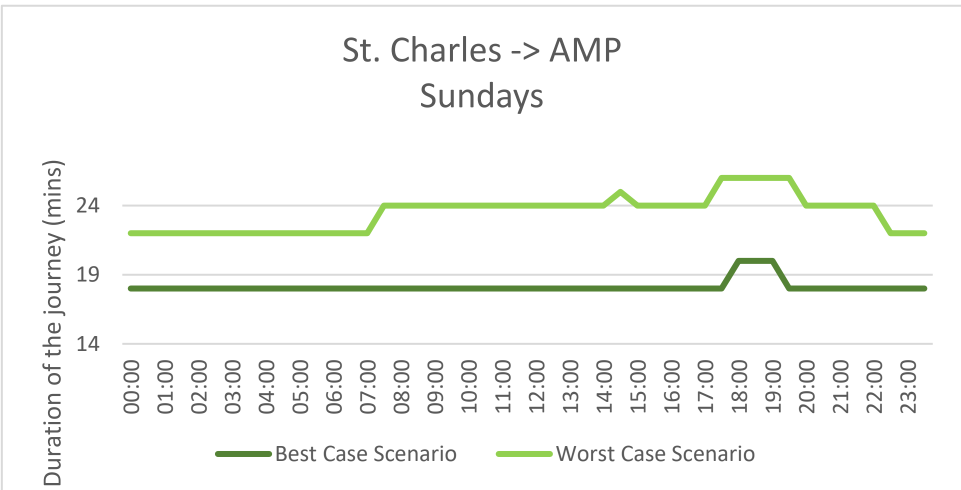

Figure 22: Duration of the journey between St Charles and AMP throughout the day on Sundays. (Source: own production)

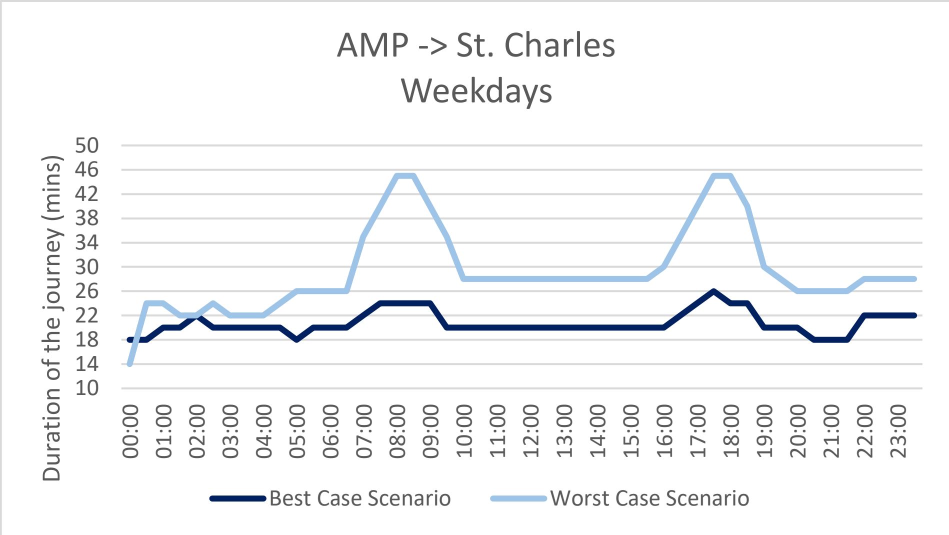

Figure 26: Duration of the journey between AMP and St Charles throughout the day on weekdays. (Source: own production)

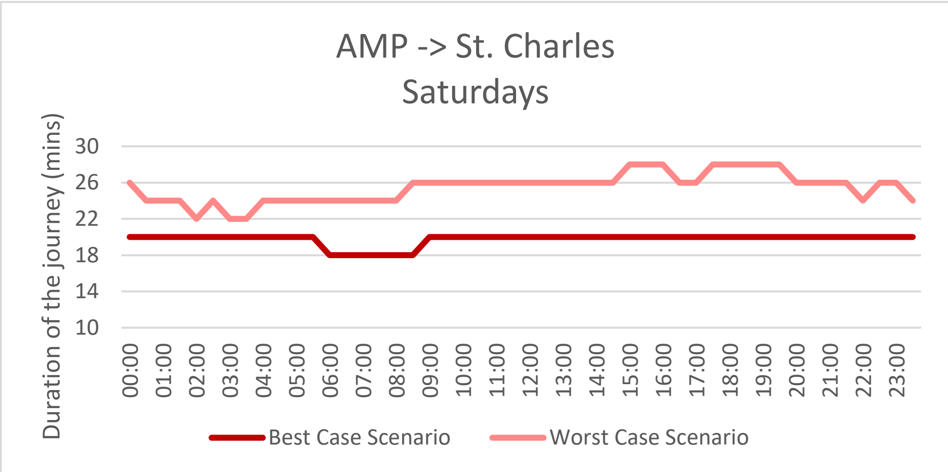

Figure 24: Duration of the journey between AMP and St Charles throughout the day on Saturdays. (Source: own production)

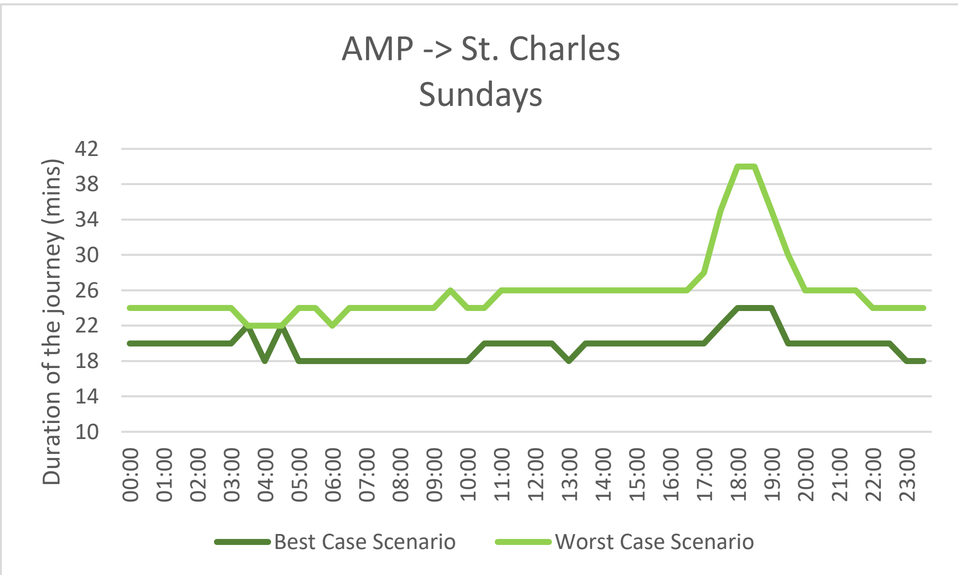

Figure 25: Duration of the journey between AMP and St Charles throughout the day on Sundays. (Source: own production)

These graphs show a weekday rush hour between 05:30 and 09:00 and 15:30 and 19:00, a slight shift to the left in them can be appreciated in the direction AMP -> St Charles. These hours are consistent with a typical working day in France and the half-hour shift can be explained by the type of jobs in and outside the city: in the wider metropolitan area and outskirts of the city the typical jobs are industrial ones, while the city centre is dense with office-type jobs, which usually start a bit later. The peak in duration is between 07:30 and 08:30 in the first direction and between 08:00 and 09:00 in the second one, while in the evening it is between 17:00 and 18:00 and 17:00 and 18:30 respectively. These time slots are similar in both directions, which is coherent with the urban and industrial network of Marseille, with both types of areas intertwined and sprinkled around the dense city centre.

Saturdays present quite flat curves in both directions, which suggests a constant and light traffic during the whole day. Sundays, on the contrary, while in the direction going out of the city centre is very flat, the one that goes in the other direction shows a differentiated peak in the evening hours, probably due to the return of people who have been out of the city for the day or the whole weekend. This shape in the traffic curve is typical to large cities.

The network of public transport in the city of Marseille is made up of metro, trams, and buses. The latter are the most numerous, and together the three conform a dense mesh that interconnect the city from the busiest points in the centre to the suburbs and close by towns. The buses are managed by the "Regie des Transports Metropolitains" (RTM), a public company which is part of the wider network, "La Metropole Mobilité", which coordinates the regional services of public transportation (except the trains, which are managed by SNCF) in the whole region of PACA.

There are two bus lines that connect the centre of the city of Marseille with the airport: 36 and 91. The analysis will be done separately since they are two lines of a very different nature.

BUS LINE 91

Line 91 is essentially a shuttle service between the station of St Charles and AMP's bus station, since those two points are the only stops in the line. The bus station at AMP is ideally located between the two terminals of the airport, making a single stop for all passengers, regardless of their exact destination.

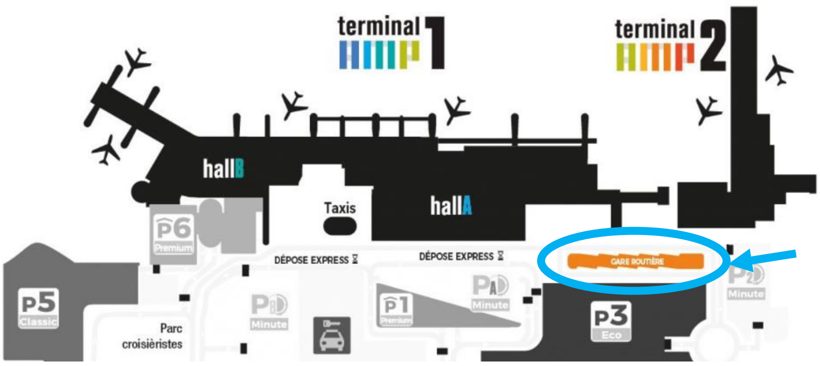

Figure 27: Location of the bus station at AMP. (Source: AMP)

The regular price of a one-way ticket is 8,30€, and 13,40€ for a round trip, with discounts for the youth, 4,15€ the single ticket for children between 6-11 and 5,80€ for people between 12 and 25, free for children under 6 years of age and a discount for groups of over 15 people, with a price of 6,10€ for a single ticket. There are also tickets that include a ride on Marseille's public transport. For frequent travellers there are weekly, monthly and annual passes.

The frequency of this bus is high, with 98 services per day, every day of the year. The first departure from St Charles is at 3:30, after that the next one is at 4:10 and then buses depart every 20 minutes until 6:50. The frequency from then until 19:10 is of 10 minutes, dropping to 20 minutes until 23:50 with a final departure at 00:50. In the other direction the schedules follow the same pattern. The first departure is at 4:10, the second at 4:50, then every 20 minutes until 7:30. After that, there is a bus every 10 minutes until 20:10, going back to the previous frequency until 00:30, and a last departure at 1:30.

With 50 seats per bus, this mode of transportation can carry 9800 people to and from the airport every day, potentially up to 3,57 million people in a year.

The duration of the trip on bus 91 depends solely on the traffic on the route between both stops. This traffic varies during the day, as in any big city, with peaks during the rush hours in the morning and evening. As these periods are common knowledge, it can deter passengers from using this service during those hours, because of the longer journey and, especially when going to the airport, the uncertainty. In normal conditions, the duration of the journey varies between 20 and 50 minutes, a deeper analysis on traffic will be carried out in the following section. There is a project currently under study of assigning a dedicated lane in the motorway for public transportation, which would make the journey's duration shorter and less variable.

BUS LINE 37

Since August 2018 there is another direct shuttle service from the city centre to the airport, which is line 37. The end of the line in the city centre is in Arenc Le Silo, the opera house of Marseille. This is less than 2 km away from Gare St Charles, and it is connected by several tram and metro lines. The interest in this line lies in that it is close to the Marseille's port, which is the biggest in France and was visited by almost 2 million cruise passengers in 2018. This line also counts with an intermediate stop in the airport, at the helicopter terminal.

The pricing of this bus is the same as bus 91, 8,3€ for a single ticket and all the other pricing options also apply. However, this line only works during the week, from Monday to Friday and only offers 8 daily services. The first departure from the city centre is at 07:45, the last at 18:15. From the other end of the line the first bus leaves at 07:00 and the last one at 17:30. The duration of the journey, according to the official timetable is 30 minutes. However, it is analogue to the one of bus 91, since the route is almost the same, and is subject to traffic conditions both within the city and on the motorway.

BUS LINE 36

Bus line 36 of the regional network Cartreize, managed by Lepilote, covers the route between Arenc Le Silo and the airport, but the main difference with the previous one is that it makes many intermediate stops, since it is a regular bus. This can be a deterrent for people who want to go from the city centre to the airport, since bus 91 is faster, but it is an attractive option for people who live along the route the bus covers, shown in the following figure.

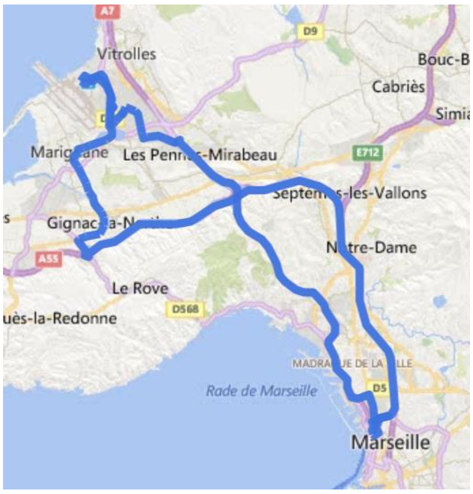

Figure 28: Route bus 36 follows. (Source: LePilote)

The duration of the journey in this case is longer due to the stops on the way, with a minimum travel time of 40 minutes and a maximum duration is estimated at 65 minutes. However, the variability is less predictable and probably higher, due to the use of urban ways instead of motorways, thus being subject to traffic lights, pedestrian traffic, etc.

Regarding price, from stops within the municipality of Marseille to the airport the single trip costs 8,3€ and for stops in other municipalities 4,4€. The first departure from the city centre is at 05:00 in winter and 05:40 in summer, while the last departure from the airport is at 21:17. The first departures can attract early travellers, since the duration of the journey will probably be at its shortest due to the light passenger and vehicle traffic at that time of day.

CAR

There are four different methods to arrive by car to Marseille-Provence Airport, and the time of travel is the same for all as it only depends on the traffic present along the route. All of the considerations will be regarding a one-way journey between Gare St Charles and the airport. The time taken to cover the trip will be analysed at the end of this section, since it is common for the 4 sub-modes described below.

Private car

The private car is the most commonly used method to go to the airport, although the origin point will likely not be Gare St Charles. However, for the sake of the study and to get comparable data, the cost and time will be calculated taking the station as the starting point. The motorway A7 reaches the centre of the city, starting at a distance of just 700m from the train station.

The cost per journey is made primarily of the cost of fuel plus the cost of parking if the car is left there for a certain period of time. The cost of ownership is negligible for a 25km trip. The cost of fuel depends on the type of fuel and the consumption rate of the vehicle, which in turn depends on the make, model and age of the car. The make and model selected to calculate the cost of fuel is the most common car in France, a Renault Clio, with an age of 8 years, which is the average age of the automobile park in France (34), (35). The consumption of fuel is broken down in the following table.

	Road [L/100 km]	Urban tissue [L/100 km]
Gasoline (2011 Renault Clio)	4,9	7,6

Figure 29: Fuel consumption of the most common car in France. (Source: Groupe Renault)

Out of the 25,4 km that lie between the station and the airport, 700m correspond to urban tissue, and 23,7km to motorway. Thus, the consumption of fuel for this trip is:

$$0{,}7 \times \frac{7{,}6}{100} + 23{,}7 \times \frac{4{,}9}{100} = 1{,}214 \; litres$$

Regarding cost, the price of a litre of gasoline varies notably during the year, reaching a peak in the summer months. However, for the sake of simplicity and because of the short nature of this journey, an average value will be taken to calculate the cost of fuel. The following graph shows the average cost of a litre of gasoline from the 25th of February 2019 to the 3rd of June 2019, which vary from 1,46€/litre to 1,6€/litre, with an average of 1,52€/litre, which is the value chosen for this calculation.

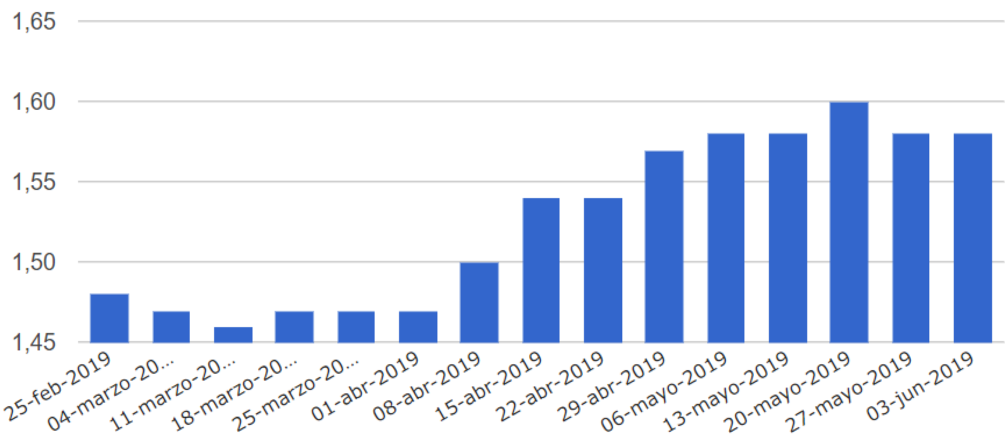

Figure 30: Price of gas between 25/02/2019 and 03/06/2019. (Source: globalpetrolprices.com)

Finally, the total cost of fuel for a one-way trip between Gare St Charles and AMP is:

$$1{,}215 \; litres \times 1{,}52 \; €/litre \; = \; 1{,}85€$$

This is the total cost of the journey per vehicle, which has to be divided between the number of passengers going to the airport. For this study the assumption of a single person travelling per vehicle will be taken, and the cost is assumed in its entirety by the traveller and not the driver, in case it is not the same person.

Regarding parking, there are two differentiated options: if the passenger has been dropped off by a relative or friend, the parking time, if existent, will be very short, while if the passenger drives themselves, the car will be parked for a longer time, at least one working day (8 hours). AMP has a wide offer of long-term parking services, prices range from 9,9€ to 18,7€ per day. There is a special parking for stays between 4 and 24 days with very low fares, less than 5€ per day when the stay is longer than one week. (source: AMP website). For stays under 1 day there are no fees available online.

Taxi

The are several taxi companies in Marseille, but the prices are common to all of them, since they are regulated by municipal law. The cost of the trip between the city centre of Marseille and the airport is a fee of 50€ during the day and 60€ during the night (36). This price must be divided among the passengers in the taxi. Due to the lack of further data, the following assumption will be taken: since it is an expensive option, it is reasonable to assume that the majority of taxi customers will be business travellers, who usually travel alone, so the price will be assumed to be for one passenger.

Uber

Uber offers two services in Marseille, Uber X and Berline, which are high-end cars and therefore the trips are more expensive.

An Uber X trip from Gare St Charles to AMP costs between 40€ and 56€, while a Berline trip costs between 60€ and 79€ (37). The exact price depends on several factors, which Uber's pricing algorithm takes into account. The total price is calculated by summing several fare types and then multiplying that by a number that depends on the current demand of Uber in the area, which is proprietary data of Uber. Without considering this last factor, the price is made up of a base fare, a minimum fare (depends on the city and country, so this is specific for Marseille), a fare per minute and per km, explicitly shown below:

Price [€]	UBER X	BERLINE
Base fare	5	5
Minimum fare	6	15
Per minute	0,3	0,5
Per km	1,2	1,75

Figure 31: Break down of the cost of an Uber ride. (Source: Uber)

Considering this data, and with a demand factor of 1, which would correspond with the average demand in the area, the following table shows the different prices of an Uber ride depending on the duration of the journey and the type of service chosen by the customer.

Duration	UBER X [€]	BERLINE [€]
22 min (average)	48,08	75,45
45 min (max)	54,98	86,95
18 min (min)	46,88	73,45

Figure 32: Cost of Uber trip depending on the service and traffic conditions. (Source: own production)

BlaBlaCar

BlaBlaCar is a carsharing platform which connects drivers and passengers that have a common destination. The average price for a trip between St Charles and AMP is 4€ per passenger. The usage of this option, although marginal, exists. Currently there is one car per day leaving St Charles between 12 and 12:30 and arriving to the airport at around 13:00, always the same driver, who makes this journey daily (38). However, the trip is only offered in that direction and not the opposite one, even if they may come up if a driver decides to offer the trip. The clear limitation of this solution is that the passenger must adapt to the driver's schedule.

Summary of current accessibility

It has been shown that the airport can be accessed by using many means of transportation that can adapt to different kinds of passengers. It is also clear through this analysis that Gare St Charles is a crucial point in the city in terms of transportation, and it is a good example of an intermodal hub in a big city, which acts as a gravitational point which attracts trips. The following table summarises the analysis made above and makes a direct comparison between all the means of transportation studied in terms of monetary and time cost.

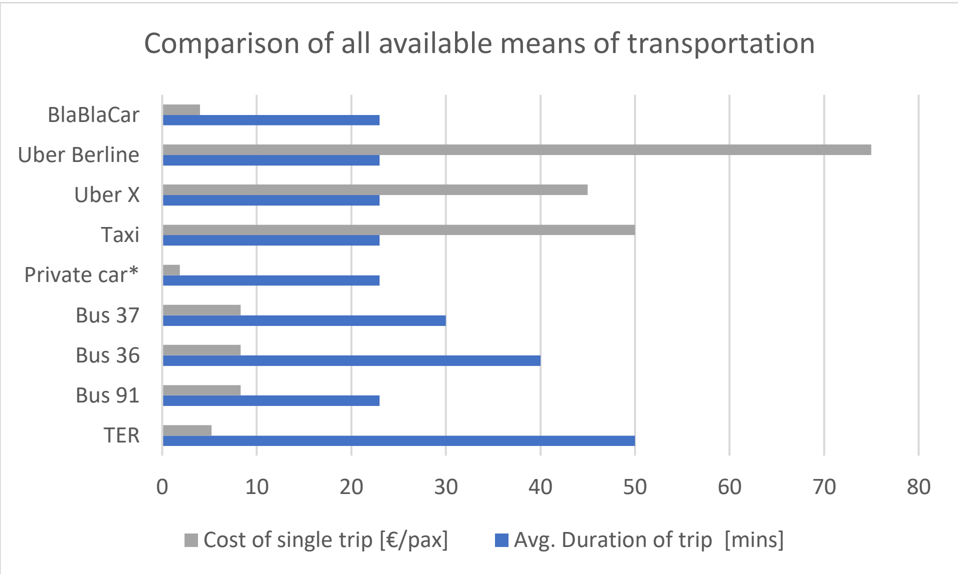

*Figure 33: Comparison of average duration and cost of trip between the means of transportation studied. (Source: own production) *The cost of trip by car does not include the parking fees*

The values displayed are all average values. This graph shows the most expensive means of transportation is Uber Berline, while the cheapest one is the private car (this graph does not include the cost of parking). Regarding duration, since most of the options use the same road, the difference is not as evident as the one in monetary cost. The maximum duration corresponds to the train, since it implies a change in mode of transportation and the waiting times increase the total duration of the journey notably. It is worth mentioning that this mode of transportation is one of the cheapest, and that ma, and that may counteract the effect of the long average duration. When it comes to buses, they all cost the same, but bus 91 has the shorter average duration, which makes it the most attractive considering only efficiency. This is because the head of the route is very close to the beginning of the highway, minimising the time spent driving in urban tissue. Finally, Uber and Taxi are quick but expensive compared to the other solutions, which probably means it is an option predominantly used by business travellers and the part of the population with greater spending power.

5.3 IMPACT

The introduction of a new connection of the characteristics of TransPod between the city centre and the airport will ideally have an important impact on the city in many dimensions. As a new means of collective transportation, it will transfer some of the traffic corresponding to private vehicles, with the consequent benefits in terms of reduction in pollution, traffic and other environmental issues. As a new, cutting-edge technology mode of transportation, it will pinpoint the city of Marseille, making it stand out in the map as a pioneer city in terms of transportation, inter-modality practices and technology in general. Furthermore, it will improve the accessibility between AMP and the city centre by adding not only a new connection but a new mode, with no dependence on traffic and a large potential transportation capacity. Finally, it will add a new mode of transportation to the intermodal hub of St Charles, doting it of even more added value as a nerve centre of the city.

Description and general impact of the new connection

The new connection proposed by TransPod consists in constructing a line between the city centre of Marseille and the airport of the city. The point chosen within the city centre is Gare St Charles, because it already is an intermodal hub, with good connections both with the surrounding suburban area and the wider metropolitan area, including larger population nodes like Aix-en-Provence, Martigues, etc. The overarching idea is that this line will be part of a larger European network, which will have as nodes not just city centres but also airports. In the age of Mobility as a Service, it is crucial that airports are integrated in the regional transportation network by different modes and means of transportation to successfully compete and generate business opportunities and value for the ecosystem.

The new line would be a direct connection with no intermediate stops. One end would be at St Charles, ideally the TransPod boarding area would be included as new "wing" of the station, becoming part of it, seamlessly inserting a new mode in the city's network. The other end of the line would be at AMP, with the terminal as an addition to the airport but being part of it, to favour an easy and quick transfer. It is fundamental that the terminals are constructed as a new area of the existing facilities, to guarantee true intermodality and make this new mode of transportation an attractive offer for potential users, and this is true for both ends, but especially for the one at the airport. If the station were to be separated from the airport and another means of transportation was needed to cover the "last mile", this solution would lose most of its interest for many potential users, and it would basically be the same service as the current TER.

One of the things that differentiates this solution from the current offer is that it is independent from traffic and weather conditions, since the pods travel inside hermetically closed tubes, which run segregated from other infrastructure and protect the vehicles from any external agent. Although weather is not usually an issue in the case of Marseille, it can be a determining difference in other parts of the world. Even in this case, weather can have adverse effects, especially when it comes to events like heavy rain or snow, which are uncommon and therefore alter the normal traffic conditions more than in other areas. These events can also cause problems in railway lines, although they are less common. This makes TransPod an option that is reliable, always taking the same amount of time to make the trip between both stations, which is a valuable trait in a journey of this characteristics. Principally when going towards the airport, the trip is time sensitive, and having a means of transportation that is not subject to external events like traffic accidents or adverse weather conditions can reassure many passengers and drive them towards the choice of TransPod as their preferred transfer mode.

Regarding safety, avoiding interaction with any external agent doesn't only make hyperloop a reliable means of transportation, it also makes it safe, since it cannot be altered by invasion of the lanes by other vehicles, people or any kind of object. Driverless, it averts accidents caused by human errors. Probably the most comparable existing means of transportation to hyperloop is the Shinkansen high-speed rail in Japan, because it uses magnetic levitation and reaches speeds of over 300 km/h, and it has not had any fatal operating accidents in its whole history.

The ultimate objective is to offer the city a new high-capacity line that can offer a viable, reliable, safe, quick and environmentally friendly means of transportation that can make people change their commuting habits. The maximum benefits of implementing this solution would be obtained if TransPod is able to attract trips and transfer demand from non-collective transportation, meaning taxi, Uber and private cars. This way it removes traffic from the roads, which is a benefit of its own accord, but also achieving a reduction in greenhouse gas emissions and providing benefits in terms of time savings, which are especially relevant in commuting trips (39). This benefit is especially enjoyed not by the people who choose TransPod as the means to go to and/or from the airport, but for the drivers that use the roads that connect the city centre with AMP (mainly A-7 highway) because a reduction in traffic will mean a reduction in their average commuting time. Moreover, by reducing the number of vehicles on the roads, the number of accidents will decrease as well. In this sense, TransPod fits into the up-and-coming business model of creating an ecosystem, where value is not created in a straight line, as a "pipeline", but in a reticular way for all stakeholders.

Furthermore, TransPod is a clean mode of transportation, since it uses electricity as a fuel and the infrastructure is doted with solar panels which can generate the energy consumed by the system. Marseille is an ideal city for this kind of system since it is one of the sunniest cities in the country, with over 2.800 hours of sun per year.

In terms of speed, while for a long line of several hundreds of kilometres a hyperloop line makes all the difference, for one so short, the reduction in travel time in absolute terms is not radical, since the estimated time of this trip is 20 minutes. It is a value very close to the minimum duration of the trip by road, 18 minutes, but as mentioned before, the strength is that the duration of the trip is constant throughout the day. When compared to collective means of transportation the reduction is larger, of up to 56 minutes in the case of the train.

Regarding landscape impact, TransPod has a negative score, since the infrastructure is large, and it runs several metres over ground level. This may be an important factor to consider in this particular line, which runs in a densely populated area. The current trend in Western European cities is to move large infrastructure like high-capacity roads and railways underground so that the space above is more usable for pedestrians. However, the benefits it provides environmentally speaking may be enough to offset this adverse impact. In addition, a TransPod line does not have a negative effect on pedestrian traffic and a limited one on the usability of the ground space.

The vehicles of a TransPod line are small pods, with space for around 30 passengers each. The size of the single vehicle is smaller than that of the bus and train, but the frequency of departures differentiates this mode from the others, reaching departures every 80 to 120 seconds (40). The operating characteristics of this mode are more like a subway train or urban bus than to a long-distance means of transportation, since the passenger buys a ticket with no specific time of departure, like an urban transportation ticket, and gets on the first available pod. This eliminates the need for planning or booking in advance.

Capacity

The capacity of a line is one of the main variables that describes the quality of a connection within an urban network. The operating capacity depends on several factors, namely the number of vehicles and the time it takes for a pod to do a round trip. The general formulation for route capacity calculation is simply dividing a certain time period P (usually 1 hour) by the headway H, which is the distance or time between two consecutive vehicles within the transit system. This gives us the capacity in vehicles per hour, which can also be described as the maximum frequency f_{max}, which then multiplied by the number of seats in the pod produces the capacity in persons per hour. The potential capacity of the line is:

$$Route\ Capacity = \frac{P}{H} = f_{max} \quad (1)$$

The minimum safe headway is dependent on the braking capacity of the system, which in the case of TransPod is very powerful thanks to the lack of friction and the kind of propulsion system it uses, described at the beginning of this report. The usual formulation to calculate the minimum safe headway is the following:

$$H_{min} = t_r + k \times \frac{v}{2} \times \left(\frac{1}{a_f} - \frac{1}{a_l}\right) \quad (2)$$

Where t_r is the reaction time of the system since it detects an issue until it applies the full braking capacity , k is a safety coefficient with a minimum value of 1, v is the velocity of the vehicle, a_f and a_l are the minimum and maximum deceleration capacity of the follower and the leader respectively. This is the distance, expressed in time, between the tip and the tail of two consecutive vehicles. To get the tip to tip headway one just has to add the length of the vehicle in time (dividing it by the velocity).

Hyperloop's headway is calculated at 80 seconds, which is the time it needs to arrive to a complete stop. This value can be considered to be in a medium range when compared to other means of transportation such as high-speed rail, with a headway of 150 to 180 seconds and to cars and busses, with a headway of 2 and 5 seconds respectively (40) (41).

With this information, applying (1) we get the maximum frequency the system can achieve is:

$$f_{max} = \frac{3600}{80} = \mathbf{45}\ \boldsymbol{vehicles/hour/direction} \tag{3}$$

Considering this frequency and a vehicle capacity C_v of 30 people, the maximum potential capacity Q of the system (in both directions) would be:

$$Q = 2 \times f_{max} \times C_v = 2 \times 45 \times 30 = \mathbf{2700}\ \boldsymbol{pax/hour} \tag{4}$$

However, the capacity needs to comply with the constraints of this particular route, which depend on the time it takes a pod to do a trip, the number of available pods (which can be considered as a variable) and the maximum number of pods that "fit" in the line considering their length and the minimum headway. In other words, the frequency f in number of trips per hour cannot be larger than the number of vehicles N_v divided by the time it takes each vehicle to make a round trip (T):

$$f \leq \frac{N_v}{T} \tag{5}$$

T is the sum of the time spent moving from one station to the other plus the time spent stopped at each station, in which passengers get on and off the pod. Regarding this last element, to maximise the capacity of the line, it should be as short as possible. The preliminary design of the pods made by TransPod takes this into account, which is why their pods have doors on both sides, one of it is intended as the entrance and the other one as the exit. It would be possible to start the boarding with very little delay with respect to the disembark, with passengers leaving through one door at the end of the pod and coming in through a door on the opposite end and side of the vehicle. The total time for a round trip T can be calculated in a simplified way as the sum of the time spent dwelling at both terminals t_s plus the length of the route L divided by the average velocity of the pod, v:

$$T = 2 \times (t_s + \frac{L}{v}) \tag{6}$$

Finally, N_v must be compliant the with physical constraints of the line, the maximum number of vehicles is the length of the line (L) divided by the length of the pods (l) plus the minimum headway in distance units, multiplied by 2 because the line is double:

$$N_v \leq \frac{2L}{l + H_{min} \times v} \quad (7)$$

Operating with equations (4), (5), (6) and (7), the maximum potential capacity Q_{max} of the line can be formulated as follows, where v will be considered as the average velocity of the pods in the line:

$$Q_{max} = \frac{2vL}{2t_s H_{min} v^2 + (2t_s l + H_{min} L)v + 2Ll} \times C_v \quad (8)$$

The values obtained from the route calculation give an approximate length of the line L = 20,83 km and in their current design state, the pods have a length of 25 metres. The minimum headway has already been established at 80 seconds. It is reasonable to assume that the time spent dwelling at each station will be short, for this study it will be assumed that the value of t_s is equal to 5 minutes. The only unknown variable is the average velocity of the pods, which strongly depends on the geometrical characteristics of the route. As of the moment of writing this report, the output from TransPod's model is not ready yet and therefore there is no data on velocity. To get an idea of the possible capacity of the system, these is the capacity of the system Q for different values of the average velocity. The curve shows there is an optimal velocity after which the maximum capacity decreases. This optimal velocity can be calculated by differentiating equation (8) and making it equal to 0:

$$\frac{\partial Q}{\partial v} = 0 \quad (9)$$

Carrying out this operation and simplifying the outcome, the optimal average velocity of the pods inside the tubes, taking into account all the assumptions previously made, is the following:

$$v = \sqrt{\frac{Ll}{t_s H_{min}}} = \sqrt{\frac{2083000 \times 25}{300 \times 80}} \approx \boldsymbol{166 km/h} \quad (10)$$

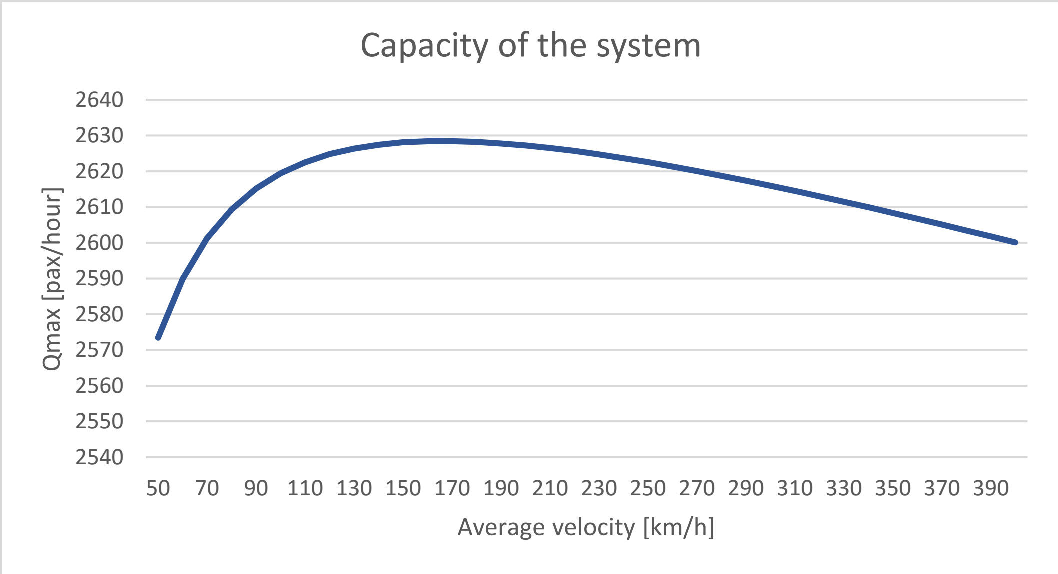

Figure 34: Capacity of the route as a function of the average velocity. (Source: own production)

Finally, the maximum capacity corresponding to the optimal average velocity v=166km/h is:

$$Q_{max}\,(v = 166\ km/h) = 2628\ passengers/hour \tag{11}$$

Compared to the other collective transportation options currently available to reach the airport, TransPod offers a better quality of service, it is capable of absorbing demand from those means and also from private transportation. The maximum number of vehicles per hour for both TER trains and busses is 6, and their capacity is around 250 and 50 seats respectively. With this data we can compare the maximum capacity in

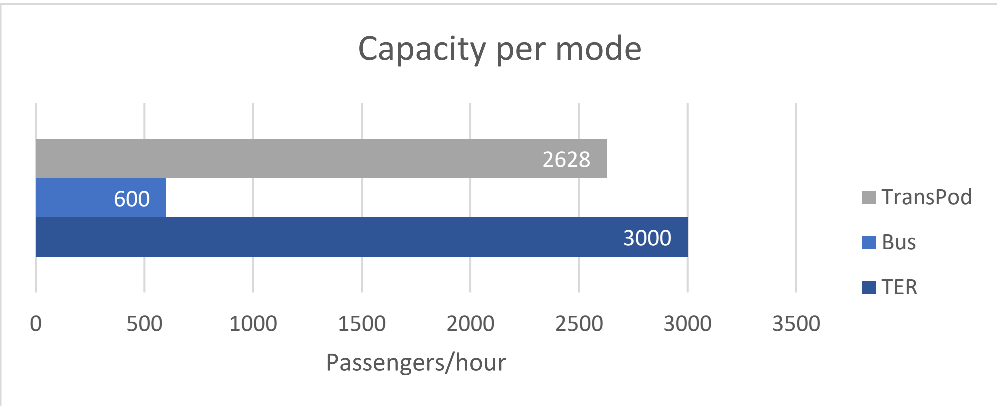

Figure 35: Capacity in passengers/hour per mode of collective transportation. (Source: own production)

passengers per hour of the different transportation systems.

The train has a potential maximum capacity that is slightly superior to the one of TransPod, but a key fact needs to be taken into account, which is that the TER train connects several other stations, not just the two terminal points like the bus or TransPod, so that capacity will not be exclusively used by people moving between the airport and Gare St Charles. Considering that, TransPod's offer is vastly superior to the other two in terms of transportation capacity.

Cost Analysis

The main costs of inaugurating a new infrastructure, whichever its nature, are divided among investment costs and operating costs. There can also be other type of costs like financial costs, but these will not be taken into account in this analysis.

Investment costs are made up of the cost of constructing the infrastructure and buying/manufacturing the rolling stock and related equipment. The infrastructure costs have a basic variable, which is the percentage of the line which has to go underground. Although it is significantly more expensive, building underground is sometimes inevitable due to the characteristics of the terrain and to keep the route as straight as possible to enable high velocities. In this case, there is a large area of elevated ground between both ends of the route, making it necessary to have a significant percentage of the line, between 35,8% and 41,4%, buried.

The following data is taken from a study carried out by TransPod on the order of magnitude of the costs of infrastructure. Since the cost of constructing in France is similar to that of constructing in the US (42), the costs which appear in table have only

Description	Cost T. CAD	Estimated Cost/km (€)	Elevated costs (M€)	Underground costs (M€)	Total costs (M€)
Pier Type A (38U/km)	3.011.000	1.987.260	23,99		23,99
Galvanized Metal Ladder	262.000	172.920	2,09	1,48	3,56
Galvanized Catwalk	1.344.000	887.040	10,71	7,57	18,27
Tube - Diam 4m; 1000m	11.063.000	7.301.580	88,13	62,29	150,41
Solar Panels	2.310.000	1.524.600	18,40	13,01	
Emergency Exits (2U/1km)	1.504.000	992.640	11,98	8,47	20,45
Service Road	1.660.000	1.095.600	13,22		13,22
Power Substation	392.000	258.720	3,12	2,21	5,33
Service Compound	1.386.000	914.760	11,04	7,80	18,84
Indirect Costs	2.293.000	1.513.380	18,27	12,91	31,18
Contingencies and risks	3.670.000	2.422.200	29,23	20,66	49,90
TOTAL COSTS			230,17	136,38	**335,15**

been applied the current currency change from CAD to EUR.

The total cost of construction, considering the worst-case scenario of having 41% of the route underground, ascends to 335,15 million €, which corresponds to a cost of 16,27 million € per km. This is almost half of the cost of constructing a high-speed rail line in France, estimated at 30,4 million € per km (43).

Regarding operating costs, they can be very important in a transportation system of this characteristics, given its complexity in management and maintenance. Variable costs include energy, pod maintenance and maintenance labour cost. Fixed operational costs are made up of infrastructure and equipment maintenance, labour cost, administrative costs, insurance, taxes, etc. Given the nature of the service it provides, although the frequency will vary in peak and valley periods, the system could run for up to 19 hours per day, to be able to serve passengers with very early or late flights, thus being able to pick up demand that other collective transportation methods can't. The remaining 5 hours of the day can be used for routine maintenance activities to favour smooth operations.

6. CONCLUSIONS

The sheer concept which inspired Elon Musk to come up with hyperloop is not new or revolutionary, but something that has been explored as means of transportation for the last hundred and fifty years. However, its development was halted due to a lack of interest, support and sufficiently advanced technology. However, in less than seven years hyperloop has passed from being a non-existent word to having over seven million results on Google. Nowadays it is a well-defined concept being developed by several different companies who have received tens of thousands of euros in investment. Although there are still voices that claim it is an impossible dream, these facts show that most people believe otherwise, and that is why there has been such an exponential evolution.

Out of the many people working on hyperloop, some companies stand out because of their work in the field, the stretch of their advances and their involvement in the development of the concept as a whole, not just their particular company. There are a couple of operating test tracks at the moment and as many under construction, and the technology of the whole system is only getting further and more sophisticated as the days pass. Most companies now claim they will have a functioning hyperloop system and operative line in a decade's time.

Virgin Hyperloop One is the company which seems to be more advanced and closer to actually having a functional hyperloop, with many tests carried out with full scale capsules and a lot of investment put into research and development. Besides this, it counts with some very prominent names in the tech world like the former CEO of Cisco Systems. Hyperloop TT, the other company of the first two ever created has been working for the same amount of time and has equally big names in their Board, but has not been able to construct a test track even though they have presented a full scale prototype of their pod. They have also reached an agreement with the Saudi Arabian government to develop a hyperloop line in their country and are receiving ample support from them. This is an important endorsement since laws may be laxer in such a territory and the orography in the desertic part of the country is certainly favourable for a hyperloop line.

Meanwhile, in Europe, two of the companies studied came from participating in Musk's contest, showing that it really does foster creativity and entrepreneurship, besides being extremely useful in developing technology. One of those companies is Dutch and is the receiver of a multi-million investment of the European Commission, showing that there is involvement on behalf of the establishment, and has built a test track in which they have carried out several successful experiments. The other company is Spanish and has also received economic support from several governmental institutions, apart from winning prizes for their work as a start up and as innovators. These two companies, together with TransPod, a Canadian company, have an agreement to work together not in developing the technology of their particular systems, but other issues related to the system.

TransPod has wanted to differentiate itself by eliminating the word hyperloop from the product they sell and refer to it as tube transportation or other similar nomenclature. Their system differs from the design Musk proposed in his paper Hyperloop Alpha, which is how they justify it, but it is actually very similar to other designs, like Zeleros' one. In their case, they have opted to be an international company from the beginning, and have offices in Canada, Italy and France. All companies are trying hard to have something that differentiates it from the others and are in a race to be the first who has a safe and functioning hyperloop system. They know that collaboration amongst other stakeholders is crucial, and some companies are collaborating even among themselves. However, they do guard their technology very fiercely, revealing little to no technical information about their vehicles, motors and infrastructure, even though some have patents of them.

Being such a capital-intensive investment, it is unlikely that all of these companies end up setting up their own systems and own lines around the world. Some may merge, some may disappear, maybe some will succeed. It is very complex to develop the technology for a hyperloop system to work, and to make it safe enough for it to carry passengers, which is why it will still take a lot of work, time and effort to get there.

Besides the technological challenges that hyperloop obviously faces, now that it has become a real possibility other issues come up that have to deal with the implementation of such a system in a working society. Some companies have formed an alliance to work on these challenges, namely TransPod, Zeleros and Hardt Hyperloop. This agreement is participated as well by the European Union, and the objective is to explore current regulation to gather which can affect a future hyperloop system, and work together towards developing a common regulatory framework, certification procedures and guarantee interoperability from the start. This is a crucial step towards succeeding, which will be easier and faster if there is an existing legal and technical structure to support themselves on.

Regarding this issue of what kind of regulatory framework will administer and control a future hyperloop market, it is likely that it will be similar to laws that regulate similar issues, that is, other modes of transportation. Within the existing modes of transportation, the most similar is the railway, so it is reasonable to assume that a future hyperloop regulation will have things in common with it, especially in the areas which are homologous between modes. It so happens that the railway market is under a deep transformation and opening process, which makes this similarity between modes even closer. That is why the analysis of the current railway market regulation can be very relevant for hyperloop, in order to prepare a system made ad-hoc to fit in the regulatory framework instead of having to adapt and undergo changes once it is fully designed.

The main message of the Fourth Railway Package is that domestic rail markets must become a competitive market where all players are equal. The basic way of working is that every infrastructure or length of infrastructure has a manager, a company. The infrastructure manager is in charge of leasing that infrastructure to operators who can exploit it and earn revenue from it in exchange for a fee. All operators have to be treated equally and given the opportunity to use the infrastructure, which must be utilised in an efficient way, but always guaranteeing a minimum level of service to the customers. The consequences of opening the market are expected to be an overall improvement of the domestic rail services, a decrease in the price of the tickets and achieving a more dynamic market which fosters innovation in technology and practices. There is no reason to believe that if the European Union was to allow the introduction of a fifth mode of transportation, it would support a monopoly situation, since it has been working for the last twenty years to eliminate that from rail. That is why all of the characteristics of the railway market listed above will likely apply to hyperloop in the future.

This means companies will have to adapt to it, but how will the market be shaped? As of now, the current business model of all hyperloop companies is they are the infrastructure managers and the service operators, all in the same company. This sort of organisation is not allowed in rail anymore, so if it is assumed that the case will be the same for hyperloop, managers and operators will have to become two different companies, even if they are under the same holding company. The Fourth Railway Package only allows this until 2034, which suggests that kind of provision will never be a part of a potential hyperloop regulation, meaning infrastructure managers and service operators will have to be two completely independent entities. This is one of the challenges and main changes that affects the current structure of hyperloop companies. Another issue is how is the infrastructure going to be financed, since if the infrastructure manager cannot have a favour treatment when using it, the motivation for building it at all falls. Again, this calls for collaboration between different hyperloop companies and the governments, at local, national and European level. It is the only way a hyperloop network can prosper, by sharing obligations and responsibilities and therefore allowing all stakeholders, including the general population, to reap the positive results.

One of the many challenges hyperloop may face lies within the provisions of the Fourth Railway Package, which clearly states that "High-speed rail services link people and markets in a fast, reliable, environmentally friendly and cost-effective way and encourage a shift of passengers to rail. It is therefore of particular importance to encourage both public and private investment in high speed rail infrastructure". The European Commission and the Union in general has put a lot of time and effort in developing the rail market and in promoting high speed rail as a viable alternative to short-haul flights. Should hyperloop succeed as a viable option, it will render high speed rail obsolete, as was its creator's mindset. This creates a reasonable conflict of interest for regulatory bodies, governments and investors alike, since investments in high speed rail infrastructure don't have short term returns and neither will hyperloop ones. This means that by the time a hyperloop line begins its construction, there will also be high speed rail lines under construction and other ones operating that have not reached the break-even point yet. Will investors want to put their funds on the line for either infrastructure if they are set to compete against each other, knowing that it is very difficult for both to coexist? There is a risk of both types of infrastructure hitting a wall due to the fear of neither advancing in their development. In the European Union the

European Commission and other regulatory bodies have a tremendous power in deciding which infrastructure is built and which is not. This means that it is their call whether hyperloop will be developed in the near future or not. The most likely outcome is that the EU will support hyperloop lines where they don't compete directly with the existing or planned high speed rail network, to try to maximise their investment and involvement with rail until now without compromising the development of a potentially revolutionary mode of transportation.

Coming back to a more tangible aspect of hyperloop, the case study done in this paper focuses on a short line of barely twenty-five kilometres in the South of France. The procedure followed was to study the current accessibility of the area and in particular of the route between the airport and the city centre, which is the line under study. Findings show that while there is an extensive transportation offer for that particular route, travel times are excessive for any other means of transportation than the car and one bus which does not make stops. It was also found that the majority of passengers choose the car to go to the airport, which is un efficient in a number of ways: transports a small amount of people, emits more pollution per passenger than any other vehicle and adds to an already grave problem of congestion in the area. Initially, a hyperloop line makes sense, an alternative that people are willing to choose because it is fast, clean and direct. However, due to the characteristics of the terrain, the geometry and the length of the line do not allow the vehicle to reach a great velocity, meaning the difference in travel time is not consequential. Taking into account the length of the line and the capacity of the pods, which is relatively small, the actual capacity of the system is not extremely high, and comparable to that of a train, setting the optimal speed for maximum capacity at just 160 kilometres per hour. This is achievable with a regular train, let alone a high-speed one. In terms of cost, this particular line has a higher cost per km that the average calculations made so far by different hyperloop companies, because of the high percentage of it that would have to be underground, if not the whole tube: the majority of the line either passes through mountains or through very dense urban population.

So, would building this line really make sense? Does it bring a new service to the population or fill a gap in current transportation? The immediate answer is no, it does not. If it does not make the journey any shorter it is almost as expensive as a high-speed line, why would the local government endorse it or the public use it? The answer is that this line is not thought as a stand-alone infrastructure, but as part of a large European network, connecting city centres and airports all across the continent. That way, someone from Marseille can catch a flight departing from Paris without having to spend the night in another city, or arrive at Paris and sleep in their own home in Marseille in just a few hours. It is in longer distances where hyperloop really makes a difference, but it is important to consider the connections between city centres and airports too, because they will be part of the network, and if they can be sustainable on their own, better. Besides this, building the infrastructure is a long process, and if the sooner the company can start exploiting it, the sooner it will start giving back revenue to fund more construction and operations. It makes sense that the European network will start developing as little lines connecting airports and city centres, and those nodes will then be connected through longer arches, effectively building a European “subway network”.

Hyperloop came to the world as something from out of science-fiction books and is gradually inching towards reality, fast. The moment has come to consider of its actual fit in the territory, the society and the economy. This consideration will take time to study the current situation and how it can be improved by a revolutionary concept such as hyperloop, and the best way to introduce it so that society as a whole can get the most out of it. The main appeal of hyperloop is the speed of its vehicles, but in order for it to actually succeed it also has to be safe, clean and achieve a seamless integration into the existing network. Unlike other modes of transportation, hyperloop arrives to a world collapsed by the number of vehicles, roads, tracks and passengers, and it is the responsibility of all stakeholders involved in the development of the system to find the right fit.

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