Tesi Magistrale

Ing. Energetica e Nucleare

Innovazione nella produzione energetica

High-speed trains comparison to Hyperloop: energy and sustainability

Hyperloop safety analysis and integrations to reach the NOAH concept

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Tanks to my family, for all you do to make me a better man, for all your support, for your gratitude and your teachings. I always keep you in my heart.

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Executive summary

In a time of global changes, where humanity wakes up after a period of indiscriminate exploitation of resources and uncontrolled pollution of air, ground and sea, every chance to reduce damages to the environment must be taken on the fly. Transportation sector consumes, in Europe, one third of total end use energy relying for 90% over fossil fuels, a problem from environmental point of view. Assuming that long displacements are almost a need for actual society and that the airplane is a non-sustainable mean of transport, because of the great energy consumption and the total addiction to fossil fuels, High-Speed Train (HST) seems to be next principal long-distance continental operator.

Objectives of the present analysis are to verify if hyperloop solution is more convenient than others HSTs and to implement an innovative, renewable, large and smart grid, to meet the need for an eco-friendly mean of transport. The method and the technologies under investigation are presented to have good foundations on which build the analysis. Results from a MATLAB flat-travel simulation are compared to evaluate energetic consumption *linked to the only traction system* for AGV, MAGLEV and HYPERLOOP. To find the more ecologic mean of transport a qualitative analysis of sustainability completes the comparison. A focus on hyperloop, through the Preliminary Hazard Analysis (PHA) of the propulsion system and the description of the Network Operator Autonomous Hyperloop (NOAH), completes the paper.

From simulations hyperloop appears like the best high-speed transportation on ground ever, consuming far less than other technologies in traction. Permitting almost 50% of energy regeneration at travel end, going uphill with a lower increase in consumption compared to maglev and AGV. Also, the qualitative analysis indicates it is the best HST to implement, point of view of performance, operational, maintenance and disposal costs.

To make hyperloop a safe system is the work of RAMS ‘engineers, they should localize, analyze and resolve hazards step-by-step advancing in synchronization with the progression of the design. A short introduction to some standard is followed by the presentation of the inductive-deductive method employed to find hazards, then the worksheet based on ECSS standard is commented.

Hyperloop seems the best technology to implement, but, once the energetic needs of vacuum pumps are estimated and added to results, the wind change direction. A solution can be to add an integrated photovoltaic plant on top of its mammoth infrastructure, like TransPod suggests, even if the best solution remains to save energy, not just to produce it from renewable sources. A critical analysis leads to implementing a new concept of the system. Smart energy storages, methanation plants near arrival stations, transportation of thermal energy and precious goods as water and an integrated intermodal system are presented in the NOAH concept.

Concluding, magnetically levitated trains are the future of HST because of better performances and the possibility to reach higher speed. Hyperloop is suggested when crossing mountains and hills, it can regenerate huge quantities of energy thanks to quasi-complete loss of friction, it can be a smart energy operator (for production, storage and transportation). The more suitable infrastructure to build is hyperloop, which implies a series of advantages in the domain of intermodality and real connection. Great attention must be put in the domain of cybersecurity. Further analysis must be developed in the regenerative braking system, which is the best solution and how it is preferable? (onboard or connected to the guideway?). Hyperloop can be only a political project in Europe, connecting all countries in a unique network. Even if this new concept can assume some sci-fi aspects, it is achievable.

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1. Introduction

In this chapter the reader can find the background in which XXI century' society lives, an introduction to different mass transportation points of view, a presentation of the high-speed sector and the characterization of partners for this work.

Nowadays travel is normal, even a must. Going to work, to school, to the sport center, to a club or in holyday, it is possible because it exists an efficient transportation system, public or private. Nowadays society can't renounce the comfort of a fast displacement, perhaps on a new trendy vehicle. Even if everybody knows he/she pollutes heating up consequently the whole planet, generating irreversibilities, he/she can't stop traveling. Energy and transportation are closely linked.

The goals of every mean of transport are to be competitive reducing cost of the whole system, to guarantee safety and security, to have a low environmental impact, to have the capacity of displacing a big variety of heavy loads, to have an easy operativity, to guarantee availability and reliability, to work whatever atmospheric condition and to reach a high level of multimodality with the other means of transport. The goals of the energetic industry are almost the same, thinking about renewable energies and disruptive technologies it is possible to have big advantages in both sectors of transportation and energy production.

This paper deals with a comparison between high-speed ground transportation systems in order to find the best system that will be upgraded with innovative renewable energy production, transportation and storage plans.

1.1. Social background

Transportation sector consumes, in Italy, 32.1% of end use energy in 2015 (123.0 Mtep in 2015) compared to 29.0% in 1990 [1], becoming the second energy consumer sector after the civil one. In France the trend is the same, with a progressive growth (1973-2015) from 20% to 33% of end use energy (162.2 Mtep in 2015) [2]. Dramatic is that the source of transportation energy is fossil fuel for more than 90%: in Italy petroleum products absorb 93.5% of the demand in 2015 suited by bio-fuels (3.0%), natural gas (2.3%) and others (electricity, combustion oil); in France petroleum products are close to 94% of the mix, bio-fuels reaching 6 %.
The major transport modality is road, especially for freight (in Italy 86.5% of freight travel on streets), then aircraft, water and finally we found rail.
To reach one of the objectives of the "Paris Agreement" of long-term temperature rise limited to 2°C is undeniable that an urgent change also in this sector must take place.

1.2. Possible developments of mass transportation

Two major visions, opposed at a hasty approach, but confluent at the same goal, are centered the first on fast mobility connecting long distance cities each other, the second on dense and efficient mobility linking the periphery to the city center(s).
The first approach is well explained by Cesare Marchetti and Jesse H. Ausubel in "The Evolution of Transport" [3], taking in account that human been has four instincts to respond:

- budget of time dedicated to mobility;
- return to the lair in the evening;
- spend within the travel-money budget;
- large accessible territory, as territorial animal;

They propose as solution to enlarge the territory reachable in the travel-time budget or to gain time on the same length by high speed "green" mobility. Resuming the words of Marchetti and Ausubel "*Hard limits to the possible speed of maglevs do not exist if the maglev runs in an evacuated tunnel, […] maglevs may offer the alternative of a city of separate neighborhoods with fast connections*

between them" [3], in 2013 Elon Musk will call this concept HyperLoop, promising to connect cities hundreds of kilometers away.
The second vision, proposed by Yves Crozet [4] and resumed by Carlos Soliman in his report "Hyperloop, le 5ème mode de transport: facteurs de succès et freins au développement" [5] , focus on the generalized social speed, a balance between travel speed, the purchasing power of individual hourly wage and the cost per kilometer payed by the end user and society (this concept was illustrated first by Ivan Illich [6]). A problem with the very high speed is the cost of infrastructures and operations that low the generalized social speed affecting also the real capability of travelers, because travelling at higher speed means higher cost and involve higher hourly salary to afford the gain in time, consequently the users pool shrinks, and the technology can collapse. *Crozet find in trucks and sharing-cars the future of transportation in Europe, because of cheaper infrastructures and lower operative costs.*
At the end, both concepts deal with an increased efficiency, in time or in social cost, and an augmented service in public to the detriment of private transportation. As Latin people used to say: "*verum in medio"* (the truth is in the middle) and a high-speed system cannot exist without an efficient, cost effective, short distance, low speed transportation system.
In this society the second vision is not enough to guarantee the freedom people is used to, that's why this paper will focus on the first vision, high-speed connections between cities. Green mobility is important to the travel network of the future and multimodality will be applied to connect also different environment like the transportation and the energetic ones.

1.3. Actual high-speed systems description

1.3.1. Aircraft

Plane is the more spread high-speed network all over the world. With a cruise speed around 900 km/h at an altitude of about 10000 m, it can connect cities directly and quickly. The principle of lift caused by wings redirection of air is well known and the innovation processed in time permit nowadays to mount performant engines on vehicles to increase thrust and safety while reducing consumption. The cruise altitude is similar for aircrafts with similar propulsion system because performances of engines are strictly linked with air density, for dissipative effects and for combustion efficiency. Aeronautics' reaction engines can be splitted in two major groups: propeller or jet propulsion. Propeller technology increase the amount of motion of external air through blades, that in opposition increase the thrust on the plane. Jet technology can be further splitted in Air-Breathing systems, that increase the amount of motion of the propulsive fluid (a combination of external air and fuel) into the engine, and Rockets systems, that give thrust with the employ of only the on-board fluid [7].
Those technologies are strictly linked with fossil fuels and the carbon dioxide production is huge compared to others means on transport. In addition, the saturation of airports, travel lines and the rise of petroleum cost in future is competing to the search of a valid replacement at least for continental travels.
In 2015 Carbon4 did a research on "Sustainable mobility" for Thalys [8], the Belgian-French-German-Netherlandic high-speed railway operator, underlining that there is a gain in useful time traveling by train (66%) compared to bus (51%), plane (34%) and car (19%) in a door-to-door voyage. Also, from the point of view of the real cost of a business trip "travelling with Thalys can save at least 400 € versus plane and 560 € versus car". In addition, the punctuality is higher for HST and the carbon dioxide per person produced for example in a trip Paris – Amsterdam is ridiculous (6 kg) compared to plane (59 kg), car (48 kg), carpooling (29 kg) and coach (11 kg). Even considering indirect CO_2 emissions the HST system remains less emissive than competitors.
Railway stations are close to city centers, high speed is more efficient and less energy consuming. For sure, intercontinental travelers find in airplanes the only practical way of transport and HST can't substitute but complete the service.

For these reasons in this paper plane is no more investigated for the future of transportation at high speed.

1.3.2. High-Speed Train (HST)

HST uses electro trains, then it is no more linked directly with fossil fuels, hence more sustainable. Two groups of HST are approached, the "traditional" electro train, that found its most famous example in French TGV, and the magnetically levitated electro train, called maglev.

I. "Traditional" electro train

All the "traditional" electro trains have the same conceptual energetic structure.
To power the onboard engines electricity is collected by mean of a pantograph pressing on a catenary, on top of the gauge, or by a third rail or similar systems. Then a transformer low the voltage from the grid and a converter regulates phases to respond to AC or DC needs of the engine. Finally, through a control-communication unit power, energy is given to the motor that can be typically asynchronous or synchronous. Basic differences between two technologies are explained in the following [9].

1.3.2.I.1. Traction technology

Asynchronous motor is supplied by alternating current connected with the stator windings and the definition is given because the rotating magnetic field produced in the stator is faster than the rotor angular speed. Rotor is typically called a squirrel cage because of its cylindrical shape, even if more structures and options are available, the simplicity and operativity of the cage structure dominate the market. Important to understand that all induction motors are asynchronous motors, so the asynchronous nature come from the slip between the rotational field of the stator winding and the induced field in the cage that produce the thrust, or better the torque, following Faraday's law so permitting the rotor angular motion. In this configuration there is no contact between the rotor and the stator, the current needed by rotor reaction is transmitted through induction laws of magnetic field and collected into metallic cage structure made of heavy copper, aluminum or brass. A north pole in the stator induces a south pole in rotor and the stator pole rotates with variation of AC voltage amplitude and polarity.
Synchronous motor has a specific configuration allowing the rotor moving at the same speed of the stator magnetic flux, there is no slip. Basically, there are two major classes of synchronous motors: self-excited and directly excited. The first class uses principles similar to induction motors, containing a rotor that includes teeth, called salient poles, that permit the synchronization with the stator magnetic field. Different solutions are proposed in literature, the best of which, to the context of HST sector, contains stacked steel laminations with a series of teeth for the rotor, with no windings, no permanent magnets, no rare-earth materials, that is called *switched reluctance motor (SRM)*. It is the simplest electric motor feed by direct current, in addition, the absence of any form of conductor on the SRM's rotor lows considerably electric losses. To control the rotor torque, then speed, only the magnitude of winding current in the stator electromagnets is modulated. *The torque is proportional to the amount of current, being unaffected by motor speed*. Many benefits are linked with SR technology as high efficiency over a wide control range, high torque at low currents, unlimited overload performance and constructional advantages [10]. The second class, directly excited motor, uses typically a rotor that contains *permanent magnets* (PM). PM are the salient poles on the rotor, in synchronization with salient pole electromagnets on the stator. The principle is that when the magnetic flux from the stator cross the air gap to the rotor, if the flux is perpendicular no torque is applied and the synchronization is reached; if not, meaning that an angle is formed between the stator and rotor salient poles, a torque is induced in the rotor to reach the synchronization. Switching power to stator electromagnets means controlling the rotor speed, if done at the right time. *With the technological improvement of power electronics and the arrival of IGBT, synchronous engines are more compact and controllable, so they can be installed even in railway traction systems with several advantages*.

1.3.2.I.2. Actual limits

The technology seems ready to be applied everywhere with benefits, transforming hold-fashioned railways in performant HST just developing the traction system, but a closer sniff reveals bad smells.

A problem for the "traditional" HST is the operation between different countries, because of different standards. Just in Europe there are five different electrification systems because on different historical events and evolutions. It means that a train crossing neighboring countries must be equipped to interact with different voltages at high speed, or it must take the time to stop, switch alimentation system then to restart. To maintain a reasonable number of components, not to increase disproportionally the traction system mass, solutions are found in terms of onboard transformers and converters multi-systems, able to switch from a configuration to another quickly and efficiently.
An additional limit, there are more than 20 signaling systems, also there just in Europe, for almost the same functions, affecting the comprehensibility of drivers. To increase interoperability, safety and free market between countries, the *European Rail Traffic Management System* (ERTMS) has been created as a single system for all Europe. Nevertheless, the economic effort for the conversion to a unique system, even if it will increase competitiveness, is high and the realization difficult for each country.

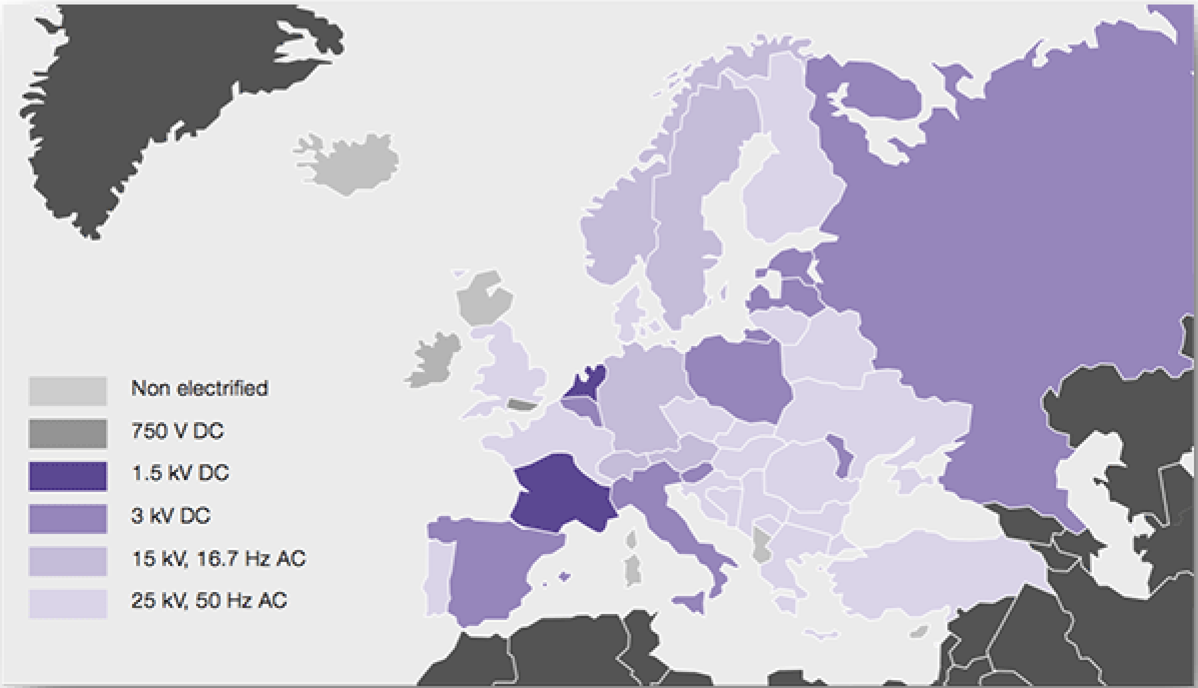


Figure 1 The European railway electrification system [11]

As mentioned above, the actual railway network is not so suitable for the high velocity international connection.
To reinforce this feeling, it is important to know that HST needs a specific rail setting, a minimum radium for curbs, a different power alimentation, a more solid ballast for stability, summarizing a proper infrastructure. It is not just the train that makes the difference. In addition, there are problems of vibration and acoustic pollution at very high speed and natural phenomena, including crossing animals, can affect directly and importantly the journey. The accessibility to the railway permit vandalism, as the catenary tearing to steal the copper. So, it is not suitable to modernize ancient railways to modern HST, it is better to build a new system.

II. Magnetically levitated electro train

The second HST technology, maglev, is contactless, the train levitating on electromagnets installed on or under the guideway. The maglev train is lighter than traditional one first because there are no more wheels, second because the traction system itself is half on board and half on the guideway. In fact, the Linear Induction Motor (LIM) or the Linear Synchronous Motor (LSM) utilize the stator and rotor concepts, but no more on a close-loop rotative way, they stretch the stator on a straight line and the rotor is a segment sliding on it.

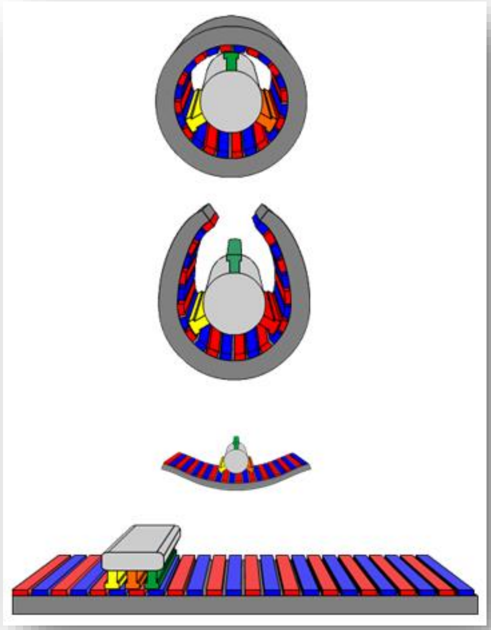


Figure 2 Magnetic engines: from rotational torque to linear thrust [12]

1.3.2.II.1. Traction technology

- *LSM*
  The rate of movement of the magnetic field is controlled, usually electronically, to track the motion of the mobile part (often made of permanent magnets, or soft iron). It exists a long stator LSM version and a short stator one.
- *LIM*
  The force is produced by a moving linear magnetic field acting on conductors in the field. Any conductor that is placed in this field will have eddy currents induced in it thus creating an opposing magnetic field, in accordance with Lenz's law. The two opposing fields will repel each other, thus creating motion as the magnetic field sweeps through the metal.

Main differences between LIM and LSM are the same as for rotative motors. Typically, the “rotor” is the train and the guideway the stator, thus there is the need of powering the guideway. A smart way is power just the section where there is the maglev. The train needs energy to levitate and to move, so power is collected by induction windings from the guideway then transformed and converted for onboard applications. In some solutions there are onboard batteries, that assure the departure and emergency conditions procurement and they can be recharged. LIM technology, as asynchronous motors, doesn’t need physical connection to the power supply system for onboard windings, because of direct use of induction; LSM technology, at the contrary, needs a direct alimentation, provided by batteries which are recharged by induction currents or by an alimentation line. Levitation can be included in the traction system or be a system apart.

1.3.2.II.2. Levitation technology

There are three historical families of levitation systems, Electro Magnetic Suspension (*EMS*), Electro Dynamic Suspension (*EDS*) and *INDUCTRACK*. EDS is founded on magnetic repulsion, so electromagnets on the guideway push upward the electromagnets of the vehicle, the clearance is of few centimeters. Levitation and guidance are assured by the same system, even if they can be separated as in the case of Japanese Chuo Shinkansen.

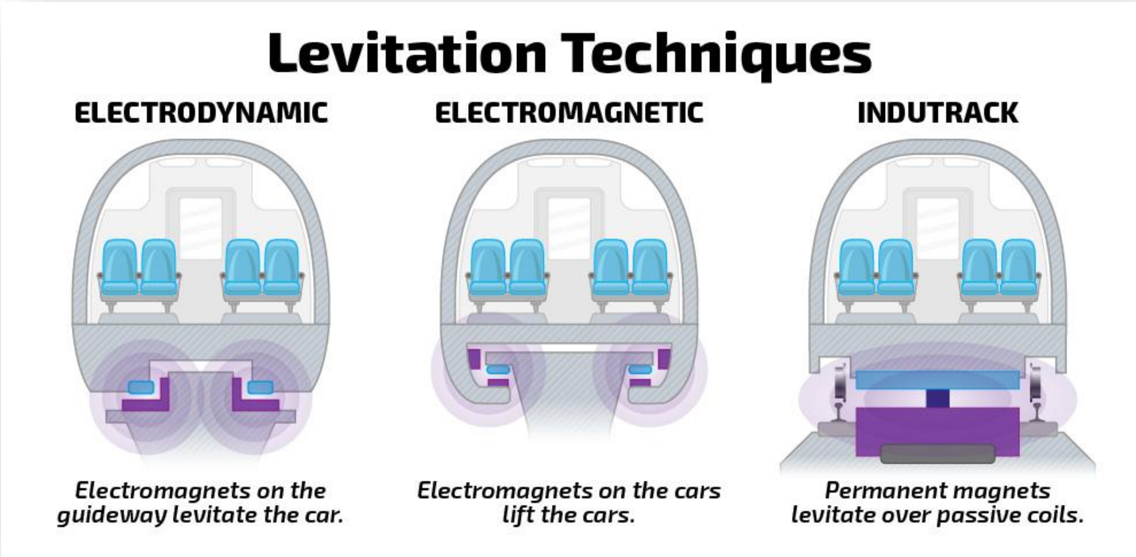


Figure 3 Different configurations for levitation [13]

EMS is founded on magnetic attraction, the electromagnets are put under the guideway and the on-board electromagnets, are pushed upwards until the nominal air gap, 8 - 10 millimeters, is left to provide contactless stability and an efficient magnetic field interaction. In this technology levitation and guidance are physically separated but they act in the same way.

INDUCTRACK, instead of having electromagnets on board, mounts permanent magnets. The material cost is higher, but the operative cost decreases due to a lower energy consumption. Clearance is of few centimeters and the guidance is managed by a secondary system. A new concept of levitation is sorted as a start-up in 2015 in Italy by Ales Tech, called *IRONLEV*. This technology has great advantages [14]:

- it can be applied directly on existing railway infrastructure, allowing more stability and safety requirements than traditional HST;
- it doesn't need energy adopting a passive ferromagnetic levitation due to material properties, permitting lower costs than competitors;
- it is cost affordable for a mass scale system;
- active and dynamic suspensions;
- guidance and levitation are allowed by the same passive system;
- lower magnetic friction due also to the lower parasitic currents in iron (in comparison with aluminum for example);
- better soldering in the hyperloop system, using the same material for the tube and the guideway (same thermal-mechanical-chemical properties);
- elevated maximum cargo capacity;

1.3.2.II.3. Actual limits

Maglev is a quite mature technology and it finds more and more success as a medium-low velocity transportation system. This technology permits also great performance at very high speed, but the cost of infrastructure and operation are still unaffordable. A special guideway must be built, very stable, and only a specifically constructed maglev can operate on it, closing the market for the infrastructure owner. The loss of friction resistance with the guideway decreases the maintenance costs and the acoustic pollution, but it's not enough to convince investors.

1.4. A fifth way of transport, Hyperloop

The bet for the future is Hyperloop, a new concept of transportation. It is somehow similar to a plane, a coach and a train. The vehicle of 27 seats levitates in a near vacuum environment into a tube, propelled at a speed around 1000-1200 km/h for distances of more than 500 km. As an airplane it can connect directly cities by a direct line, even better operating with more renewable energy consumption and increased efficiency (in fact the air friction is almost gone). The vehicle traction system is conceptually similar to maglev, with coupling of an aircraft compressor. The infrastructure cost is like other traditional high-speed train transportation systems (assuming TransPod preliminary cost analysis), the travel experience is faster and safer than an aircraft and, with some precautions, completely eco-friendly.
The Hyperloop system is fascinating and propose ambitious solutions to complete high speed transports of nowadays: plane and High-Speed Train. Its detailed description is afforded in the fourth chapter.

1.5. Partners

This report is made possible by an internship contract between *Polytechnic of Turin* and the R&D section of *IKOS Consulting*, *IKOS LAB*, in Paris.

Ikos was found in 2005 by two engineers having great hope in railway industry, it is a consulting corporation specialized in railway sector starting also an energetic program. Currently with 650 employees in 12 countries, *Ikos* 2020 objectives are to reach the leadership in railway area, catch the goal of 1000 employees, extend operation all over the world and stay at the top of innovation with the R&D section*, Ikos Lab*. *Ikos* is partner since January 2017 of *TransPod*, a Canadian start-up founded on October 2015 carrying on the Hyperloop project. With offices in Canada, France and Italy, *TransPod* has a big support from its partners, as *MERMEC, SITAEL, LIEBHERR-AEROSPACE, Blackshape Aircraft, REC Architecture, MaRS Discovery District*. The collaboration between *TransPod* and *Ikos Consulting* permits the realization of a solid based analysis also for Hyperloop, even if specific parts remain confidential.

TransPod team is looking to build a new transportation system, applying on magnetic levitation in quasi absence of air. The objective of Ikos Consulting is to elaborate the power converter unit, including the cooling system, and to reinforce the partnership it proposed a series of internship centered on the investigation of Hyperloop possible benefits. To validate TransPod choice, Ikos Lab team, as expert in complex problem-solving, proposed different analysis:

1. Analysis of actual freight transportation, prevision of future trend applying TRIZ methods, then research of possible market places where Hyperloop can be competitive;
2. Analysis of success factors and slowdown factors to the development of Hyperloop in France;
3. Evaluation of an Hyperloop corridor Paris-Berlin;
4. Analysis of different HTS from an energetic and sustainable point of view;

The author thanks these companies for their support and commitment.

By mean of this introduction the author hopes to attract the attention on the global impact that transportation has on everyday life, focusing just on a little portion of the total: high-speed long travels. Energy consumption in this sector must develop outside the fossil tradition.

2. Objectives

Introducing the objectives of his work, the author directs the reader to a full understanding of the paper, giving a conceptual map of the scheme followed. Chapters' content is presented step by step.

The goals of this paper are *to validate* what designers affirm on hyperloop, showing its benefits and drawbacks compared to other high-speed ground transportation systems; then *to support* hyperloop project performing a safety analysis on its propulsion system and an energetic based and eco-friendly grid of continental breadth (Network Operator Autonomous Hyperloop). In the NOAH concept the "railway" is no more a way of displacement, it is the way European countries can coalesce towards a better common future. Then underlining problems and possible solutions to hyperloop implementation, the author wants to enlarge the discussion about this new technology in different environment (political, economic, decision-making) directing possible work developments. To reach his objectives, he answers the following questions:

- What is the more energy saver and sustainable HST for long (more than 500 km) journeys between AGV, MAGLEV, HYPERLOOP?
- Is hyperloop a safe mean of transport?
- Why should people accept such a mastodontic work?

To answer the first question an energetic quantitative analysis, related to the only traction need is simulated on matlab. A qualitative analysis of performance, production, operativity, maintainability, disposal and environmental impact is addressed to find the more sustainable HST. For the second aspect, hyperloop is safe if it is well designed. The starting point is the preliminary hazard analysis. To answer the third question a critical analysis is addressed to main obstacles individuated in the technology, which result is a new concept of connection: NOAH. Energy, intermodality and connectivity are the key word of the project.

Following the typical structure of a presentation, the articulation of the activities is presented chapter by chapter in a logical succession.

Chapter 1 – Introduction

The social background in which HST should be implemented is analyzed. Two different points of view, as regard possible developments of mass transportation, are discussed and, consequently, actual high-speed systems are introduced. A brief opening to hyperloop is followed by the presentation of the firm, and partners, where the author did the internship.

Chapter 2 – Objectives

Of interest and synthesis, this chapter aims to describe the common thread of this work. The goal being to support hyperloop project, a series of steps are proposed to validate the better behavior in terms of energy, sustainability and safety. To potentiate this position, the author introduces aspects related to innovation in energy production, storage and distribution. Also, with NOAH concept, the author supports the project scratching the surface in the fields of intermodality and augmented connectivity.

Chapter 3 – Methodology

In this chapter are described all the steps that allow to get to the main objective. The first point is to uniform a common base level knowledge about the physics concepts applied to the completion of the energy simulation, the principles of mechanics and thermodynamics are outlined and explained. Then a more detailed presentation of formulae useful for simulation are introduced, followed by the presentation of the algorithm implemented in matlab. Leaving the quantitative analysis, the qualitative is described, by mean of the criteria followed by the author. Afterwards, the presentation of different standards to perform the Preliminary Hazard Analysis (PHA) are shown, the ECSS standard is selected to proceed into the work. An inductive-deductive method to find out hazards is implemented with success. The chapter concludes with the description of TRIZ, that has been applied to hyperloop for the critical analysis.

Chapter 4 – High-Speed Trains description

It follows the description of the state of the art of different technologies: Italo AGV, Shanghai Maglev and TransPod Hyperloop. An historical background with a technical description will be the foundations on which start further analysis and discussions.

Chapter 5 – Energetic and sustainability analysis, assumptions and results

Main point of this chapter is to show results from the application of the principles of mechanics and thermodynamics to the three cases studied, to get quantitative results. The energetic analysis is performed to each system with a MATLAB simulation of a 500 kilometers flat travel. The aim is not to have a complete analysis of the energy consumption, including control, communication, signalization, air climatization, passenger comfort and other auxiliaries, but *only the traction system energetic need is analyzed*. This approach underlines the best technology only in the field of propulsion, without difference between the kind of journey and the kind of service. It follows the economic and environmental qualitative analysis, showing assumptions and results.

Chapter 6 – RAMS and critical analysis: NOAH, a new transportation concept

A focus on the hyperloop project, new entry in the HST kingdom, is necessary. The first part of the chapter is consecrated to the explanation on how the Preliminary Hazard Analysis is applied, with the presentation of results. It is a first step into the RAMS analysis that will make hyperloop the safer ground system ever through a continuous development of technology and engineers' expertise. The second part aims to resolve criticalities found during all previous analysis. A survey is made to verify if a real gain in energy consumption is reached with the hyperloop solution, as designers affirm, englobing also vacuum system needs and implementing possible benefits from an integrated PV plant. The author proposes to englobe into the infrastructure innovative energy production plants, storage systems and a service of energy transportation. Hyperloop is a challenge for actual engineers, and the potentialities linked to this disruptive technology are under investigation. Sustainability can reach a level never met before if some aspects are not neglected, like intermodality. And safety must be reached by application of standards and by hard work.

Chapter 7 – Conclusion

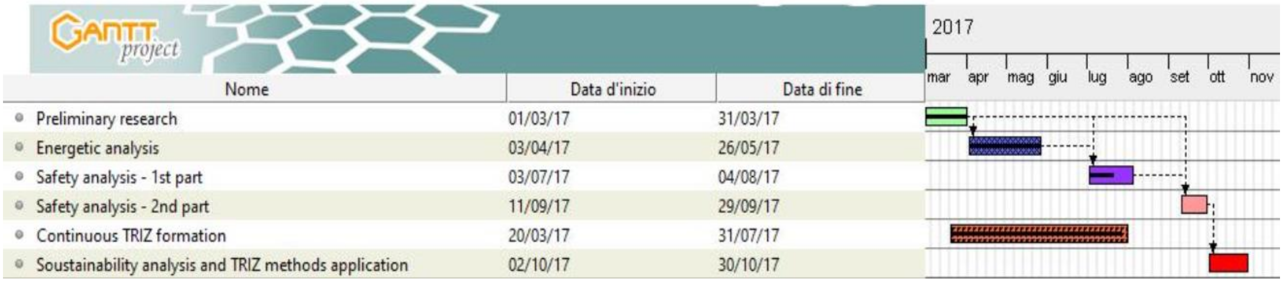
In conclusion, after a digest of results obtained and some technical considerations, a general comment about the possibility to establish European roots by a solid autonomous network is addressed.

Once the conceptual scheme of the paper is presented, the reader can continue his lecture starting to immerse into methodology.

3. Methodology

As announced, the technical part of the study is addressed in the following lines. It is useful to understand the logic behind, to validate results, to found limits and to give an estimation of the error that affect the work.

To begin it is presented an introduction on the management of the internship, which has been defined with Ikos Lab's manager and temporally divided as follow.



During the first month the learning of engineering railway's laws and equations is approached. A big variety of books, articles, papers and direct experiences have detailed and integrated the apprenticeship. Platforms as *ResearchGate, HAL, TRIP (*now *TRIMIS) and ENERGY.GOV* have been explored with success. During this first month the energetic analysis is outlined, though not in detail, and the activity of the internship becomes consistent. While the definition of the energetic analysis takes shape, the documentary analysis is addressed more in detail focusing on data interesting for the development of this paper. A preliminary contact is also addressed to important figures of the railway sector in France, while integration into Ikos Lab team is promoted with great success.

3.1. General physic

Basic knowledge of physics is the starting point to run the iterative simulation. The laws of mechanics are here presented, first from Newton's formulation:

1. *A body not subjected to external forces remains in a state of stillness or uniform rectilinear motion;*
2. *The resultant of the forces applied on a body is equal to the product of the body mass for acceleration;*
3. *When two bodies interact, the force that the first exercises on the second is equal and opposite to the force that the second exercises on the first*

It will follow the presentation of mechanics and thermodynamics.

Dynamics argues about the causes of motion, thus forces, and explains interactions between bodies.

$$a = \frac{F}{m}\left[\frac{m}{s^2}\right]$$

To study the motion from a descriptive point of view, independently from the causes that provoke it, then kinematics is needed. Talking about the uniformly accelerated rectilinear motion with initial instant $t_0 = 0$:

$$v = v_0 + a * t = \frac{\Delta s}{\Delta t}\left[\frac{m}{s}\right]$$

$$s = \frac{1}{2}at^2 + v_0 * t + s_0\ [m]$$

Combining the laws of mechanics is possible to evaluate the velocity starting from a determined comfortable acceleration, at the same the path space. From dynamics, knowing the mass and the acceleration, the force is extrapolated. From the principles of thermodynamics is possible to evaluate power and consequently energy. Here the formulae and in the following the explanation of thermodynamics:

$$P = F * v \; [kW]$$

$$E = P * t \; [kWh]$$

The thermodynamic principles applied to this study are the fundamental laws of fluids:

- Law of conservation of mass
- Law of variation of the amount of motion
- Law of energy conservation (1st Principle of thermodynamic)
- Law of energy evolution (2nd Principle of thermodynamic)

Generally, also in this paper, the fluid is considered as homogeneous, continuous and isotropic. The upper two laws deal with fluid dynamic, while the others two are the base concepts for thermodynamic. To be able to apply those laws to a system a description of the matter involved and the way it interacts with the environment is needed, so a focus on *state equations* is necessary. Perfect gas equation is applied for the study of *compressible fluids* as air:

$$pv = RT$$

Pressure $[Pa]$, specific volume $[m^3/kg]$ and temperature $[k]$ are linked by $R = \frac{\Re}{\mu}$, the ratio of the gas elastic constant $\Re = 8314.47 \left[\frac{J}{kmol\ K}\right]$ over the molecular weight μ $[kmol/kg]$ of the gas. Perfect gas equation can be further splitted into ideal or quasi ideal gas. Ideal gas has constant properties, like the pressure or volume mass thermic capacity (c_p, c_v); quasi ideal gas has those two properties as function of the temperature. In the typical perfect gas case study, the evolution of the fluid follows a polytropic transformation:

$$pv^m = constant$$

$$dQ_{tot} = c\ dT$$

Where m, the exponent of the polytropic, and c, the constant specific heat, have special value linked with the concerned evolution:

EVOLUTION	m	c
$Isochoric\ (v = constant)$	$\pm\infty$	c_v
$Isobar\ (p = constant)$	0	c_p
$Isotherm\ (T{=}constant)$	1	$\pm\infty$
$Isentropic\ (S = constant)$	$k = c_p/c_v$	0
$Polytropic\ (c = constant)$	$constant$	$constant$

In the study of *uncompressible fluids*, not performed in this paper but addressed here for completeness, a simple state equation can be:

$$\rho = cost \left[\frac{kg}{m^3}\right]$$

It exists two different ways to approach the phenomena occurring in the thermodynamic system:

- The substantial point of view (Lagrangian one)

  It refers to a well-defined and constant-in-time portion of matter, called $close\ system$. There is no exchange of matter with the external environment. During the process the close system is delimited by a $control\ surface$ that can deform itself.

- The local point of view (Eulerian one)

  It refers to an $open\ system$, exchange of matter with the external environment is possible. The system is defined by a $control\ volume$ nondeformable. A well-known easy case is the $permanent\ flux$, where thermodynamic parameters are independent from time

Both are valid but depending on the case one can be more convenient than the other. In this paper a *Lagrangian point of view is followed, assuming that the train body is a close system*. The *law of conservation of mass*, can be expressed as:

$$m_1 = m_2 = m\ [kg]$$

The *law of variation of the amount of motion***,** a vector quantity, can be written:

$$m\vec{v}_1 + \vec{Q} = m\vec{v}_2$$

Meaning that applying an external force to the system, $\vec{Q}$, velocity and direction will vary dependently. The law of energy conservation affirms that all the thermal and mechanical energy received by a system from its external environment has the consequence to be transformed into inner energy for the system. It means that energy cannot be created or destroyed, just transformed from a form to another. The *1st Principle of Thermodynamic* (1st PoT) assumes the form, for the *Lagrangian point of view:*

$$Q_e + L_e = \Delta U + \Delta E_{c,cf,gr}$$

$$Q_e + L_w = \Delta U + \int pdv$$

$$L_e = -\int pdv + L_w + \Delta E_{c,cf,gr}$$

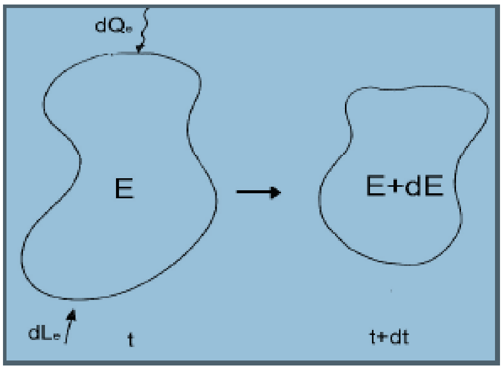


Figure 4 Control surface for 1st PoT, Lagrangian point of view

The 1st Pot for the *Eulerian point of view:*

$$Q_e + L_i = \Delta i + \Delta E_{c,cf,gr}$$
$$Q_e + L_w = \Delta i - \int vdp$$
$$L_i = \int vdp + L_w + \Delta E_{c,cf,gr}$$

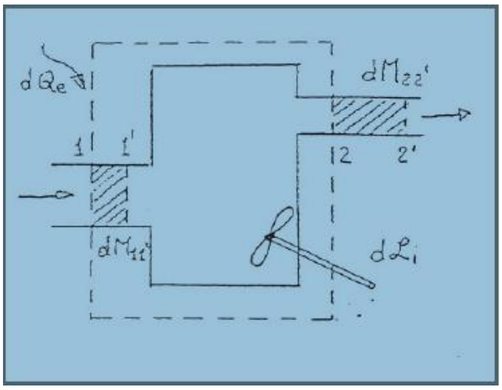


Figure 5 Control volume for 1st PoT, Eulerian point of view

The law of energy evolution affirms that every time there is a transformation of energy from a form to another (mechanical, chemical, electrical, etc.), while the conservation of total energy is guaranteed by 1st PoT, there is a degradation on energy from a higher to a lower form, the lowest form being the thermal one. Energy degradation is due to a state function called *entropy* and it is a measure of irreversibility of the evolution. *The 2nd Principle of Thermodynamic (2nd PoT)*

$$dQ_e + dL_w = TdS$$

For an ideal gas, starting from condition *i* and finishing to condition *f*:

$$\Delta S = S_f - S_i = \int_i^f \frac{dU}{T} + \int_i^f \frac{pdv}{T} = c_v \ln \frac{T_f}{T_i} + R \ln \frac{v_f}{v_i}$$

$$\Delta S = S_f - S_i = \int_i^f \frac{di}{T} - \int_i^f \frac{vdp}{T} = c_p \ln \frac{T_f}{T_i} - R \ln \frac{p_f}{p_i}$$

It is possible to sum up the general consideration that:

i. If $dL_w = 0$, there are no losses for fluid dynamic friction (reversible transformation)
ii. If $dQ_e = 0$, there is no heat transfer from the exterior (adiabatic transformation)
iii. Then $dS = 0$, an adiabatic and reversible transformation is also isentropic

Leaning on the previous principles the energetic analysis takes shape. The Lagrangian point of view is followed, and the close system is the train itself. It is assumed that there is not heat exchange between the close system and the environment (adiabatic system), the inner energy is constant at a first approximation and the gravitational energy is constant too, being the simulated travel completely flat.

$$L_e = L_w + \Delta E_c + \Delta E_{cf}$$

3.2. Formulae for simulations

Keeping in mind the foundations of mechanics and thermodynamics, the reader can proceed into the understanding of the formulae included into the simulation.

For more traditional ***AGV*** it is possible to dispose of a chart containing force (F) on y axis and velocity (v) on x axis, completed with the curb of cumulative resistive forces (R), that considers rolling resistance, mechanical rubbing and aerodynamic friction. The 25 KW AC supply energy system is utilized with the 0 ‰ curve (flat travel) for R.

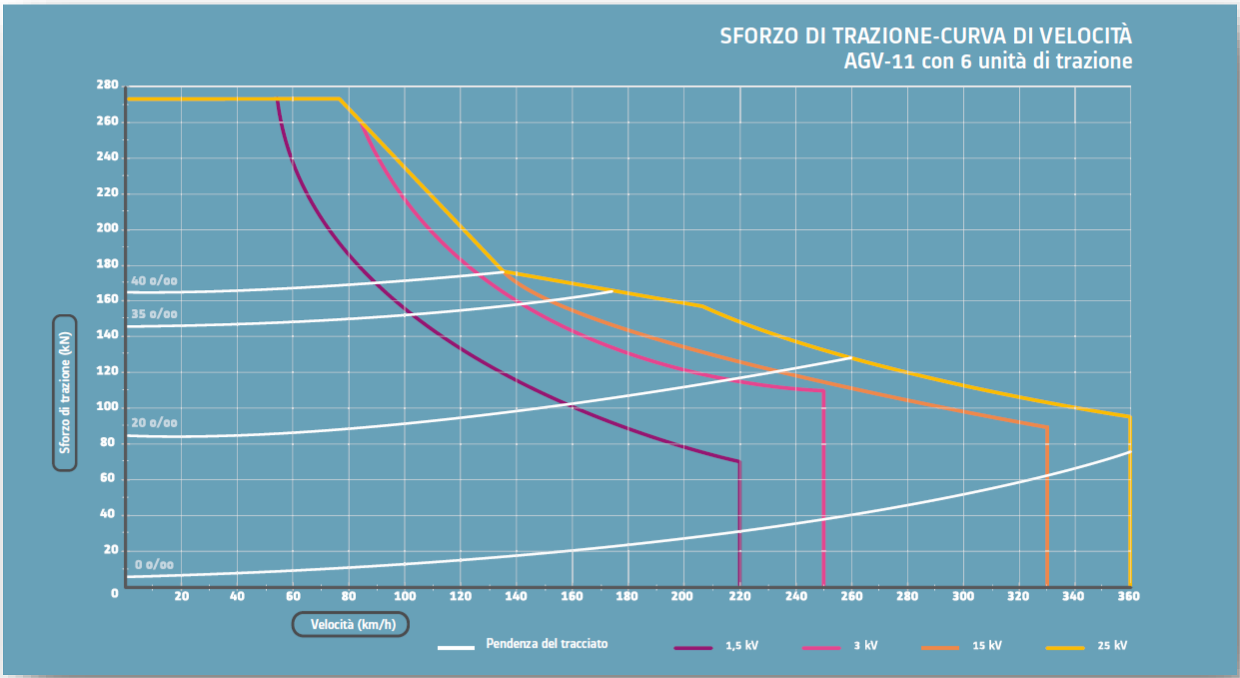


Figure 6 Traction - Velocity curves for AGV with 11 vehicles and 6 traction units [15]

Friction losses are known, the previous chart link traction effort with speed, then the *general equation of motion* can be presented, putting in result the connection between forces

$$F_j - R - Mgsin(h) = (1 + \beta)M\,a$$

Traction effort, reduced of resistance and opposing gravitational component, must be equal to global mass multiplied by acceleration and the inertia coefficient for rotating bodies. Typical rotating bodies are wheels, shafts and rotors, the all-inclusive value utilized in the simulation is the higher proposed in literature [16]. Incrementing in an iterative algorithm speed by a dv appropriate, from $v = 0$ until v_{max}, it is then possible to evaluate power consumption and energy needs of the propulsion system:

$$P_{ps} = F_j * v \ [kW]$$

$$E_{ps} = P * t * eff$$

The simulation takes in account also the evolution of the virtual travel, so it enlarges the study to space and time evolution, to mention a few, but formulae are not presented here because they are not essential for the comprehension of traction needs. In attached all the scripts are available.

Entering more in detail in the study of ***MAGLEV*** and ***HYPERLOOP*** technologies, very similar from the functional point of view, knowing that there are not rotative parts, neither rolling resistance nor mechanical rubbing, it is possible to simplify the equation for a flat travel:

$$L_e = L_w + \Delta E_c + \Delta E_{cf}$$

Obtaining:

$$F_e * s = F_{drag} * s + M\frac{v_2^2 - v_1^2}{2}$$

Simplifying the *general equation of motion* is found, and the external force can be expressed as:

$$F_e = F_{drag} + Ma$$

The drag force equation is obtainable from literature

$$F_{drag} = \frac{1}{2} * \rho_{air} * v^2 * c_D * A_{front}$$

Differently from AGV, it is not possible to have a chart force-velocity, so it is necessary to adopt another solution. It is assumed constant acceleration of the vehicle $\bar{a} = const$, then the real acceleration is calculated:

$$a_r = \frac{M * \bar{a} + F_{drag} + M * g * \sin(\alpha)}{M}$$

From this acceleration, multiplying for total mass, the traction effort is obtained. Then power and energy are easily calculated after evaluating velocity by kinematics.

$$F_e = M * a_r$$

$$P_{prop} = F_e * v + P_{lg} * M$$

$$E_{prop} = P_{prop} * t * \eta$$

P_{lg} is the mass power consumption for levitation and guidance. This number is extrapolated from literature and it is a constant value in the present analysis.

3.3. Quantitative analysis: algorithm application

The algorithm of the simulation is the practical way in which previously presented formulae interact in a logical consecution, to give birth to quantitative results on MATLAB.

During the second and third months of the internship, the simulation of a virtual flat travel of 500 km has been performed on MATLAB to calculate energy traction needs. For the sake of simplicity, a visual representation of the iterative process will explain how the formulae are connected in the algorithm. Even if the following explanation is expressed for AGV, the same conceptual operations are valid for Maglev and hyperloop' simulations, with differences discussed later.

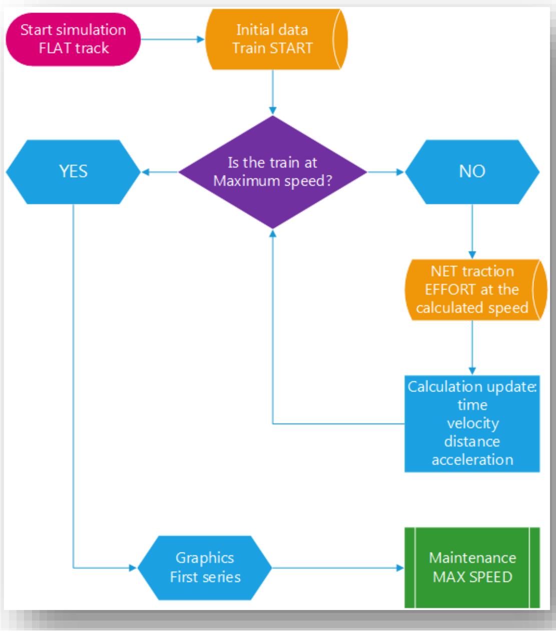


Figure 7 First phase: Acceleration from zero to maximum speed

<u>First phase</u>

The algorithm has in input F_j, R, β, M, the maximum and the initial speed ($v_j = 0$ at the first step). As implementation for processing next step, a constant speed increase dv is applied. In output it calculates space, time, speed, acceleration, power and energy.

<u>Second phase</u>

Until the virtual vehicle reaches 498 km, since the braking distance is calculated at 2 km from the end of the virtual travel, speed is maintained at a constant 360 km/h by a start&stop simulation. That means the engines are off until speed is around $V_{max} - \Delta v$, then when speed goes down this limit, due to friction losses, engines turn on until V_{max} is reached.

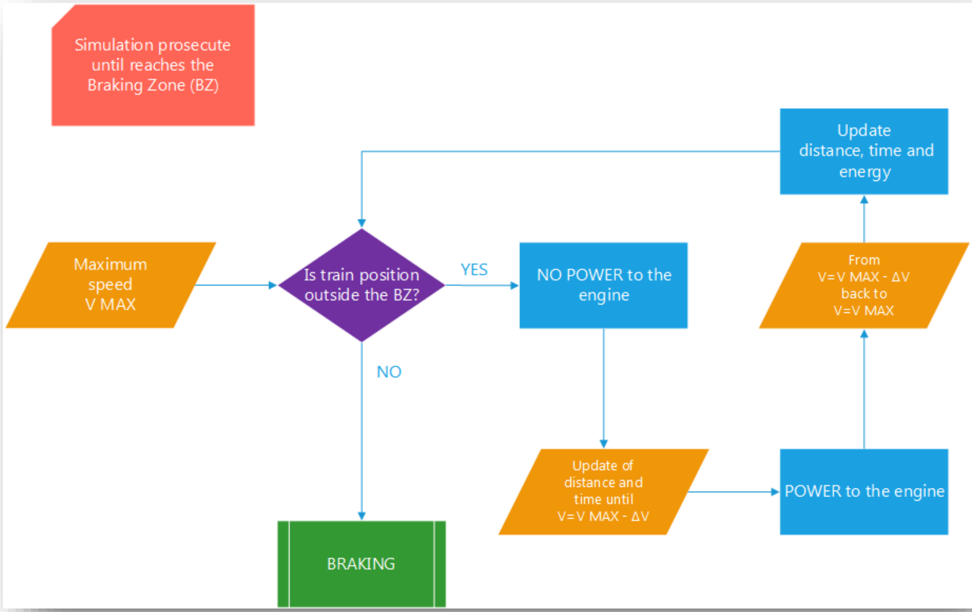


Figure 8 Second phase: Maximum speed is maintained for all the journey

<u>Third phase</u>

Regenerative braking, available due to PMM adaptability to serve as generator in switched mode, is adopted until a comfortable threshold value of deceleration is reached, then a traditional pneumatic system, thus dissipative, stops the virtual vehicle.

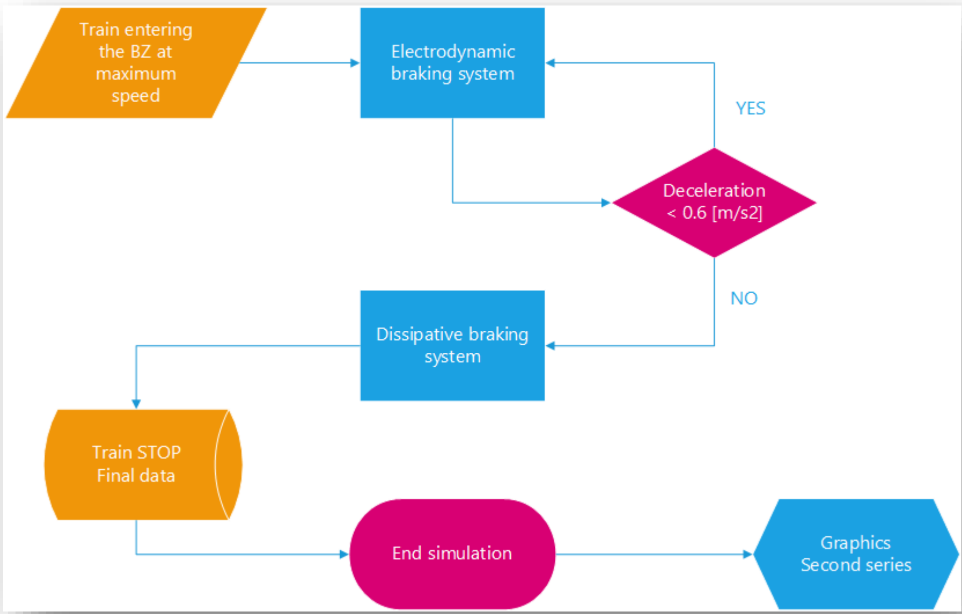


Figure 9 Third phase: regenerative braking and pneumatic brake for stoppage

The conceptual development of the virtual travel, divided into three phases, is quite the same for MAGLEV and HYPERLOOP. Iteration is driven by *time increase* dt. As long the maximum speed is not reached, simulation loops in a first phase of uniformly accelerated motion. The algorithm evaluates instantaneous real acceleration needed to obtain the constant average comfortable acceleration that people can feel into the vehicle, consequently energy need for traction. Once top speed is reached, acceleration gets to zero and the traction system simulates a start&stop system driven by velocity control, that is the second phase: maximum speed maintenance. Finally, the third phase starts when virtual vehicle enters the last 12 km for maglev or 40 km for TransPod, that is the appropriate braking zone for a comfortable stop. Comfortable means a deceleration/acceleration of $1{,}3\,\frac{m}{s^2}$ in normal operation (up to $5\,\frac{m}{s^2}$ in emergency braking). All the energy produced by braking system is considered available for regeneration, even if just a 40% can be harvest by actual technology.

AGV under investigation can take on board 460 passengers, Shanghai maglev can dispose of 562 seats in high-density condition or 376 in a low-density condition, here a 460 passengers' capacity is established to fit with other systems. TransPod has just 27 seats, so to equalize results for hyperloop technology 17 Pods are launched. An average mass of 75 kg per person takes in account also the baggage. It is evident, to compare those technologies the author imposes an equal number of passengers to be displaced.

As we deal with simulations, there are *hypothesis and limits*.

For AGV, F-v chart is the main data source and it is reliable, so even if some boundary conditions are proposed, as sunny weather, wind absence, cleanliness of the rail and ideal gas behavior for the air, simulation should fall close enough to reality.

Focusing on the MAGLEV case, average acceleration is extrapolated from a real-based energy consumption graphic [17], but referring to different operative conditions than the simulated ones. The same for the evaluation of the mass power consumption for levitation and guidance [18]. Also, real energy consumption curb is applied to the model by visual reconstruction on Matlab. The same weather condition as for AGV is proposed.

Focusing on the HYPERLOOP case, average acceleration is estimated at $\frac{1}{10}g$ for both acceleration and deceleration, even if TransPod suggest a higher acceleration ($5\,\frac{m}{s^2}$ that is uncomfortable for actual standard). It is assumed a 100 Pa condition for air into the tube. The mass power consumption for levitation and guidance is the same calculated for maglev. This is a conservative choice, in fact Hyperloop technology, lighter and with strong physical boundaries to the environment, should consume less energy to levitate. The air compressor consumption is assumed linear with pod' speed, reaching its maximum at 1000 km/h that is the top speed in simulation. Removing or drastically reducing air friction is without any doubt the best improvement, so it is fundamental to take in account, in the critical analysis, *energy demand of the vacuum system* for hyperloop technology and the *integrated photovoltaic production*.

To guarantee the completeness and the reliability of the simulations, a bibliography research is developed continuously, enlarging the domain of data and the precision of information. When the lack of data interrupts the energetic analysis, time is spent to investigate new solutions and different approaches to the goal of evaluate traction needs. Some quantities, like the global power supply efficiency for hyperloop, are estimated with caution by the author. *The error associated to the simulation is not predictable, but the author considers that the error affects simulations in a homogeneous way, so results are comparable.*

The instrument of the quantitative research is explained, with its conceptual base and its limits. The simulation is the base point to get numerical results to compare technologies point of view of energy consumption by the traction system.

3.4. Qualitative analysis

The logic behind the qualitative analysis is explained. The comparison is made by a combination of different strategic environments.

This step of the analysis involves a comparison between different technologies, to find the more sustainable mean of transport. Based on the descriptive analysis of chapter 4, the qualitative comparison can be judged by the author. This analysis lies on an economic comparison and an environmental one, focusing on various steps of the life cycle. The conceptual, prototyping, test and validation phases are not proposed, the reader can imagine that it is not the aim of the author to investigate this sector deeply, because the technologies presented have a different maturity and evolution in time. Thus, it is assumed that all technologies are available and commercial. To perform the analysis and get results, a score is assigned to each system under investigation, from 1 to 3. “1” identify the worst technology, “3” the best one and “2” the middle one. At the end of the analysis the HST that totalizes the highest score is the more sustainable. The analysis relies on performance, production cost, maintenance cost, operative cost and environmental cost.

3.5. Preliminary Hazard Analysis

In the following an introduction to RAMS through different standards. The ECCS standard, selected for the present paper, is well described, together with the method used to find hazards.

A deep immersion in RAMS analysis, just for hyperloop propulsion system, covers two months. The first approach is to detect the better analysis to perform. The hyperloop project is at an early stage, so only a preliminary hazard analysis (PHA) can be finalized. After the PHA is selected as instrument, the choice of the standard to apply takes some time for investigation. The analysis of four different standards reveals that the military standard should be correct, nevertheless to follow TransPod approach *the ECSS standard is followed*. TransPod has developed the concept in a detailed way, for confidential reasons in this paper it cannot be published. The functional analysis of the traction system of the hyperloop pod (vehicle) is built by the author on the project design and description. Once the system is defined, the identification of hazards is performed by mean of an inductive-deductive-iterative method. The risk matrix is built and a worksheet is performed. For critical events some countermeasures are identified to low the risk associated. The analysis presents an assessment of the potential hazards and possible safety mitigation measures that may be associated with the implementation of the TransPod Hyperloop Project. The objective of the PHA is to start a work that will follow the design in every step, from conception to disposal. Safety can be reached, even if there are apparently hazards that cannot be overtaken. To explain that hyperloop is not by definition a safe mean of transport, but hard work from a team of experts must develop instruments, countermeasures, auxiliary and emergency systems to low risk under the acceptability threshold.

The PHA cover three typical hazards:

- Fire/Life Safety – Hazards resulting in accidents involving injuries, fatalities, or property damage due to fire, smoke, explosion, or toxic due to these causes;
- System Safety – Hazards resulting in accidents involving injuries, fatalities, or property damage due to system design, construction, equipment, operations and maintenance, or lack of quality assurance;
- Security – Hazards from acts of intentional harm, including terrorism, resulting in injuries, fatalities, or property damage. The PHA does address limited security hazards but does not include a Threat and Vulnerability Assessment.

3.5.1. Military standard

MIL-STD-882E
11 May 2012

SUPERSEDING
MIL-STD-882D
10 February 2000

DEPARTMENT OF DEFENSE
STANDARD PRACTICE

SYSTEM SAFETY

[SCOPE] This system safety standard practice identifies the DoD SE approach to eliminating hazards, where possible, and minimizing risks where those hazards cannot be eliminated. This Standard covers hazards as they apply to systems / products / equipment / infrastructure (including both hardware and software) throughout design, development, test, production, use, and disposal.

[PURPOSE] The purpose is to perform and document a Preliminary Hazard Analysis (PHA) to identify hazards, assess the initial risks, and identify potential mitigation measures.

It contains a list of definitions, hazard severity categories and hazard probability levels accommodated in later standards. In the domain of RAMS definitions are of crucial importance to make a unique comprehension of the work, the same can be said about the definition of severity, probability and the risk matrix.

SEVERITY CATEGORIES		
Description	**Severity Category**	**Mishap Result Criteria**
Catastrophic	**1**	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	**2**	Could result in one or more of the following: permanent partial disability,injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	**3**	Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	**4**	Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K.

Hazards associated with the proposed design or function shall be evaluated for severity and probability based on the best available data. That can be done by database research if the technology is mature, by analyzing historical disaster reports, by acknowledgment of experts and by inductive/deductive methods.

PROBABILITY LEVELS			
Description	**Level**	**Specific Individual Item**	**Fleet or Inventory**
Frequent	**A**	Likely to occur often in the life of an item.	Continuously experienced.
Probable	**B**	Will occur several times in the life of an item.	Will occur frequently.
Occasional	**C**	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	**D**	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.
Improbable	**E**	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.
Eliminated	**F**	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.

The combination of probability and severity gives the Risk assessment matrix, here below an example.

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

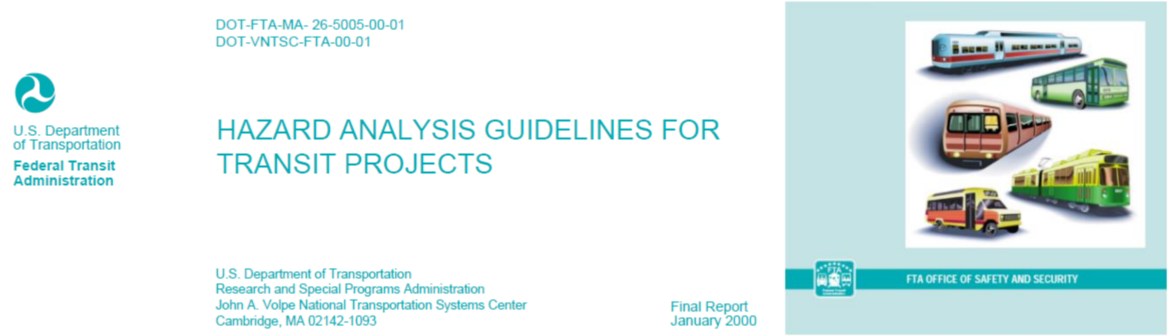
The PHA shall identify hazards by considering the potential contribution to subsystem or system mishaps from:

a. System components
b. Energy sources
c. Ordnance
d. Hazardous Materials (HAZMAT)
e. Interfaces and controls
f. Interface considerations to other systems when in a network or System-of-Systems (SoS) architecture
g. Material compatibilities
h. Inadvertent activation
i. Commercial-Off-the-Shelf (COTS), Government-Off-the-Shelf (GOTS), Non-Developmental Items (NDIs), and Government-Furnished Equipment (GFE)
j. Software, including software developed by other contractors or sources. Design criteria to control safety-significant software commands and responses (e.g., inadvertent command, failure to command, untimely command or responses and inappropriate magnitude) shall be identified, and appropriate action shall be taken to incorporate these into the software (and related hardware) specifications

k. Operating environment and constraints
l. Procedures for operating, test, maintenance, built-in-test, diagnostics, emergencies, explosive ordnance render-safe and emergency disposal
m. Modes
n. Health hazards
o. Environmental impacts
p. Human factors engineering and human error analysis of operator functions, tasks, and requirements
q. Life support requirements and safety implications in manned systems, including crash safety, egress, rescue, survival, and salvage
r. Event-unique hazards
s. Built infrastructure, real property installed equipment, and support equipment
t. Malfunctions of the SoS, systems, subsystems, components, or software

The military standard is complete and address a huge family of hazards, of course not of them must be investigated in the present paper. Because it was one of the first appeared it has been a source of inspiration for following standards, so the interest in presenting its global overview.

3.5.2. U.S Department of Transportation standard (FTA)



[SCOPE] This document presents guidelines for the preparation of hazard analyses to assist local authorities in developing a safe and secure transit system. The guidelines discuss safety critical systems and subsystems, types of hazard analyses, when hazard analyses should be performed, and the hazard analysis philosophy.

[PURPOSE] A primary goal of the FTA is to assist the transit industry as well as state and local organizations in providing the highest practical level of safety and security for the passengers and employees of the Nation's mass transportation systems. […] The purpose of the PHA is to provide an early assessment of the hazards associated with a design or concept.

The hazard identification and resolution process can be resumed in a graphic way.

DEFINE THE SYSTEM

- DEFINE THE PHYSICAL AND FUNCTIONAL CHARACTERISTICS, AND UNDERSTAND AND EVALUATE THE PEOPLE, PROCEDURES, FACILITIES, EQUIPMENT, AND THE ENVIRONMENT.

▼

IDENTIFY HAZARDS

- IDENTIFY HAZARDS AND UNDESIRED EVENTS
- DETERMINE THE CAUSES OF HAZARDS

▼

ASSESS HAZARDS

- DETERMINE SEVERITY
- DETERMINE PROBABILITY
- DECIDE TO ACCEPT RISK OR ELIMINATE/CONTROL

▼

RESOLVE HAZARDS

- ASSUME RISK OR
- IMPLEMENT CORRECTIVE ACTION
  - ELIMINATE
  - CONTROL

▼

FOLLOW-UP

- MONITOR FOR EFFECTIVENESS
- MONITOR FOR UNEXPECTED HAZARDS

System Definition: equipment, procedures, people and environment. A knowledge and understanding of how the individual system elements interface with each other are essential to the hazard identification effort.

There are five basic methods of *Hazard Identification*:

- Data from previous accidents (case studies) or operating experience
- Scenario development and judgment of knowledgeable individuals
- Generic hazard checklists
- Formal hazard analysis techniques
- Design data and drawings

Hazard Assessment: assess the identified hazards in terms of the severity or consequence and the probability of occurrence of each type of hazard (in general conformity with the latest MIL-STD-882 (D)).

Hazard Resolution: hazards can be resolved by deciding to either assume the risk associated with the hazard or to eliminate or control the hazard.

- Design to eliminate or reduce the hazard
- Provide safety devices
- Provide warning devices
- Institute special procedures or training
- Accept the hazard
- Eliminate the use of the system/subsystem/equipment that creates an unacceptable hazard

Follow-up: it is necessary to monitor the effectiveness of recommended countermeasures and ensure that new hazards are not introduced as a result. In addition, whenever changes are made to any of the system elements (equipment, procedures, people and/or environment), a hazard analysis should be conducted to identify and resolve any new hazards.

Generally, the result of a PHA assumes the form of a worksheet containing ordinate and condensed information. Method and discipline are the key features of this domain.

Preliminary Hazard Analysis (PHA) Form Sheet

System:			PRELIMINARY HAZARD ANALYSIS (PHA)				Of
Subsystem:			Rev. No:			Prepared by:	Date:
Drawing No:						Reviewed by:	Date:
OHA No.:	Rev. No.					Approved by:	Date:
General Description			Hazard Cause/Effect		Hazard Risk Index	Corrective Action	
No.	Hazard Description	Failure Rate	Potential Cause	Effect on Subsystem/ System		Possible Controlling Measures and Remarks	Resolution

3.5.3. European standard

NORME EUROPÉENNE | **EN 50126-1**

EUROPÄISCHE NORM

EUROPEAN STANDARD | Septembre 1999

ICS 29.280; 45.020 | **Comprend corrigendum de mai 2006 et de mai 2010**

Version française

Applications ferroviaires -
Spécification et démonstration
de la fiabilité, de la disponibilité,
de la maintenablité et de la sécurité (FDMS)
Partie 1: Exigences de base et procédés génériques

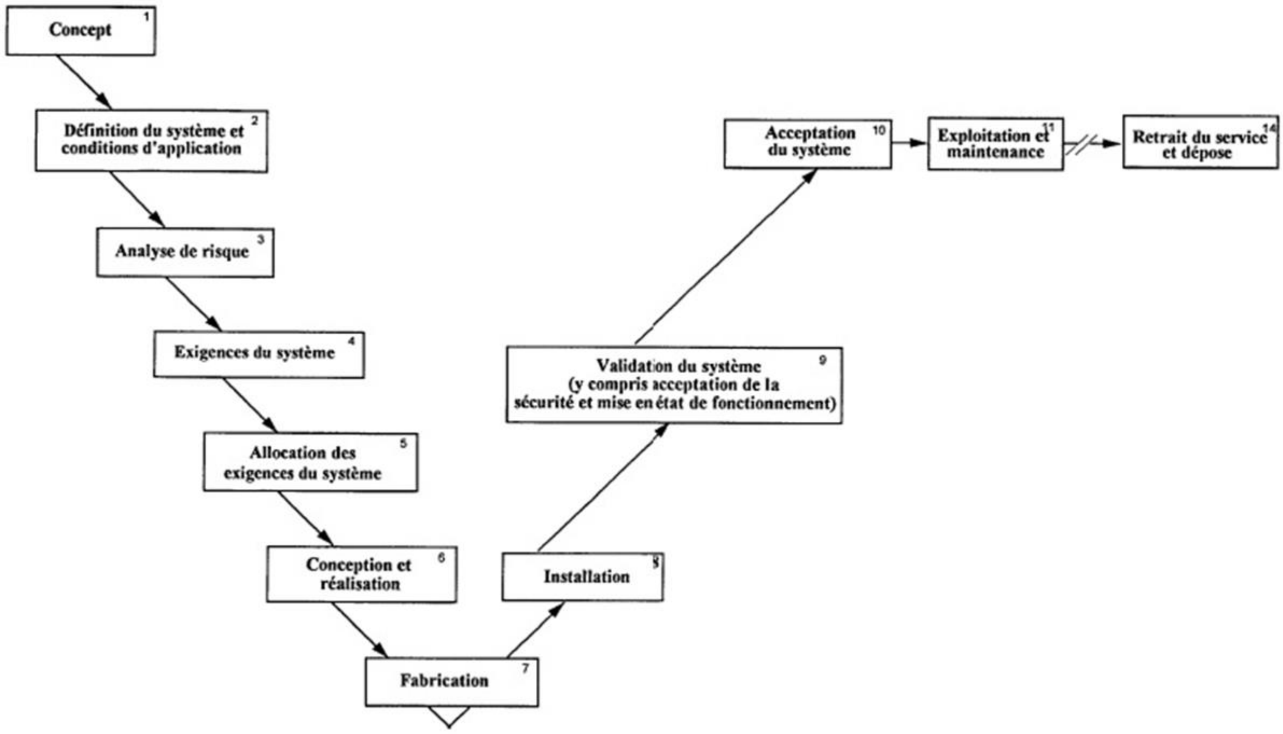
Bahnanwendungen -
Spezifikation und Nachweis
der Zuverlässigkeit, Verfügbarkeit,
Instandhaltbarkeit, Sicherheit (RAMS)
Teil 1: Grundlegede Anforderungen und
genereller Prozess

Railway applications -
The specification and demonstration
of Reliability, Availability, Maintainability
and Safety (RAMS)
Part 1: Basic requirements and generic
process

cen CENELEC

This standard is mostly like military's one, adapted for the specific railway application.

The object of the analysis is fragmented into is life cycle phases through the so called "V representation", that helps identifying at which point the technology is processed and it defines the correct instrument to figure out results for the RAMS analysis, between other uses.



Only the points 1, 2 and 3 of this representation are interesting for an early analysis like the PHA, so the other are not addressed in the following and the most curious can find all the information in the European Standard.

Life Cycle Phase	General tasks	Reliability Availability Maintainability tasks	Safety tasks
• **Concept**	• Define application domain and project's goal • Define project's concept • Undertake the financial analysis and the feasibility studies • Establish project's management	• Examine RAM performances previously obtained • Take into account RAM aspects of project	• Examine previous safety performances • Take in account safety aspects of the project • Examine safety goals and politic
• **System definition and application's conditions**	• Define mission profile of the system • Prepare system description • Identify exploitation and maintainability strategies • Identify maintainability conditions • Identify the influence of constraints of the actual infrastructure on the system	• Evaluate feedback data relatively to RAM • Perform the preliminary RAM analysis • Establish the RAM politic • Identify long term exploitation and maintainability conditions • Identify the influence of the existent infrastructure's constraints on the system's RAM	• Evaluate feedback data relatively to safety • Perform the preliminary analysis of dangerous situations • Establish the (global) plan for safety • Define the risk acceptability criteria • Identify constraints of existing infrastructure on the system' safety

• **Risk analysis**	• Undertake the risk analysis linked to the project		• Perform the analysis of dangerous situations and hazards for system' safety • Open the register of Dangerous Situations • Proceed risk evaluation

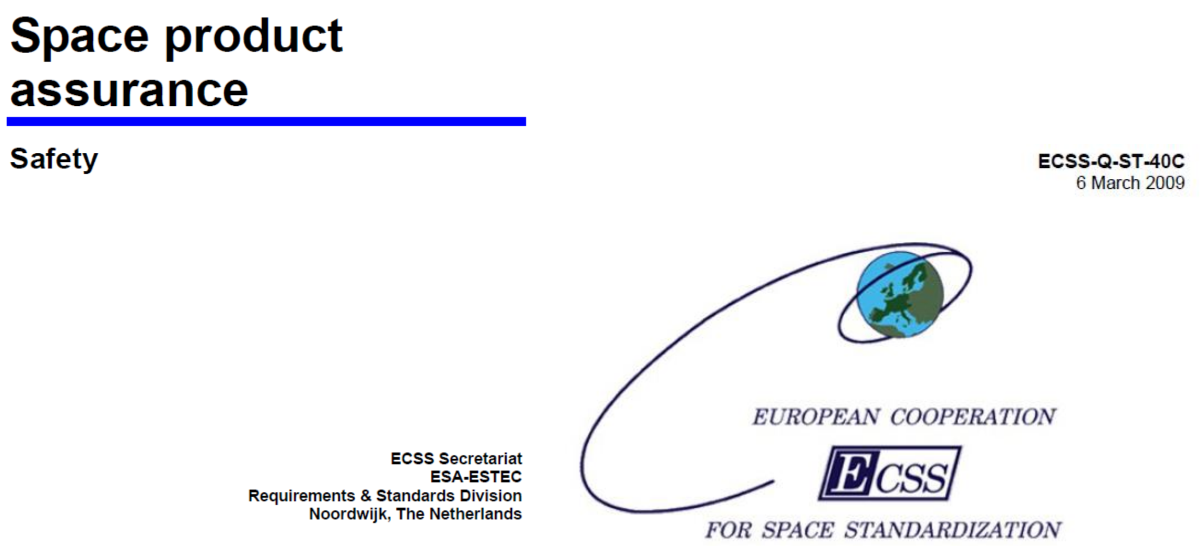
The concept phase has as objective to develop at a sufficient comprehensible level the system to realize in a satisfactory way further tasks to perform the RAMS life cycle analysis. Goals of phase 2 are:

- Define the system mission profile;
- Define borderlines;
- Define application conditions influencing system's characteristics;
- Define analysis domain of dangerous situations;
- Define RAMS system's politic and establish system's safety plan.

Risk analysis at point 3 has multiple objectives:

- Identify dangerous situation associated to the system;
- Identify hazards and establish a continuous process for risk management;
- Determine the risk associated to dangerous situations

3.5.4. ECSS standard


Space product assurance

Safety

ECSS-Q-ST-40C
6 March 2009

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Objective and scope of this standard are the same of the military standard, but with boundary conditions linked to space activity. In this environment a big interest is put on machines and engines, considering the Artificial Intelligence as paradigmatic part of the system. Accuracy, precision and punctuality of actions are assisted by computers. As regard for TransPod, every action will be controlled by remote from a Control Unit Base governed by sophisticated software. In the standard it is specifically addressed that:

Electronic, electrical, electromechanical (EEE) components used to support safety-critical functions in flight standard hardware shall be selected and procured in accordance with the applicable program requirements of ECSS-Q-ST-60.

Software criticality:

- Safety aspects associated with the software function shall be an integral part of the overall system safety efforts and not be assessed in isolation
- A software component shall be considered safety-critical if the loss or degradation of its function, or its incorrect or inadvertent operation, can result in catastrophic or critical consequences

As the goal of this paper is to argument a PHA, just *Phase 0* of the following program task has relevance.

5.7.1 Safety program tasks and reviews

- *Phase 0 – Mission analysis/Needs identification*
  a. *Analyze safety requirements and lessons-learnt associated with similar previous missions*
  b. *Perform PHA of the proposed system and operations concept to support concept trade-offs*
  c. *Perform comparative safety risk assessment of the concept options*
  d. *Identify the relevant project safety requirements*
  e. *Plan safety activities for the feasibility phase*
  f. *Support the mission definition review*
- *Phase A – Feasibility*
- *Phase B – Preliminary definition*
- *Phase C/D – Detailed definition, production and qualification testing*
- *Phase E – Utilization*
- *Phase F – Disposal*

It is interesting to see similarities and differences between the previous standards not only to select one method in place of another, but also to see how the same concept can evolve in different areas with different boundary conditions.

3.5.5. Focus on selected ECSS standard

To process the PHA of TransPod's Hyperloop Project the ECSS-Q-ST-40C [2009] standard has been selected as the most suitable. Hazard analysis, as written in *ECSS standard*, shall be performed in a systematic manner, beginning in the concept phase and continuing through the operational phase, until end-of-life and disposal. Hazard analysis shall support the hazard reduction process, identify and evaluate:

- ❖ hazards associated with system design, its operation (both on ground and in flight) and the operation environment;
- ❖ the hazardous effects resulting from the physical and functional propagation of initiator events
- ❖ the hazardous events resulting from the failure of system functions and functional components
- ❖ time critical situations

The following potential initiator events shall be considered:

- hardware failure (random or time dependent)
- latent software error
- operator error
- design inadequacies, including:
  - inadequate margins
  - unintended operating modes caused by sneak-circuits
  - material inadequacies and incompatibilities
  - hardware-software interactions
- natural and induced environmental effects
- procedural deficiencies

Hazard analysis includes a systematic analysis of the “system” operations and operating procedures that shall be performed in the detailed design and operational stages of a project. The systematic analysis of system operation and operating procedures shall be repeated as the design and operational detail evolves, including the system’s operational modes and man-machine interfaces. *Terms are specific to the standard* and they must be used in the right way:

- HAZARD
  Hazards are potential threats to the safety of a system. They are not events
- ACCIDENT
- FAILURE
- RISK
- SAFETY
- CAUSE
- LIKELIHOOD
- SYSTEM
  Set of interdependent elements constituted to achieve a given objective by performing a specified function [IEC 50:1992]. *NOTE* The system is separated from the environment and other external systems by an imaginary surface which cuts the links between them and the considered system. Through these links, the system is affected by the environment, is acted upon by the external systems, or acts itself on the environment or the external systems.

The HAZARD DESCRIPTION is also important and represent a key word for a fast and unique interpretation, here below some examples:

- Function loss
- Malfunction (fail to start/fail to stop)
- Malfunction/ Loss of Other System
- Human Error / Misuse
- External Circumstances

Of capital role the definition of the RISK MATRIX. The RAMS analysis can be applied only after the risk matrix is presented, as indicated in ECSS standard the severity of consequences is the following.

Table 6-1: Severity of consequences

Severity	Level	Dependability (refer to ECSS-Q-ST-30) *Extract from ECSS-Q-ST-30*	Safety (ECSS-Q-ST-40)
Catastrophic	1	Failures propagation	Loss of life, life-threatening or permanently disabling injury or occupational illness; Loss of system; Loss of an interfacing manned flight system; Loss of launch site facilities; Severe detrimental environmental effects.
Critical	2	Loss of mission	Temporarily disabling but not life-threatening injury, or temporary occupational illness; Major damage to interfacing flight system; Major damage to ground facilities; Major damage to public or private property; Major detrimental environmental effects.
Major	3	Major mission degradation	---
Minor or Negligible	4	Minor mission degradation or any other effect	---
NOTE: When several categories can be applied to the system or system component, the highest severity takes priority			

Then the probability levels aim to give an order of magnitude to the occurrence of events. For a PHA in fact it is not possible to have the probability in terms of specific numbers, as happens in more advanced life cycle phases.

PROBABILITY LEVELS			
Description	**Level**	**Specific Individual Item**	**Fleet or Inventory**
Frequent	**A**	Likely to occur often in the life of an item.	Continuously experienced.
Probable	**B**	Will occur several times in the life of an item.	Will occur frequently.
Occasional	**C**	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	**D**	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.
Improbable	**E**	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.
Eliminated	**F**	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.

The author defines an appropriate RISK ASSESSMENT MATRIX that influences the results of this analysis and it will be a starting point for further analysis.

RISK ASSESSMENT MATRIX				
Severity / Probability	Catastrophic (1)	Critical (2)	Major (3)	Minor or Negligible (4)
Frequent (A)	HIGH	HIGH	HIGH	SERIOUS
Probable (B)	HIGH	HIGH	SERIOUS	MEDIUM
Occasional (C)	HIGH	HIGH	SERIOUS	MEDIUM
Remote (D)	SERIOUS	SERIOUS	MEDIUM	LOW
Improbable (E)	MEDIUM	MEDIUM	LOW	LOW
Eliminated (F)	Eliminated			

Finally, for the comprehension of the worksheet an ulterior legend (Hazard Log) explains the operative condition taken in account, giving also a compact structure to identify hazards. In the last row of the table below, by the acronyms PE the author identifies a general condition of operativity that has no incidence on the analyzed system, but by the system to the ambient.

HAZARD LOG	
ACCELERATION / BRAKING	AB
BOARDING PASSENGERS	BP
MANUTENTION	MN
INSTALLATION / CONTROL	IC
EMERGENCY	EM
PEOPLE & ENVIRONMENT	PE

3.5.6. Method to find hazards

For the present PHA a method based on inductive and deductive analysis is applied to find out hazards [19]. There are general rules that must be undertaken, for example a team of at least 5 people from different working areas and different background is suggested to have a more complete global overview. For the present analysis it was not possible to finance a team, but some suggestions come out from the RAMS' pole of skills in IKOS group.

The proposed method has the objective of:

- Determine the dangers (hazards) and their causes (dangerous entities, situations, potential accidents);

- Evaluate the severity of the consequences of situations and accidents previously determined;
- Deduce the measurement and the suitable actions to eliminate or reduce dangerous situations and the potential accidents.

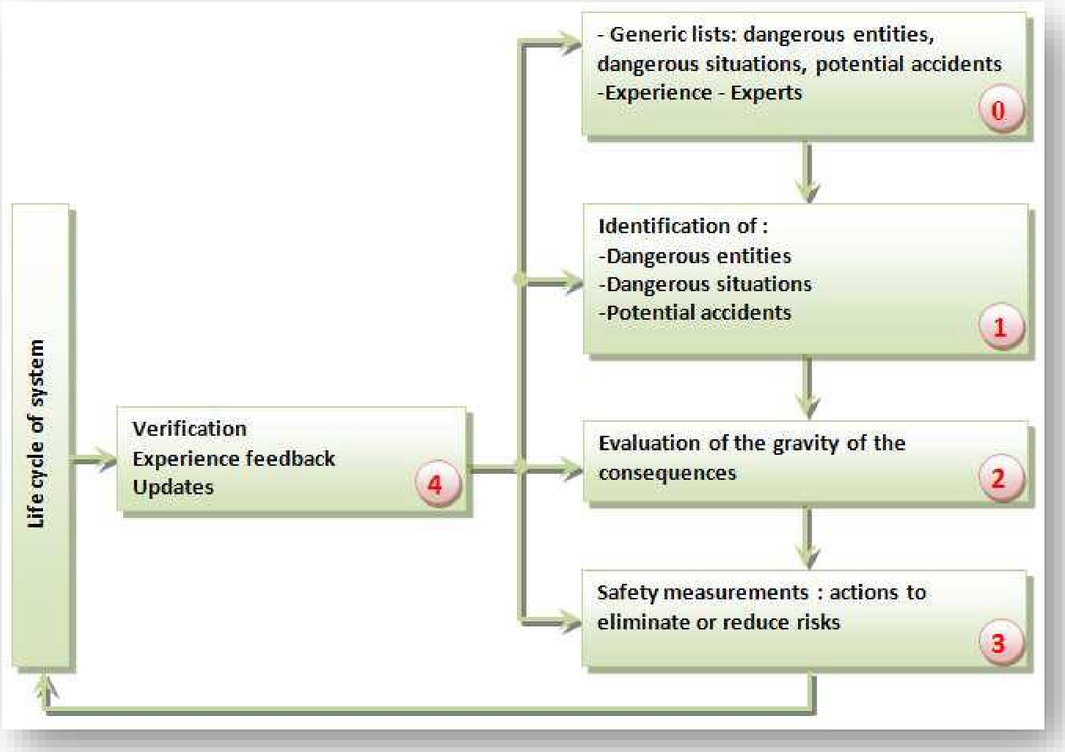


Figure 10 Steps of PHA evolution [20]

This method is related only to point 1 in the previous figure, where both inductive and deductive approaches are employed. When it is possible to access a complete list of all potential accidents a deductive method is suitable and complete. But for a system allowing a great number of scenarios or with consistent lacks in the list of potential accidents using only a deductive method lead to an insufficient result.

		ER [Dangerous entities / feared events]	D [Dangers]	A [Potential accidents]
Phase 0	By knowledge of the authors, literature analysis and meetings with experts, a previous list is drafted	ER0	D0	A0
Phase 1	(Inductive phase) For every component of list ER a match must be obtained in list D. There will probably be components of D0 not linked with ER0 (D01) and a generation of new dangers from feared events (D1)	ER0	ER0 → D0 ER0 → D1 D01 = DD1	A0

Phase 2	(Inductive phase) For every component of list D a match must be obtained in list A. There will probably be components of A0 not linked with DD1 (A01) and a generation of new potential accidents from dangers (A1)	ER0	DD1	DD1 → A0 DD1 →A1 A01 = A1
Phase 3	It is used to identify the damages from AA1	ER0	DD1	A1
Phase 4	(Deductive phase) For the components of potential accidents not already linked (A01) are determined possible dangers (D02)	ER0	DD1 D02	D02 ← A01
Phase 5	(Deductive phase) For the components of dangers not already linked (D01 U D02) are determined feared events (ER01)	ER0 ER01	ER01←D01, D02	A1
Phase 6	It is like phase 0, a new starting point. Re-cycle from phase 1 to phase 5 only if there are still some elements not connected to elements of the other lists.	ER1	D1	A1

3.6. Critical analysis

Once the results are obtained and technologies compared, a critical analysis, taking in account major auxiliary systems for hyperloop, rebalances the verdict. Trying to solve negative aspects of hyperloop, following safety precautions, some innovative solutions are presented and grouped under the acronyms NOAH.

After the conclusion of simulation, for each system, a power point presentation is performed at Ikos Lab to explain results and limits, then to collect opinions by the team to further enlarge the analysis. This activity, with focus on the only hyperloop technology, reveals weaknesses:

- The quantitative analysis is addressed only to the traction system, with no interest in auxiliary consumption (the vacuum system is a strong auxiliary system);
- Power losses from sub-station to the vehicle are not taken in account;
- Electric national grid that supply energy to electro-trains produce for a large quantity from fossil fuels, not reducing but localizing the production of pollutants.

Other points are outlined to the detriment of HSTs:

- Car is the major mean of transport because it is the faster service door-to-door;
- There is no need to displace goods at high velocity;
- High velocity implies computer-based control of the travel with high risk in case of damage to electronics or infiltrations;
- Hyperloop has a big impact, crossing land for thousand kilometers.

A critical analysis tries to overcome these weaknesses suggesting innovative solutions. *TRIZ* formation is a great advantage of the internship period. “Teoriya Resheeniya Izobreatatelskikh Zadatch”, better TRIZ, is a methodic technique to apply innovation and creativity to solve real complex problems. Ikos Lab’s manager is expert in this art and he applies TRIZ to manage and direct factory R&D. After a problem analysis phase, the general TRIZ method discomposes a real problem into a more approachable problem, by abstraction. Then applying TRIZ solution patterns and inventive principles an abstract solution is reached. The last step is to go back to a real specific solution. By TRIZ methods innovation in hyperloop can be explored from different points of view. Finally, the new concept of Network Operator Autonomous Hyperloop (NOAH) is delineated, referring to implemented intermodality by use of a Personal Public Transit (PPT) unit, arguing about renewable energies linked with Hyperloop, air cleaning chance, water purification and precious goods efficient transportation. Connections are established by the knowledge and experience of the author to push further autonomy and self-sufficiency.

To resume, in this chapter a complete description of the methodology that allows the author to validate its results is shown. The reader can find all the physics behind, the methods and the description of the arguments that lead to the conclusion. It is suggested to fully understand this part before approaching results and critical analysis.

4. High-speed trains description

To understand differences between technologies, a global overview is addressed for each case studied. In the descriptive chapter an historical presentation lets place to a technical one.

4.1. ALSTOM AGV

The principal historical benchmarks in railway can be regrouped in three periods:

- The steam age during XIX century
- The electricity age from roughly 1880 to 1970
- The electronic age from 1970 up to now

The electronic age has a champion known all over the world, the French TGV. It was just an option during early ’60, accompanied by AeroTrain and Turbotrain, but after the first *Shinkansen* line in Japan (1964) and the petroleum crisis of 1973, French investors focused on the full electric TGV. It started operativity on September 1981.

During the last 50 years rectifiers and inverters have been deeply innovated, from Diode, Thyristor, GTO thyristor to IGBT (Insulated Gate Bipolar Transistor). The evolution of power electronic allows to install AC engines, more performant, instead of DC ones and with this technology a motor can be converted in a generator easily and in a short time; the engine is more reliable and less heavy.

Figure 11 AGV: train, catenary and ballast [21]

“Automotrice Grande Vitesse” is the French extension of AGV, meaning “Railcar High Speed”. It is the last evolution of TGV, coming out from ALSTOM [22], [15], [23], [24]. This company experiences high speed trains from 1970, incrementing safety, comfort and performance gradually. In June 2004 the prototyping project for AGV starts, enabling ALSTOM to present the full-scale model at EurailSpeed in Milano, November 2005. Only 2 years later the first coach is build and the 3rd April 2007 a TGV Duplex with AGV components establish the new speed record on rail at 574.8 km/h.

The 17th January 2008 NTV ("Nuovo Trasporto Viaggiatori"), Italy's first high speed private operator, sign a contract for 25 AGV trainsets. For some years AGV is tested alternatively in Czech Republic and France, starting commercial service in 2012 with "Italo". During these five years, the AGV.italo has consolidated its presence in Italy and NTV has decided to enlarge its fleet of high-speed trains. Up-to-now the 25 trains have run 60 million kilometers and transported over 40 million passengers, the service has been expanded with the inclusion of a bus service from 2015, to link even more cities to the main Italian railway stations. In September 2017 the French ALSTOM fused with the German SIEMENS, following the Macron-Merkel axis to create "European industrial champions" in order to be relevant on a world-wide scale.

The AGV structure is innovative compared to most famous TGV because of peculiar structure and upgraded traction system. A train usually hosts in the first and last vehicle the motor, with the energy alimentation, transformation and control system: the motor truck or locomotive. The simply hauled passengers/baggage compartments or trailers host people and auxiliaries for passenger's comfort else goods.

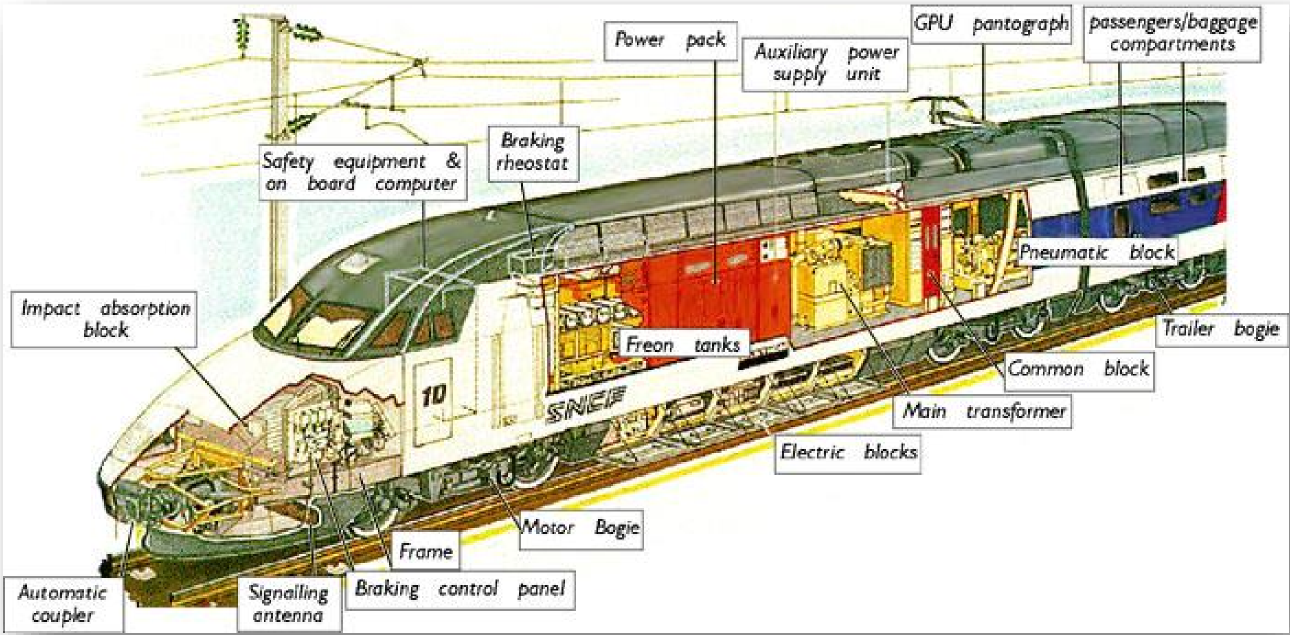


Figure 12 Traction unit of TGV [48]

With AGV technology the motor is distributed directly on boogies, for an optimized traction efficiency and safer configuration in case of fail. The concept of locomotive is loss, even the first coach can embark (less) people. Here the main difference between train and auto-train. In addition, the boogies are no more distributed in a traditional way, namely one at the beginning and the other at the end of each coach, but the boogie is shared by two close coaches. A train of eleven vehicles has no more 22 boogies, but 12 with a gain in mass reduction. The articulated trainset architecture is considered the safest in Very High Speed (VHS), to know that AGV is not the first mounting this solution.

Figure 13 AGV motorized boogie [25]

Thanks to lower mass, dislocated traction and Permanent Magnet Motor (PMM), this system is less dissipative and has increased agility. Motorized boogies are the odd ones (the even ones are trailed) and they host two PMM each. The PMM technology, totally electric, is more efficient in acceleration, when in braking it can regenerate energy that can be injected in the power system supply, with a peak power of about 9 MW for a 11 coaches train with 460 passengers. This braking energy is useful mostly when another train is within 30 km from the regenerative system. PMM is a synchronous DC motor with permanents magnets in the rotor, controlled by an IGBT traction converter.

MAIN MOTOR CHARACTERISTICS	
Traction motor type designation	12 LCS 3550 C
Technology	Synchronous
Power rating	900 kW @ 3,500 rpm
Continuous torque	2,456 N.m
Mechanical transmission	Coupling
Cooling system	Self-ventilated
Closed/Open	Closed
Outline: width x height x length (mm)	650 x 650 x 735
Weight (kg)	785

Figure 14 PMM in service on Italo AGV train,
main motor characteristics [26]

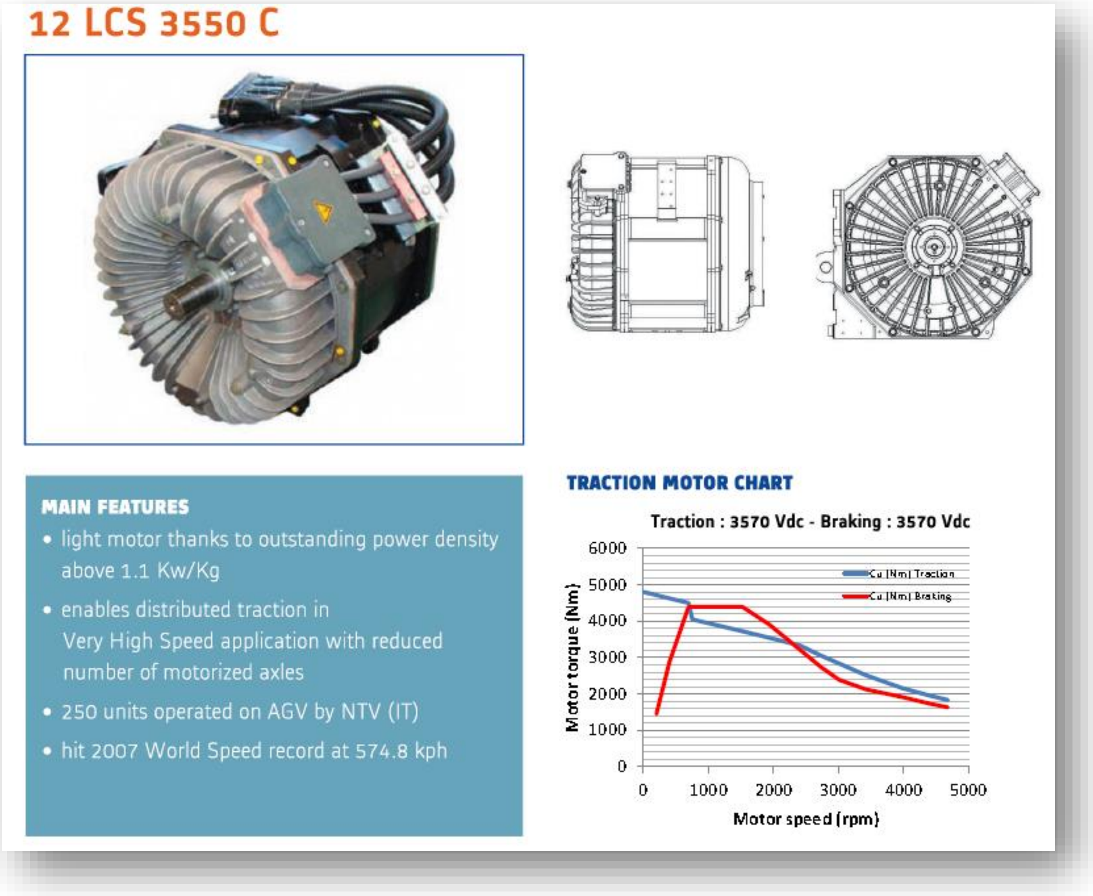


Figure 15 PMM main features and traction chart [26]

In this paper, only the energy chain from the pantograph to the motor is considered so *no further investigations are made for the sub-stations and the catenary transmission*. Main components of the traction system are:

- the pantograph for the electrical reception when in contact with the catenary
- the switch for the system protection
- the transformer for the modulation of voltage
- the converter for the variation of AC-DC current
- the engine for the electric transformation in mechanical energy
- the boogie for the support and stabilization
- the wheel in contact with rail, for the adherence necessary to motion

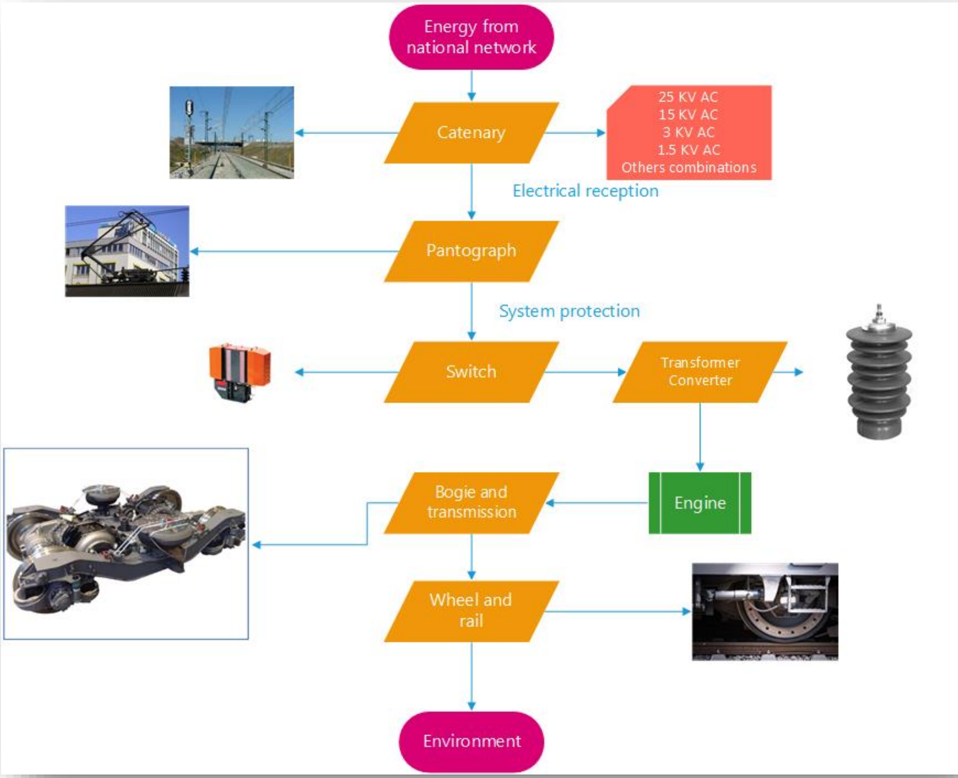


Figure 16 Energy path through AGV components

The *AGV* obtains power onboard from the *pantograph* mounted on top of the vehicle. This instrument collects by friction from the power supply line, a medium voltage cable which extends along the entire length of tracks that can operate between 25 and 1.5 kV AC, the so-called catenary. The infrastructure of this HST is the lightest compared to Maglev and Hyperloop. In fact, there are the catenary with its structure, tracks above sleepers and ballast. The majority of the structure is fully recyclable, being made of metallic components (steel, iron, copper), permitting to manage oscillations of great value without encumbering travel safety, even if comfort is drastically reduced and velocity lowered. Last to underline that AGV can cross every European Country thanks to ERTMS configuration system installed onboard.

DATA SHEET AGV	
Class	AGV
Status	Certified for passenger transport
Guideway (support/guide)	Passive
Guideway (propulsion)	Catenary
Power transfer	Pantograph
Transmission of trust	Contact wheel/rail
Boogies	12
Propulsion	Synchronous PMM (12 LCS 3550 C)
Power supply	25 kV AC
Braking system	• Electrodynamic system (eddy-current brakes) • Inversion of propulsion by IGBT traction converter (motor becomes generator) • Friction brakes
Braking energy recovery	Up to 9 MW
Architecture	• Distributed traction • Articulated architecture • Shock absorption dispositive • High comfort interior (noise, vibration, air climatization)
# of vehicles	11
Net mass	380 [t]
Axle load	17 [t]
Length	200 [m]
Width	2995 [mm]
Interior width	2700 [mm]
Max speed	360 [km/h]
Max cargo capacity	500 people
Length of the way	Variable
Travel time	Variable
Frequency	Variable
Stations	Variable
Environment	• Low energy consumption (20-30% less than TGV) • Reduced carbon emission (3 times less than a bus, 8 times less than a car, 15 times less than an airplane • Easily recyclable materials • Enhanced aerodynamics and special brake pads to reduce external noise
Cost (infrastructure)	25-30 million €/km [27]

4.2. SHANGHAI MAGLEV

A first concept of MAGnetic LEVitation (MAGLEV) was announced in early 1900's by Goddard and Bachelet, but the technology was limited. In 1922 Hermann Kemper started his research and in 1933 he succeeded creating a technical concept for levitation based on electromagnetic attraction, he had the patent in 1934. [28] It will take fifty years more to see the first commercial low-speed maglev shuttle that was in service in Birmingham between 1984 and 1995. Levitated by electromagnets and propelled with a Linear Induction Motor (LIM), it was too expensive to reinstate and maintain the 600 meters connection between the railway station and the Airport. It was replaced with a people mover (AirRail Link) fully automated cable-hauled system in 2003.

Figure 17 Maglev used to connect Birmingham's International Airport with Birmingham's International Railway Station [29]

Following the studies of Kemper in 1987 Transrapid International, a German company created by Siemens and ThyssenKrupp, built a test track line in Emsland, with a total length of 31.5 km that started application in 1991. In 2011 the operating license for the Emsland test truck expired and in 2012 demolition and reconversion of the entire site was approved.

Figure 18 Transrapid monorail test track in Emsland [30]

The first commercial implementation was completed in China, the full project was to connect Shanghai with Beijing with a high-speed train. From 2002 the demonstration line or Initial Operating Segment (IOS) connects Longyang Road station in Pudong to Pudong International Airport with a

30 km guideway. The travel takes 8 min at a maximum operational speed of 431 km/h. However, the decision is eventually made to implement the Beijing–Shanghai High-Speed Railway with conventional high-speed technology. Plans for a shorter maglev extension from Longyang Road to Hangzhou, the Shanghai–Hangzhou Maglev Line, are suspended too.

Japan started research in 1962 and it bet on two independently developed maglev trains. Linimo uses EMS technology with long stator LIM for propulsion, and energy is supplied via pantograph. Chūō Shinkansen apply superconductive cryogenic magnets (SCM) for an EDS system with long stator lateral LSM for propulsion. Energy is supplied by a linear induction generator.

Figure 19 Linimo first urban application [49]

Figure 20 Chūō Shinkansen for intercity transports [50]

Many countries find the technology reliable enough to compete with traditional railways for urban and intercity transportation. In 2016 Korea is the fourth country to operate its own self-developed maglev after the United Kingdom's Birmingham International Airport, Germany's Berlin M-Bahn and Japan's Linimo.

Figure 21 ECOBEE, it adopts EMS system with Iron-cored long stator LSM [31]

The phenomena controlling MAGLEV is magnetic flux, that once conveyed in a specific area, composed of special metallic components, with an appropriate intensity and frequency creates conditions for mobility: guidance, levitation and propulsion. To produce the magnetic flux a conductor is wrapped in a coil and it is connected to an electromotive force from both ends.

Levitation is of fundamental importance and during years scientists have proved that a "classic" magnetic flux leads to instability, as expressed by the *theorem of Earnshaw* (1842): "a collection of point charges cannot be maintained in a stable stationary equilibrium configuration solely by the electrostatic interaction of the charges" [32]. As result different technics to get a safe levitation have grown up, for example putting a magnet into a *rotational field*, with good but not sufficient results. A sustainable solution was found in *servo stabilizers*, operating in a continuous measurement and correction of the trajectory of the magnet by use of electric fields, that is the principle of EMS. There was also improvement in the material research, finding out that *diamagnetic materials* naturally repulse a magnetic field, so Earnshaw's theorem doesn't apply, and pushing this research *superconductors* (that are considered as perfect diamagnetic materials in specific conditions) have been selected and tested. A superconductor absorbed in a magnetic field produces a skin current on its surface that induces in its body a magnetic field equal and contrary to the applied one, this property is known as *Meissner effect*. Diamagnetic materials are the base point for EDS. Electromagnets, like the ones discussed previously, have a constant need in alimentation to generate a current and so a flux. There are also permanent magnets that placed in a specific order can produce a stable levitation system without electronic systems. The most known union of permanent magnets is the *Harray Halbach* that has the characteristic of improve the magnetic flux on one side and almost delete effects of the flux on the opposite side. This is the technology applied onboard on INDUCTRACK system.

Two schools have been developed the most, the *dynamic* and the *magnetic* suspensions. The first uses magnetic repulsion to levitate the train body over the guideway, the second applies on magnetic attraction to lift the train body. The guideway is similar for all technologies, a long line of electromagnets that can be active or passive and on which propulsion is performed pulling the train from the front and pushing it from behind.

	Points in favor	**Points to disadvantage**
Dynamic suspension	• Elevate clearance • Higher range of air gap (few centimeters) • Active or passive system • Up to 580 km/h • High capability of load • High temperature superconductors can be installed onboard	• Nasty dirt can deposit on the guideway coils • Superconducting electromagnets or strong permanent magnets onboard must be shielded to passengers • It needs relative movement between the guideway and the train body • At low speed a secondary levitation system is necessary (e.g. wheels)
Magnetic suspension	• Reduced and concentrated magnetic flux • Less interaction with passengers • Already proved and ready-to-go technology • Up to 500 km/h • No need for wheels or a secondary propulsion system	• Active system • Huge data analysis by levitation control system • Constant management of the magnetic flux • Possible vibrational problem

It is impossible to find the best technology, it is more important to look for the best applicable technology concerned with the project.

Guidance can be an autonomous system, or it can be englobed in levitation system. Main objective is to direct the train, so only lateral forces are of interest. Passive or active, with electromagnets or with permanent magnets, the guidance follows the same conceptual role for all technologies.

For *propulsion needs*, in a technology where there is no contact between the guideway and the moving body, only linear motors can compete. A short description has been given in the introduction, here a more detailed technical analysis.

Linear Synchronous Motors have the “fixed” part composed by permanent magnets (or active electromagnets) and the moving one composed at least by three coils and the relative magnetic circuit. Alternating phases and signs of inner currents in the coils, a constant thrust is obtained on windings. There are three main constructive morphologies: forcer-platen, u-shaped and tubular [33].

> The *forcer-platen* design is the simplest, imagine unrolling a rotative motor (figure 2) with the stator as guideway (of permanent magnets) and the rotor as moving body on the guideway. The vehicle has windings and so it needs power alimentation. Even if the structure is the simplest there are inconvenient sides as a strong asymmetry of the magnetic flux. This system allows anyway the maximum thrust performance also because the heat created in windings can be easily evacuated.
>
> The *u-shaped* morphology is designed to avoid attractive problems of forcer-platen. Two “winding motors” are mounted on left and right sides of the guideway, letting the moving body of the vehicle transit between them. Positive points are a better utilization of the magnetic flux and a better adaptability to strong accelerations. On the other side the heat created into windings has difficulty to evacuate reducing so the potential of this technology.
>
> The *tubular* design provide that all the moving vehicle is surrounded by windings for a homogeneous and symmetrical magnetic flux. The vehicle moves into a “coil tunnel”. Even if it is the best solution in small scale, for a maglev it is too much expensive and so it loses in interest.

LSM has some advantages like an easy power supply system and control system, it is in continuation with traditional projects as regard for plants and design approach. Nevertheless, the high cost of permanent magnets and the troubles they can bring (clearance, protection from ferromagnetic dust, oscillating attraction force, etc.), it imposes to find new solutions.

Linear Induction Motors are asynchronous linear motor driven by alternating current. The stator part is composed by windings that are powered by three or two phases AC. The sinusoidal currents produce a translating magnetic field on the guideway. The “linear rotor” (the traditional squirrel cage is open into a ladder) faces the translating magnetic field producing parasite currents in it and an opposite magnetic flux.

LIM are economic, robust, structurally essentials and quite easy. They are applied when the stator length is big, and they can afford both high velocity and high thrust. The real problem with this kind of motor is the cue, the starting point. A solution well implemented is the use of vector inverters to start gradually. In comparison with LSM, LIM has a lower efficiency and a higher weight. Thanks to implementation in the sector of electronics is nowadays possible to use this kind of motor in several applications avoiding the previous problems and in some branches, it has outclassed LSM.

Shanghai Maglev Project mounts on-board attractive EMS and lateral guidance electromagnets over a passive ferromagnetic guideway. It has a clearance of 10 mm assured by onboard electronics and onboard batteries guarantee levitation independently from propulsion with an autonomy of about an hour in case of no more power supply, for a fail-safe configuration. The long stator LSM is continuous over all the guideway, even if it is segmented in sections powered when needed, to reduce energy consumption. Inductive power transfer is the source of alimentation for the on-board instrumentation, also batteries are recharged by this Linear Induction Generator.

Maglev and *hyperloop* collect energy in the same way, by *electromagnetic induction*. To explain this principle, it is suitable to start from the physic behind. An electric current generates in its neighborhood an electromagnetic field that can variate in intensity and direction, driven by the current itself. Imagine an infinite cable at which extremities a potential difference sets electrons in motion. If an electrical circuit enters this first magnetic field a new magnetic field will be created in the second conductor opposite to the field variation, until the magnetic flux to the circuit varies in time, for *the* *law of Faraday-Neumann-Lenz*. This second field produces an induced current, that follows the principle of action-reaction, with direction given by the *force of Lorentz*. When well directed, this current can be collected and employed.

In this paper it is addressed only the semi-active guideway, meaning that power for propulsion only comes from the supply system integrated in the guideway. In the figure below, semi-active guideway supply is represented in green and in red the onboard electromagnets that propel the vehicle. Smartly, only a section of the guideway is activated at the train passage, dispersing less energy in thermal and electromagnetic losses. To remember that onboard batteries, recharged by an induction system, guarantee levitation and guidance.

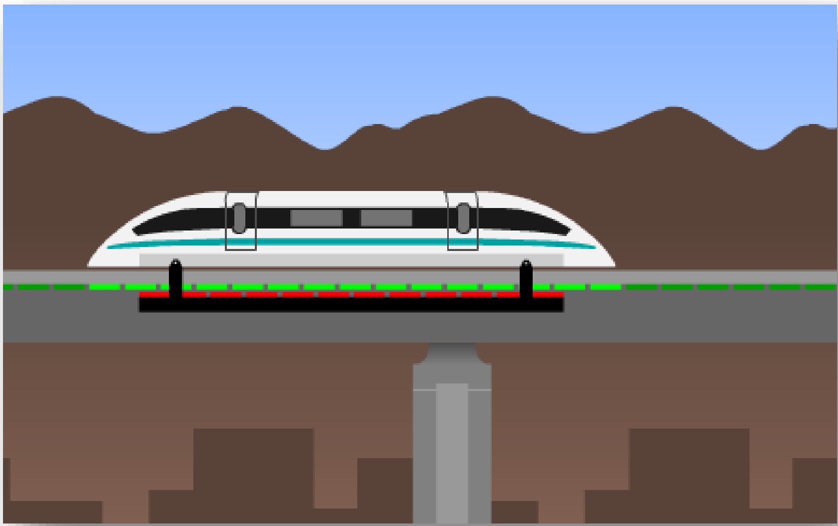


Figure 22 Semi-active guideway for a Maglev train

The guideway assumes two principle functions for propelling the vehicle and recharging batteries for levitation and guidance. For the important role it assumes, some restrictions in terms of robustness, oscillations, clearness and cleanliness are mandatories. This means a strong infrastructure, that should be able to resist to worst operative conditions without decreasing safety and comfort. Generally, it is overhead from the ground to guarantee isolation from the environment. In terms of components the infrastructure counts the guideway with the electric supply system integrated in a smart way. Principle materials employed are cement and iron, the first employed as body core, the second as structural exoskeleton. Foundations of every pillar must be solid. The result is more compact and sturdier than traditional HST, the environmental impact is greater due to superelevation and, mostly, linked to the disposal phase due to the massive use of non-recyclable cement. Also, cross sections, bridges and stations are more complex than traditional ones. The cost of the installation is far greater than AGV one.

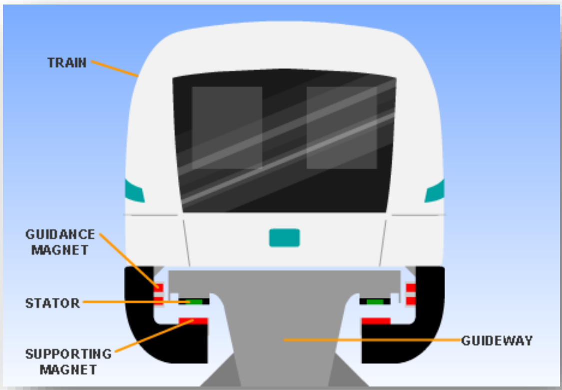


Figure 23 Shanghai Maglev front view [34]

Figure 24 Front view of the Shanghai Maglev Train

DATA SHEET SHANGHAI MAGLEV	
Class	EMS (attractive)
Status	Certified for passenger transport
Guideway (suspension/guide)	• Passive ferromagnetic guideway • Onboard later guidance electromagnets
Guideway (propulsion)	Active (power only to segment where there is the vehicle)
Power transfer	Inductive
Nominal airgap	10 mm
Propulsion	Iron core long-stator LSM
Power supply	AC variable frequency
Braking system	• Eddy-current brakes • Inversion of propulsion (motor becomes generator)
Braking energy recovery	No information
Architecture	• Monorail overhead “I” shaped • Advantage in crossing hills and mountains • Fireproof materials for the vehicle • Low maintenance (65% less than a traditional HST)
# of trains	3 trains, with 5 vehicles each
Net mass (per train)	255.2 [t]
Length (per train)	128.29 [m]
Max cargo capacity (per train)	• Passenger 80.5 [t] • Cargo 30.5 [t/m per car] (special industrial design for max. 150 km/h)
Max speed	430 [km/h]
Length of the way	30.5 [km]
Travel time	8 [min]
Frequency	Every 10 min
Stations	2
Environment	• Low electromagnetic emissions • Lower noise emissions (at 25 m of a 300 km/m Maglev L=85 dB, TGV at the same condition has L=92 dB) • Increased vibrations at maximum speed
Average energy consumption	81 Wh/s/km
Cost (infrastructure+trains)	100-200 million €/km [35]

4.3. TRANSPOD HYPERLOOP

The idea of putting a transportation vessel, with people inside, into a vacuum tube is not so new as we can imagine. Science fiction authors developed a big variety of unbelievable ideas and it is possible that some of them proposed the Hyperloop solution better than in this paper.

Over than 100 years ago this kind of vacuum-tube transportation system was conceptualized by several futuristic inventors. Needless to say, these theories were treated with skepticism. Just to mention a few, Boris Weinberg, Russian professor at Tomsk Polytechnic University, in 1909 prototyped an early version of ultra-high-speed ground transportation publishing the concept in "Motion without friction (airless electric way) [1914]". Robert Goddard, pioneer of rocket design and space exploration in the USA, published in the same years a similar concept, abandoning vacuum-tube and hanging a more realistic reduced-air-pressure condition in a tunnel were the vessel was magnetically levitated. [36]

Thanks to industrial progresses in vacuum pumps performances, increased material knowledge and magnetic flux optimization, science fiction can be reality. Marchetti and Ausbel propose maglev as next winner in the transportation market, surpassing airplane. Their study is based on logistic theory and evolution curves. [3]

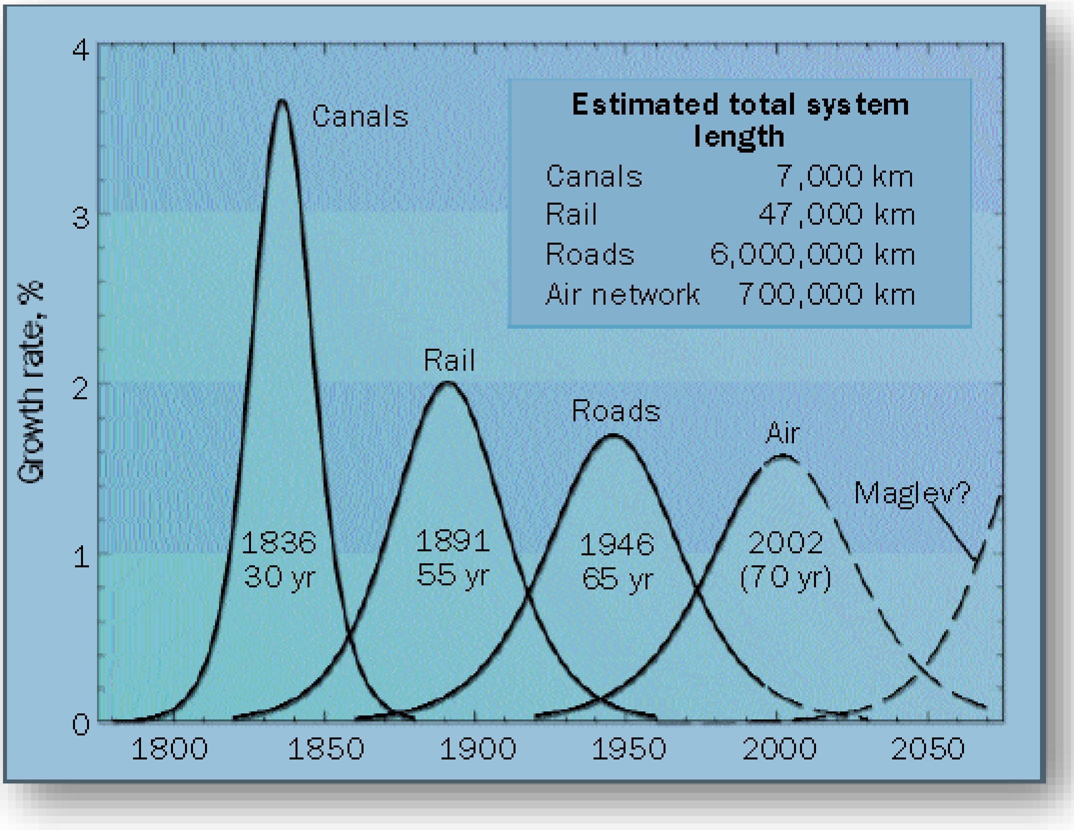


Figure 25 Smoothed historical rates of growth of the major components of the U.S transport infrastructure, showing the peak year and the time for the system to grow from 10% to 90% of its extent (conjecture shown by dashed curves) [3]

They even suggest that with an acceleration tunnel like hyperloop's one (few hundred kilometers tunnel with less than 1 g acceleration, hypothetically $a \approx 5\frac{m}{s^2}$ as hoped by Musk for his hyperloop) humanity should be able to send a train of 1000 tons at 25000 km/h with destinations around our solar system. "Even the bacteria should be impressed with the mobility humans can achieve" [3].

In 2013 Elon Musk called, for the first time, this system Hyperloop and he dares it will be operative in few decades, so a challenge started for the first being able to fully develop the system. TransPod proposed a model combining spacecraft, aircraft and rail designs to assure performance and safety both for passengers and for cargo.

The design is similar to a jet turbine of a plane, where a compressor in front of the vehicle, from now called Pod, sucks rarefied air to give off at the end of the Pod. People or goods are charged in the central part of the vehicle. Four linear motors are symmetrically positioned at the bottom of the Pod.

Figure 26 View of the front compressor of the Pod, one of the LIM and the inlet door [37]

Magnetic levitation is conceptually the same as for maglev, to resume the most spread solutions:

1. Electromagnetic suspension *EMS* is the magnetic levitation of an object achieved by constantly altering the strength of a magnetic field produced by electromagnets using a feedback loop. Electronically controlled electromagnets on the train attract it to a magnetically conductive (usually steel) passive track.

EMS incorporates guidance as an automatic consequence of levitation structure, nevertheless it can mount lateral magnets too.

2. Electrodynamic suspension *EDS* is a form of magnetic levitation in which there are conductors which are exposed to time-varying magnetic fields. This induces eddy currents in the conductors that creates a repulsive magnetic field which holds the two objects apart. Electrodynamic suspension uses superconducting electromagnets or strong permanent magnets that create a magnetic field, which induces currents in nearby metallic conductors when there is relative movement, which pushes and pulls the train towards the designed levitation position on the guideway.
3. *INDUCTRACK* is a passive, fail-safe magnetic levitation system, using only unpowered loops of wire in the track and permanent magnets (arranged into Halbach arrays) on the vehicle to achieve magnetic levitation. The track can be in one of two configurations, a "ladder track"

and a "laminated track". The ladder track is made of unpowered Litz wire cables, and the laminated track is made out of stacked copper or aluminum sheets.

EDS and INDUCTRACK present lateral magnetic fields produced by permanent magnets or inductive coils to perform the guidance of the vehicle.

4. The ferromagnetic levitation technology *FLT* comes from an application exploiting the principle of magnetic induction between materials with different permeability. The FLT allows vehicles to levitate in a stable and extremely safe way, without the need of electricity and with a cost that is lower than other magnetic levitation technology. Designed for hyperloop context, it can be easily applied to old-fashioned HST in Europe.

The guidance of this technology has a great advantage, FLT uses a “Null Flux system”: when the vehicle is in the straight-ahead position, no current flows, but any move off-line creates a flux that generates a field which naturally pushes/pulls it back into line.

The major difference with other grounds systems is the change in air pressure, much lower than normal atmospheric pressure, in order to drastically low losses due to air friction. This makes hyperloop similar to a plane travelling at high altitude. Even better because the peak of energy demand for a plane is localized in departure phase and hyperloop drastically reduces that peak. In addition, it can regenerate energy when “landing”, not an airplane.
Of course, this solution gives other kind of energy consumptions and other kind of problems, like in case of a hole in the depressurized tube shield.

To get in touch with this technology, it is preferable to think about this new system as a combination of plane, train, bus and subway.

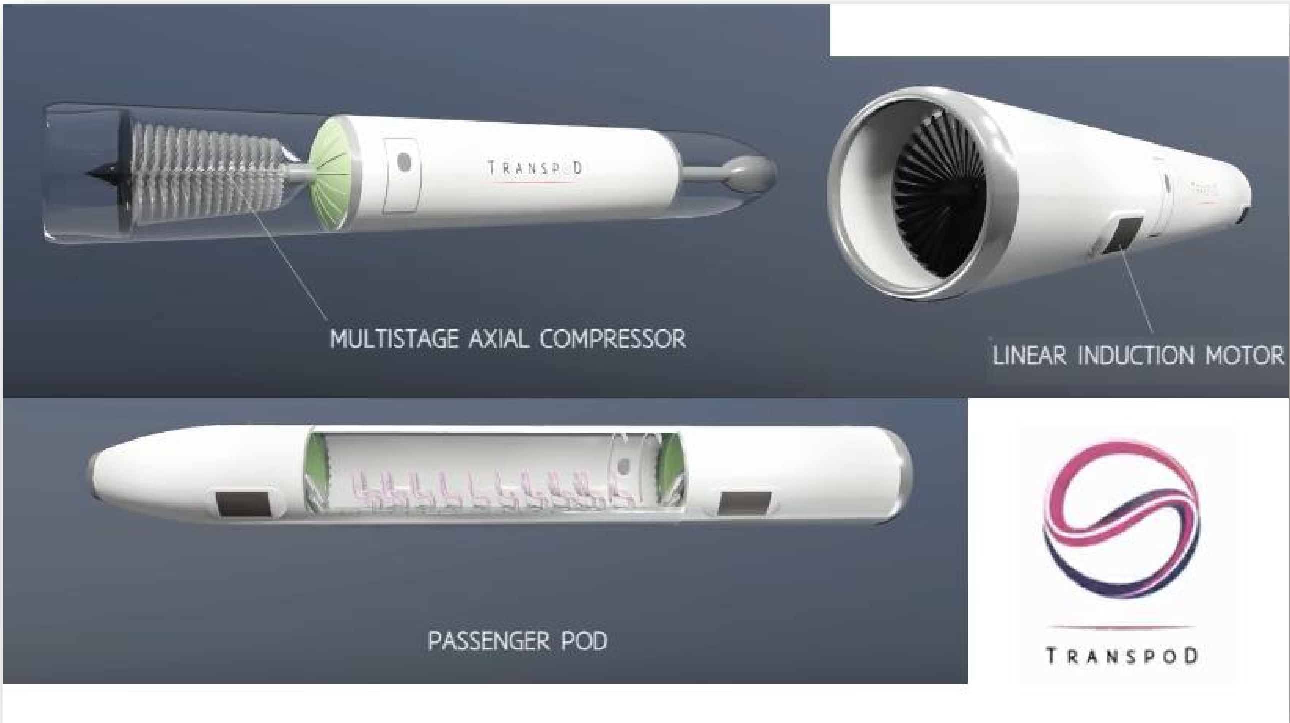


Figure 27 TransPod traction system overview [37]

The traction system is composed by a multistage axial compressor with air intake in front of the structure and an exhaust nozzle to the back. Four LIM drive motion from the bottom of Pod, two for the right side and two for the left side. In the middle part of the vehicle a cylindrical tank with pressure bulkhead isolate passengers from the inner conditions of the tube (100 Pa, 50°C).

System design:

- 4 Linear Motors
- 1 Multistage Axial Compressor (MAC)
- Energy storage on the POD
- Energy uptake technology
- Propulsion control/command tower
- Propulsion control/command software on-board unit

Operation:

- Propulsion and braking at few centimeters air gap from the guideway
- Near vacuum air friction inside tube
- 4 synchronous alimentation systems
- Thermal and mechanical stress
- 1200 km/h speed at 0,1*g acceleration
- Propulsion control software
- Regenerative braking system
- Emergency condition disposal

Operation environment:

- Stations and guideway
- Infrastructures
- Near-vacuum / atmospheric pressure alternance
- Hot internal tube environment (up to 80°C)
- PODs management in space and time
- External tube very varying environment (Temperature, weather, wind, interferences)
- Solar panel magnetic field interference

the TransPod's system description can be finally addressed.

CODE	MACRO SYSTEM	FUNCTION	VITAL (Yes - No)
PS1	4 CTS BACKUP WHEELS	Support the pod if not magnetically levitating in start/stop phases (e.g. <100 km/h)	Y
PS2	1 CTS BRAKE CONTROL	Braking control under a v_lim (e.g. <60 km/h)	Y
PS3	1 COMPRESSOR GEARBOX	Module impeller mechanical transmission	N
PS4	2 COMPRESSOR MOTORS	Compress air (100 Pa density)	N
PS5	2 VFD – COMPRESSOR	Module compressor rotational speed	N
PS6	1 THERMAL STORAGE (PCM)	Store heat produced by LIM	N
PS7	2 THERMAL RECHARGE COOLANT PORT	Replace PCM to transfer thermal energy out of POD	N
PS8	2 COOLANT PUMPS	Allow cooling fluid handling	Y
PS9	2 COOLANT HEAT EXCHANGERS	Transfer thermal energy from LIM by cooling fluid to PCM	Y
PS10	1 ELECTRICAL BREAKER PANEL	Control electromagnetic braking	Y
PS11	3 ELECTRICAL POWER PICKUPS	Collect electric power from the net to the POD system	Y
PS12	1 ELECTRICAL CONVERTER HV-MV	Convert HV tension electric power in MV	Y
PS13	8 VFD – TRACTION A & B	Manage the 4 front & 4 back LIMs by variable frequencies	Y
PS14	GLOBAL SYSTEM	Manage the different traction phases and the emergency	Y

This new concept englobes two systems that are strictly linked with performance, which are the vacuum system and the photovoltaic system. The former is under investigation by TransPod team, in this paper it is assumed a traditional industrial vacuum pump reaching 100 Pa in short less than 3 hours, the latter can be imagined as a couverture on top of tubes. The PV system even if it is an essential part of TransPod concept, will be treated apart as the author differentiates but englobe in the same technology transportation, energy production and storage.

Typical Pier Loading Assumptions

Tube dead load	2.5	tons per meter
Tube dead load safety factor	1.8	
Tube dead load per 25 m segment	112.5	tons
Vehicle dead load per tube, incl safety factor	60	tons
Tube + vehicle dead load	172.5	tons
Number of tubes per pier	2	
Total tube + vehicle dead load	**345**	**tons**

Figure 28 Cross-section of the elevated structure [37]

The infrastructure is huge and of great impact on the environment, both in positive and negative ways. Like for previous disrupting technologies like wind farms, solar concentration plants, wave system generators, hydroelectric plants, people usually dislike seeing big infrastructure close to them. The feeling, when a beautiful landscape become uglier because of these plants, is that the environment will be changed in a dramatic way, losing its beauty. Of course, more harmful solutions are accepted just because they don't affect directly human perception and daily routine.

Figure 29 TransPod infrastructure with vacuum tubes containing the guideway, the levitation and the feeding systems [37]

As regard for TransPod technology, infrastructure is heavy with a pillar every 25 meters and tubes of 4 meters inner diameter made of steel. [38] The stability is a big must because a minimal oscillation can cause the worst catastrophic event. Electric energy is feed by a special line in the inner tube thanks to a revolutionary and confidential electromagnetic wave catcher, separated both from the guideway than from the levitation system. In addition, the photovoltaic field on top of the structure feed the system with energy but increase the load on pillars, so a balance between pro and cons must be judged. At least the main structural material is recyclable, even if pillars need cement, the more suitable material in compression phase. The structure is heavy, foundations of every pillar must be correctly built to remove vibrations and oscillation to the top of the structure. TransPod designers are investigating this domain as presented by R. Janzen [36]. An ad-hoc system for switching guideway, embark people, allow safety exits, is under development and designers affirms the global infrastructure cost will be similar to a traditional HST.

Potentially hyperloop can become the “underground” that connects bigger cities on the continent, enlarging possibilities for every user, with an affordable ticket. TransPod affirms that the price will be competitive with actual TGV tariffs. Stations will be more complex than actual subways, but with the same conceptual organization, to permit a Pod in each direction every 15-30 minutes. As example, a possible station in Paris can connect to Roma, Berlin and Madrid, so three corridors are presented for a total hyperloop length of 3541 km.

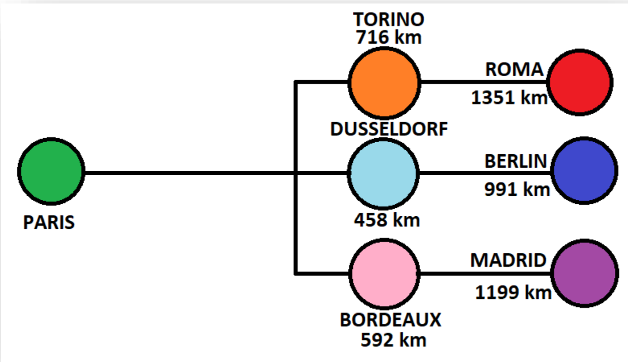


Figure 30 Possible configuration of TransPod service

For each main destination an intermediate one is figured out, so a possible departure schedule can be, starting for convenience from time “0” and incrementing in minutes:

TIME [min]	DEPARTURE	ARRIVE	TOTAL DURATION
0	Paris	Roma	1 h 20 min
5	Paris	Berlin	55 min
10	Paris	Madrid	1 h 15 min
15	Paris	1. Torino 2. Roma	1. 45 min 2. 1 h 40 min
20	Paris	1. Dusseldorf 2. Berlin	1. 30 min 2. 1 h 15 min
25	Paris	2. Bordeaux 3. Madrid	1. 40 min 2. 1 h 35 min
30	Paris	Roma	1 h 20 min
35	Paris	Berlin	55 min
40	Paris	Madrid	1 h 15 min
45	Paris	3. Torino 4. Roma	3. 45 min 4. 1 h 40 min
50	Paris	3. Dusseldorf 4. Berlin	3. 30 min 4. 1 h 15 min
55	Paris	4. Bordeaux 5. Madrid	3. 40 min 4. 1 h 35 min

The schedule is simplified, and it takes in account only departures from one station, the real net is far more complex than the one exposed.

DATA SHEET TRANSPOD HYPERLOOP	
Class	EMS
Status	Project under development for Montreal-Toronto connection
Guideway (suspension/guide)	Semi-active
Guideway (propulsion)	Passive
Power transfer	Inductive
Nominal airgap	No information
Propulsion	• LIM three-phase pulse-width-modulated (PWM) sinusoidal waveforms • Multistage propeller
Power supply	AC variable frequency
Braking system	• Regenerative braking • Electromagnetic brakes (eddy-currents) • Emergency braking system
Braking energy recovery	Up to 48.9% of total travel energy outlay or 67% of initial acceleration phase charge
Architecture	• Levitation rail on inner top of the tube • Propulsion rails symmetrically placed at the bottom of the inner tube • Revolutionary signalization and communication systems
# of vehicles	Mono-vehicle
Net mass	10 [t]
Length	30 [m] for 3.25 [m] height
Max cargo capacity (per train)	10-20 [t]
Max speed	1000-1200 [km/h]
Length of the way	500 [km]
Travel time	50-60 [min]
Frequency	80 [s] < variable < 30 [min]
Stations	4
Environment	• Very low electromagnetic emissions • Very low noise emissions • No direct emissions • Strong visual impact
Cost (infrastructure)	28-30 million €/km [38]

In the descriptive chapter, technologies under investigation are presented and a lot of information are helpful to the qualitative sustainability analysis. By mean of the final DATA SHEET the author condensates peculiar characteristics that give rise to main energetic differences in consumption.

5. Energetic and sustainability analysis: assumptions and results

The goal of this section is to individuate the more energy saver and sustainable HST between AGV, maglev and hyperloop. A Matlab simulation of a 500 km flat travel seems the best solution to the author, to collect information about, and only about, traction needs.

Before showing results, a short discussion about the complexity of the analysis and the author choices is expressed. It is particularly difficult to find data about maglev technology, even founding data for hyperloop (not experimentally proven and under confidential limits) is not easy. The simulation is needed because the interest is to *isolate only the traction needs*, without energy consumption acted by the global system (signalization, communication, comfort, etc.). A further incentive to the actuation of simulations is to dispose of an *equal and impartial instrument, so that the error can be considered homogeneous and results can be put on the same level*. In fact, there are no real data on hyperloop to compare to existing technologies, so the exigence of a uniform starting point can be solid only by simulating the same travel. Even compare a real traditional train to an existing maglev is a nonsense because of differences in guideway slope, length, operative conditions. Another positive point of the simulation is the availability of physical coordinates as space, speed, time lapse, acceleration and so on.

5.1. Quantitative results of simulations

For every simulation ideal condition is applied: constant air density, absence of wind and rain, clean tracks. Consider that all the technologies presented should be available nowadays. The technical summaries below identify in an ordinate way inputs for the analysis.

Characteristics for AGV, MATLAB simulation input	
# vehicles	11
Net mass	380 [t]
length	200 [m]
Max speed	360 [km/h]
Simulated passengers	460
Simulated cargo	34,5 [t]
Traction system	PMM
Traction simulation	By traction-velocity chart
Energy transmission efficiency	0.85

Characteristics for MAGLEV, MATLAB simulation input	
# vehicles	5
Net mass	255.2 [t]

length	128.29 [m]
Max cargo capacity	80.5 [t]
Max speed	430 [km/h]
Simulated passengers	460
Simulated cargo	34.5 [t]
Traction system	LIM
Traction simulation	By formulae
Drag coefficient	0.26
Frontal section	16 [m2]
Power consumption for levitation and guidance	7,8 [kW/t]
Energy transmission efficiency	0.85 (that is optimistic)

Characteristics for TRANSPOD, MATLAB simulation input	
# vehicles	17
Net mass	10 [t] each vehicle, so 170 [t]
Passenger sits	27 each vehicle
Max cargo capacity	10 [t] each vehicle
Max speed	1000 [km/h]
Simulated passengers	459
Simulated cargo	2,025 [t] each vehicle, so 34,425 [t]
Air density	0,0011 [kg/m3]
Drag coefficient	1,9
Frontal section	1,2272 [m2]
Power consumption for levitation and guidance	7,8 [kW/t]
Energy transmission efficiency	0.85 (that is optimistic)

To remember that the simulation starts in steady state condition of quiet, then a constant imposed acceleration is impressed to the vehicle until the top speed is reached. The drag force is calculated, and it opposes to the normal direction of motion. This velocity is maintained during the flat travel simulation until the brake zone, where finally a constant deceleration stops the vehicle. In every simulation the braking regenerative energy from the vehicle to the system is underlined.

From the table below, it is possible to understand where technologies consume the more.

Technology	AGV	MAGLEV	HYPERLOOP 1 pod	*HYPERLOOP 17 pods*
passengers	460	460	27	459
max speed [km/h]	360	430	1000	1000
from 0 to max speed				
energy [MJ] for different slope				
0%	5000	2772	585	
2%	10600	3457	695	
3,5%	14720	3971	777	
10%	-	6182	1133	
from 0% up to 2% [+%]	212	124,73	119	
from 0% up to 3,5% [+%]	294,4	143,2685	133	
from 0% up to 10% [+%]	-	223,1102	193,7	
ratio people/train mass	0,09	0,14	0,20	
total 500 km flat travel				
en consumption [MJ]	35900	26600	806	13710
en km [MJ/km]	72	53,2	1,6	27,4
en passenger [MJ/pass]	78	56,6	29,9	29,9
en production [MJ]	1500	1600	394	6700
limits for maglev and hyperloop, the performance of total energy transmission is very high				

TransPod system is without doubts the more energy saver for traction needs. This is one of the goals of this new way of transport, indeed, so this first objective is confirmed by simulation.

Consider the *first phase of simulation, from zero to max speed.*

For AGV the amount of energy to reach the 360 km/h is 5000 MJ, that is only 13.92% of total travel consumption, meaning that this technology needs a constant and huge quantity of power from the net. For MAGLEV the first phase needs 2778 MJ, almost the half of a traditional HST, but even there this is just 10.44% of total travel consumption. Removing friction losses due to rail-wheel contact has its advantages, yet, this technology is too much energivorous because still facing aerodynamics opposing forces. TRANSPOD system from zero to max speed absorbs a ridiculous amount of energy, 585 MJ for each Pod. To make a meaningful comparison 17 Pods must be sent before the same number of passengers complete the travel, consuming 9945 MJ. The most interesting, this first phase consume 72.6% of total travel need.

It is interesting to see also the *behavior facing different slopes* during travel. AGV absorbs double energy just for a little increase, from flat to a 2% slope, and almost three times more from flat to a 3.5%, not even reaching the 10% slope because of physical friction problems. This technology is heavy having all traction components on-board. Maglev has half of the motor on the guideway, so energy demand increases, but smoother. Once again, the best solution in case of uphill is hyperloop technology, with a ratio $E_{2\%}/E_{0\%} = 1.19$, $E_{3.5\%}/E_{0\%} = 1.33$ and it consumes double energy to reach a 10% slope. Magnetically levitated systems are better than wheel-rail contact technology in case of crossing hills and mountains.

From the *complete travel analysis,* it is evident the gap between technologies. If just 13710 MJ are consumed by TransPod technology, the double is taken for Shanghai Maglev with 26600 MJ and the AGV pays 35900 MJ for the same travel. Even energy indexes individuate in Hyperloop the best mean of transport with a consumption about 27.4 MJ/km against 53.2 MJ/km for Maglev and 72 MJ/km for AGV. For every passenger the total travel cost 29.9 MJ in Hyperloop, 56.6 MJ in Maglev and 78 MJ by a traditional HST.

As regard for *energy produced during braking*, due to improvement in fighting friction losses, TransPod can regenerate 394 MJ from each Pod, so 67.35% of the first phase of acceleration. Even if only a percentage of this amount can be used, it is interesting in case of Pods' synchronous arrival-departure in TransPod stations, as it is mentioned in chapter 8. Regenerative braking in this vacuum system is relevant producing 48,9% of total travel energy, so big interest is put to collect this energy. AGV is the worse solution saving 30% of departure phase energy and just 4.2% of total travel consumption. Maglev technology is between the two with a regeneration of 57.6% compared to first phase, but just 6% of total travel needs.

To understand the real interest in hyperloop is easy according to these results. Having a 48.9% of total energy traction needs restored at the end of the travel means that, in ideal conditions with no losses at all, the service with 17 Pods cost just 6704.2 MJ from the supply power grid. Here the real gain in this concept. In addition, this technology has a light chassis that increase the gain in saving energy. It is outlined by the ratio people/train mass: 20% of the mass accelerated in TransPod system are the people in there. To understand, it is essential to refer to *II Law of dynamics,* $F = m \cdot a,$ showing that force is directly linked with mass. If the vehicle has an important mass, the force to apply will be great just to move it. In other terms to move a Pod 80% of the force is absorbed by the vehicle, 20 % is used for the people inside. Having a lighter structure is then suitable, but designers must consider also to maintain stability at high velocity. A traditional solution is then heavier with a ratio people/train mass of 9%, Maglev once more is in between with a ratio of 14%, also because facing drag forces vehicles must remain stable to guarantee a safe journey.

5.2. Qualitative results for sustainability comparison

The *power supply system* and the *infrastructure* are of great interest, linked with their *performance, production cost, operative cost, maintenance cost and environmental cost*.

In the following table, a *qualitative analysis* is made to find out the best transportation system. Points are given from 0 (poor) to 3 (excellent), taking in account all information that the author has collected during preliminary research, meeting with experts and previous literature. Surely, all information about hyperloop are not validated but announced, typically in an atmosphere of optimism.

	Performance	Production cost	Operative cost	Maintenance cost	Environment cost	total
AGV	1	3	1	1	2	8
MAGLEV	2	1	2	2	1	8
HYPERLOOP	3	2	3	3	3	14

Hyperloop is by design the most *performant*, having the lowest drag coefficient. The *Drag coefficient* is a value used in aerodynamics, that represents the complex network connecting shape, inclination of surfaces, dimensions of the carrier and air conditions. The lower it is, the better, because this number represent the difficulty that the vehicle faces when it moves into a flow, typically air or water. Also, hyperloop power supply system is more efficient than the other.

Producing a new line, it costs enormously for Maglev, as comes out from Shanghai experience, when the consolidated AGV is the “cheaper” solution. TransPod affirms to be competitive with traditional technologies from this point of view, but still it has to be proven. It seems not a so reliable estimation, thinking about the increased number of components. Hyperloop needs much more material, from metals to cement, it houses a photovoltaic system, it needs vacuum pumps and like traditional technology it has a power supply system with substations.

Thinking about traction needs, vacuum pumps, assuming nominal operative condition, the worst candidate from the point of view of *operativity* is AGV. A lot of consumptions in traction, lot of energy dispersion in all the system counting stations, with hyperloop all of this is drastically reduced. If it can resist two months or more between two complete vacuum cycles, than it operates in the best ground condition ever.

Maglev is proven to need less *maintenance* than AGV, being a noncontact solution. Hyperloop is by nature a close environment with a reduced need for maintenance, both on the guideway that on the pod. Of course, having thousands of auxiliary components working in harmony, also this assumption can evolve differently than what declared.

As regard for environmental cost, maglev seems the worst system to the author. Not only most of the structure is non-recyclable, also the impact is not mitigated by any countermeasure. This is a first evolution from traditional train, but still linked to an old-fashioned vision of HST. AGV is made mostly of recyclable materials, making it the champion of disposal. Once more, it can’t be the best solution because there aren’t other mitigation actions integrated in the design. Hyperloop is the eco-friendlier, because its structure, in terms of reuse, is in between compared to maglev and AGV, because it integrates renewable energy production, storage and transportation as fundamental part of the infrastructure.

In this chapter, the analysis of the results obtained have been showed and discussed. From the quantitative analysis it is demonstrated that hyperloop consumes far less for propelling Pods. From the qualitative analysis too, hyperloop is evaluated as the more sustainable HST.

6. RAMS and critical analysis: NOAH a new transportation concept

After having read the previous chapter, where results are showed, and a comparative analysis performed, a combination of RAMS and critical analysis can add some features to improve a better service than actual hyperloop. Even if the technology has the best traction consumption between HSTs considered, it is far from being a sustainable mean of transport. Only through the implementation of NOAH concept hyperloop can find the favor of investors.

Network Operator Autonomous Hyperloop (NOAH) is the future of long-distance continental transportation and connection. In a closed and monitored environment, this technology can push people and goods at a very high-speed, saving time in most of the mandatory steps of a nowadays safe travel. Even if this can be considered a visionary project, the entire system should be more complete than what attended. In terms of eco-sustainability, hyperloop must be a closed-loop arguing about energy consumption and pollution, meaning that its impact must be at least equal to zero. Even better if the system can produce more energy than what it consumes and "clean" the environment from previous pollution. Only renewables energies have a future related to Hyperloop's goals.

Before NOAH concept is introduced, an immersion in safety is fundamental to understand how and where to improve the system. To give continuation to the energetic analysis, the propulsion system components are analyzed.

6.1. PHA of TransPod's propulsion system

The newest transportation system has multiple incognita that merit to be discussed. In general, there are two typologies of thinking when in front of a change or a different opportunity: positive and negative points of view. The first underlining upgrades, innovative and disrupting technologies, new possible interactions and benefits; the second finding problems, troubles in the passage from the actual system, dangerous events and so on. To give a unique answer to both categories a science concerning risk analysis has borne in USA 's department of defense last century. Nowadays RAMS (Reliability Availability Maintainability Safety) analysis is employed in every sector of industry and it starts to be implemented even in other environments. Every time there is a choice a RAMS analysis can clarify in an objective way the potentiality in positive and negative results. In this paper it is addressed a Preliminary Hazzard Analysis to obtain an average view on the traction system of TransPod vehicle.

A short recapitulation about TransPod's project, using their information from [36] and [38]:

- The line will extend from Montreal to Toronto (about 500 km), with 2 intermediate stations;
- 4 pumping stations per km produce a 100 Pa environment;
- Solar panels cover the structure producing 20% more energy than system needs;
- emergency egress exits every 600 m
- 1 energy power substation every 5 km
- 1 pier every 25 m for elevated guideway (40 pier per km)
- New signal processing, electromagnetic and mechanical designs
- A cylindrical POD is magnetically levitated into a near vacuum tube
- A POD containing goods (10 ton) or people (27 seats) will be send every 3 min (80 seconds in peak periods) in each direction, for approximatively 20 PODs simultaneously on each line
- Propulsion is done by a LIM reaching up to 1200 km/h
- Levitation is separated from propulsion

- TransPod uses passive rails and active LIM onboard

Components of the traction system are imagined by the author and recapitulated in the table below. The *code* is useful for identify with precision the hazard in the worksheet, the *micro system* defines the components divided in 14 categories. The column *function* describes roughly the role the component invests in the process. A strong limitation, as assumed previously, resides in the fact that is the work of one-man team.

CODE		MICRO SYSTEM	FUNCTION
PS1	4	CTS BACKUP WHEELS	Support the pod if not magnetically levitating in start/stop phases
	1	landing gear	mechanical support for wheels
	2	wheels	moving contact surface
	3	electro-pneumatic support system	support the pod massive force
	4	electro-pneumatic suspension system	reduce vibrational effects of contact pod/tube
	5	undercarriage attachements	link the landing gear with the pod structure
	6	communication-command system	link the operator with the backup wheels system
	7	Variable Frequency Drive system (VFD)	modulate the motor output for accelerate/brake
	8	electric motor	accelerate/brake from 0 to V_max_wheel
	9	Electrical Wiring Interconnection System (EWIS)	connect electrically the system
PS2	1	CTS BRAKE CONTROL	Braking control under a v_lim (e.g. <60 km/h)
	1	mechanical/electromagnetic friction brake system	dissipate energy to slow and brake the pod
	2	modulation system	modulate the braking force
	3	emergency system	manage the suspension and braking system in emergency
	3	communication-command system	link the operator with the braking system
	4	Electrical Wiring Interconnection System (EWIS)	connect electrically the system
PS3	1	COMPRESSOR GEARBOX	Module impeller mechanical transmission
	1	gear-box	variable trasmission
	2	lubrification system	optimize friction between mechanical parts
	3	mechanical connections between motor and propelle	link the compressor components
PS4	2	COMPRESSOR MOTORS	Module compressor rotational speed
	1	electric motor	power the propeller
	2	control system	control variable frequency traction motor
	3	EWIS	connect electrically the system
PS5	2	VFD – COMPRESSOR	Compress air (100 Pa density)
	1	mechanical parts (stator, rotor, blades, etc)	
	2	mechanical support (bearing, shaft, etc)	
	3	connection to the PS system	
PS6	1	THERMAL STORAGE (PCM)	Store heat produced by LIM
	1	PCM storage tank	
	2	temperature control system	
	3	coating	
PS7	2	THERMAL RECHARGE COOLANT PORT	Replace PCM to transfer thermal energy out of POD
	1	port with mechanical block	
PS8	2	COOLANT PUMPS	Allow cooling fluid handling
	1	inlet/outlet tubes	confine and drive the fluid
	2	housing	contain fluids during compression
	3	impeller	control fluid movement
	4	electric motor	rotate the impeller
	5	EWIS	connect electrically the system
PS9	2	COOLANT HEAT EXCHANGERS	Transfer thermal energy from LIM by cooling fluid to PCM
	1	inlet/outlet tubes	confine and drive the fluid
	2	HX hardware	contain fluids during heat exchange
PS10	1	ELECTRICAL BREAKER PANEL	Control electromagnetic braking
	1	hardware support	support and organize electric pieces
	2	electro-magnetic switches	open/close electric circuits
	3	emergency shut-off switches	close electric circuits when in dangerous operation
	4	EWIS	connect electrically the system
	5	interaction with braking software	link the operator with electric part of the braking system
PS11	3	ELECTRICAL POWER PICKUPS	Collect electric power from the net to the POD system
	1	3rd rail contact transmission system	collect energy from the net to the pod
	2	transmission cablages	transfer from collectors to switch
	3	security switch	control the electric flux
PS12	1	ELECTRICAL CONVERTER HV-MV	Convert HV tension electric power in MV
	1	transformer	convert HV to MV electric tension
	2	converter	convert from a.c. to d.c. and modulate
	3	EWIS	connect electrically the system
PS13	8	VFD – TRACTION A & B	Manage the 4 front & 4 back LIMs by variable frequencies
	1	salient pole	distribute the magnetic flux
	2	d.c. excitation winding	produce the magnetic flux
	3	ferromagnetic rail (yoke)	hardware of the LIM
	4	ferromagnetic reaction rail	contrast the magnetic flux to generate magnetic friction then relative movement
	5	d.c. modulator software	control the frequency variation
	6	emergency battery system	control and alimentation of LIM in case of emergency
	7	EWIS	connect electrically the system
PS14		GLOBAL SYSTEM	Manage the different traction phases and the emergency
	1	control and communication	management of PS
	2	emergency	management of emergencies

Figure 31 TransPod's PS components definition

The resulting worksheet highlight the importance of a proper design to assure redundancy, emergency plans, availability and reliability, in fact the majority of risks are assumed as high and serious. It is evident, thinking about a vehicle levitated into a tube and pushed at 1200 km/h, with people inside. In the following table the result of the worksheet.

Risk evaluated in the PHA				
TOTAL	HIGH	SERIOUS	MEDIUM	LOW
57	21	17	13	6
100%	36,9%	29,8%	22,8%	10,5%

With a total number of identified risks per operative phase shown in the table below.

	HIGH	SERIOUS
ACCELERATION / BRAKING	8	7
BOARDING PASSENGERS	0	1
MANUTENTION	4	0
INSTALLATION / CONTROL	5	6
EMERGENCY	0	1
PEOPLE & ENVIRONMENT	4	2

As regard for *HIGH AND SERIOUS RISKS* the worst subsystems are in order:

- electrical power pickups

  If energy can not be transmitted to the Pod, nothing can work properly;

- VFD – compressor

  The problem is that the compressor is big and close to the passenger area. If it brakes it produces debris, if it stops it provokes dangerous vibrations and instability;

- electrical HV-MV converter

  As for the pickup, if power can not reach engines there is a problem. The same if energy produced during braking cannot evacuate the Pod;

- coolant pumps

  As consequence of magnetic traction, heat is produced in high quantity. To manage this thermal energy is of fundamental importance to guarantee functionality of electronics, that have to be designed with an appropriate coolant system;

- thermal storage

  Heat cannot be evacuated in the tube, it has to be sent outside the hyperloop system. If thermal storage doesn't function, passengers' comfort is reduced quickly;

- CTS backup wheels

  At low speed TransPod solution is to sustain the vehicle with wheels, because the levitation system is not effective. This technology is already implemented on some maglev, so designers can use previous research to low the risk;

- VFD – traction A&B

  Less serious than a lack in the levitation system, a malfunction in the traction system can provoke serious and medium risks;

Most hazards that leads to high risk are individuated during acceleration or braking, so the normal operative condition. The main reason is a fail of the electric system, generating troubles that for the majority of times are fatal. TransPod project doesn't install an electric storage onboard, probably to reduce total mass, but maybe that's not the best choice. An alternative solution to the storage can be a dynamo system that, when a loss of current occur, uses the rotational energy from blades, guaranteeing the energy for a safe glide. There is not high risk when boarding passengers and, it may sound strange, when the emergency system is operating.

Similarly, when serious risk is evaluated in the majority of cases the operative phase is the acceleration/braking, followed by installation/control. Serious risk mean that the damage is high, even if people are not directly involved (or at least few people).

From this analysis it is clear that when passengers are directly involved in the consequences of the hazard, then the author gives high priority to neutralize the risk. When the hazard doesn't affect directly people, but the travel is compromised, or the environment disfigured, then the problem must be strongly regulated. Redesign, maintenance, redundant systems, adequate training, software control, cyber security, emergency countermeasures, mitigation actions, special equipment, preliminary tests are the suggestions for further development of hyperloop that are mentioned in the hazard reduction list.

As regard MEDIUM and LOW risk, the author thinks that most of them will be absorbed by redesigning high and serious risk. So, they have to be processed only after a second re-evaluation, in case they are not still eliminated. Even if they are not the priority, they must be managed in order to assure to hyperloop users the safer mean of transport.

The global Propulsion System of hyperloop is evaluated to be at high risk, many hazards can occur affecting the whole travel. In this analysis, only traction components are under investigation, but also with this confined environment it is evident that hard work has to be done to make this technology safe and secure. Then, it is the RAMS sector, with the work of experts, with a careful design, that has to reach this goal. It is not a matter of possible or impossible, it is just a matter of time.

To make a safer service, a lot of components have to be integrated to the structure, to monitor every little variation. Energy is then needed everywhere, continuously, but at low intensity, for electronic components. Assuming that the high-voltage net is not the best solution, the author proposes a critical analysis in which he introduces innovation in the energy distribution, base point of the NOAH concept.

Hyperloop is safe of course, in accordance with the law and the rules of the RAMS, it just needs to be well developed and it will demonstrate by its-self. The extension of the guideway is a real problem for monitoring leakages, possible terroristic attacks, accidents inside the structure, while hundreds of people are traveling on an extended and fully connected system. A single problem on the way compromises the whole line, hundreds of kilometers, with dramatic consequences. Without disturbing the imagination too much, thermal expansions can have a big impact on the tube causing deformations, breaches in sealed portions, consequently damages to operation, to the infrastructure and remotely to people.

Interest is then put on IoT, artificial intelligence, monitoring drones, satellite surveillance, employees trained in maintenance, emergency response and prevention. Specialized staff must be prepared to interact with the machines for any eventuality. Future R&D plans have to well develop *cyber security* as the main instrument to guarantee a reliable service. To remember, the problems linked to natural phenomena (storms, snow, wind, crossing animals, etc.) are managed by the infrastructure not by the vehicle that can carry on its way undisturbed, for an intrinsic safety condition during normal operation.

For those reasons, the author suggests populating the environment close to the infrastructure. Not with families and houses, but with small and medium-sized businesses. The opportunity to have a feedback from people around the structure may be important in both prevention and action.

Facing hyperloop system it is evident that hard work must be developed from RAMS engineers. In chapter 6.1 the reader has a global overview of hazards and risks. A fatal criticality is the loss of power, at any level of the analyzed traction system and at any level of the infrastructure, starting from power supply. An eco-friendly solution is proposed in next chapter to fuel hyperloop with a smart, autonomous and diffused energy grid.

6.2. Energy consumption, production, regeneration and storage

The quantitative analysis reveals the energetic behavior during traction. Traditional train pays the fact it is in friction with rails and air, maglev still fights aerodynamic forces. Hyperloop seems the great champion in terms of energy needs for the only traction system, but what if it is added the energy to depressurize thousand kilometers of a 4 m inner diameter tube? An innovative solution, connecting a smart energy grid (including production, storage and transportation) to a smart design of the infrastructure, is presented and reunited under the acronyms NOAH. A critical analysis on hyperloop is addressed, starting from the analysis of the vacuum system consumption and the photovoltaic production. Then other eco-friendly resources are proposed, as regenerative braking energy harvesting and thermal energy management to reduce losses.

6.2.1. Vacuum system

The vacuum system for hyperloop is, between the auxiliary systems, the more consuming. It is evident that it must be taken in account when comparing technologies. It is not essential part of the traction system, that's why it appears only at this stage of the analysis. After a short description of the vacuum system, the author redistributes results of the total energy consumption for traction needs, always in comparison with AGV and MAGLEV.

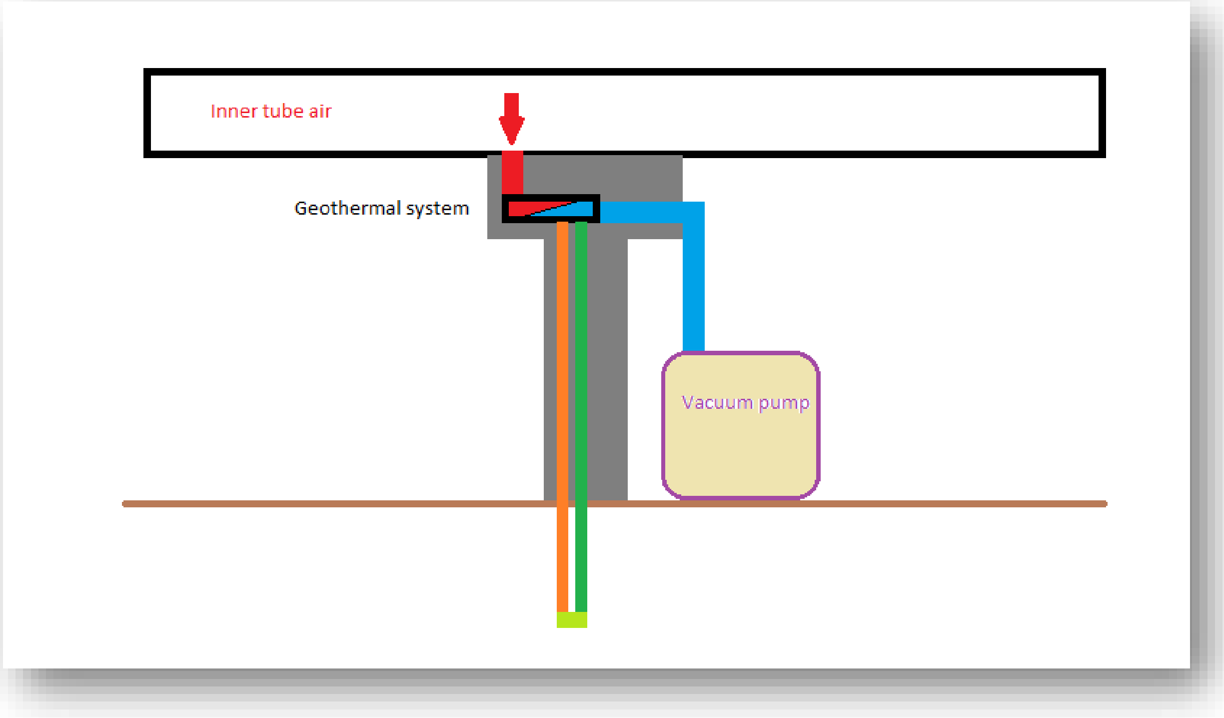


Figure 32 Vacuum pump and geothermal configurations

The TransPod team suggest the use of 4 pumping stations per kilometer, so one pump every 250 m or every 10 pillars. To the author, this is not the appropriate design. From an evaluation in first-degree approximation (1e5 Pa and 20°C as starting conditions at the inlet of the vacuum pump) the emptying of the tube, 500 km long, would be possible with a 90-kW nominal power vacuum pump every 75 meters, so using 6667 pumps (13-14 pumping stations per kilometer). For this consideration is taken in account the model GHS 5400 from Atlas Copco [39], thanks to which it should be possible to reach 100 Pa in 2.6 hours. Total power absorbed from each pump during operation is 103 kW with a maximum capacity of 5000 m3/h, so energy need for one pump is 267.8 kWh that means 964.08 MJ. The resulting total energy absorption for the vacuum system is of 6427521.4 MJ, that is a massive consumption just for one-way line. The weight this vacuum system has on every pod travel depends on how many times it is switched on from normal to near vacuum condition. The following scheme represents different operative possibilities.

	Launch every 5 min for 20 h/d	**Launch every 5 min for 16 h/d**	**Acceptability**
Total Pods launched in a day	240	192	☺ 😐 ☹
From 1e5 Pa to 1e2 Pa **Every day**			
Consumption per Pod [MJ/pod]	26781.3	33476.7	
Consumption per 17 Pods [MJ]	455282.1	569103.5	
From 1e5 Pa to 1e2 Pa **Once in a week**			
Consumption per Pod [MJ/pod]	3825.9	4782.4	

Consumption per 17 Pods [MJ]	65040.4	81300.5	
From 1e5 Pa to 1e2 Pa **Once every 2 weeks**			
Consumption per Pod [MJ/pod]	1912.9	2391.2	
Consumption per 17 Pods [MJ]	32520.2	40650.2	
From 1e5 Pa to 1e2 Pa **Once in a month**			
Consumption per Pod [MJ/pod]	892.7	1115.9	
Consumption per 17 Pods [MJ]	15176.1	18970.1	
From 1e5 Pa to 1e2 Pa **Once every 2 months**			
Consumption per Pod [MJ/pod]	446.4	557.9	
Consumption per 17 Pods [MJ]	7588	9485	

For the following consideration it is chosen to *not take in account the photovoltaic production*, because the aim is to compare the consumption of energy. At this point of the analysis it doesn't matter the origin of the energy.

Energy consumption [MJ] for traction & vacuum system			
From 1e5 to 1e2 [Pa]	AGV	MAGLEV	HYPERLOOP 17 pods
Once every 2 weeks	35900	26600	54360
Once in a month			32680
Once every 2 months			23195

Even if it should sound impossible, the best solution is to depressurize the system at least waiting 2 months, for maintainability, tests and checks. Maybe it appears more possible every month, but at this level of study it means no great improvement in energy consumption from the traditional HST. If the system has to be completely pressurized and depressurized in a period shorter than a month, this new technology doesn't reach its goals and it loses in interest, even if a gain in travel speed is achieved.

In this chapter the problem of the vacuum system is addressed to the reader, and possible solutions are found in the field of the realism. It is important to maintain low pressure condition, as far as possible, inside the tube. The author estimates that 2 months should be a reasonable period, if there are not safety restrictions.

6.2.2. PV production

In TransPod's project a field of photovoltaic panels are englobed in the infrastructure, in order to produce electric energy useful for traction needs, for vacuum systems and all others auxiliary systems. This can be considered as a personal energy source and it is important to understand benefits and limits from this renewable source. Once more, even if it is connected to the traction system, it is analyzed at this point because it is not an essential part of the propulsion system.

As regard for the *PV production*, it is assumed that the total efficiency is of 10% and just 50% of the line can collect properly energy. Assuming a solar average incident radiation of 1000 $\left[\frac{W}{m^2}\right]$ and a width of the photovoltaic infrastructure of 2.5 [m] over each line, facing sun with the best available degree:

$$PV_{power} = 1000 * 500\,000 * 2.5 * 0.1 * 0.5 = 62\,500\ [kW]$$

During air pumping the Photovoltaic system can produce:

$$PV_{energy} = PV_{power} * 2.6 = 162\,500\ [kWh] = 585\,000\ [MJ]$$

That is 9.1% of total vacuum pumps demand. It is indeed necessary to store PV energy to employ it when needed the more, this concept is addressed in chapter 8. The table below resumes the potential energy stored from PV in different time lapses, if it is productive for an average 5 h/d and the storage efficiency is of 60%.

Period	Potential energy stored [MJ]	% of total vacuum system needs
1 day	675000	10,5
1 week	4725000	73,5
2 weeks	9450000	147
1 month	20250000	315
2 months	40500000	630

Great novel, the PV system can store the energy needed for evacuating air from the tube in around 10 days with the previous assumptions.
The vacuum system must be optimized to guarantee a long period of functionality between two switches on. This means high performance insulation, constant pressure control and a low energy smart pressure stabilizer system that corrects oscillations around 100 Pa. Photovoltaic production and storage can help the system to be autonomous, but it should be an error to accept a high consumption just because of the employ of this renewable energy. Perhaps, it is also the less interesting renewable energy source that can be implemented in NOAH. In the following some interesting technology.

From the row analysis of the possible PV production and storage, it appears that hyperloop system has the chance to become energy-autonomous and maybe a producer. In addition, there are other important energy resources that can push toward an eco-friendlier mean of transport, in the following chapters a description of the more important implementations.

6.2.3. Regenerative braking

To save energy from braking is the only way to sustainability. In fact, there is a double gain, first gaining energy that before was considered as lost. Second, the energy produced by the PV system and not employed, because substituted by the regenerative one, can be consumed elsewhere or stored or sold to the national grid. As regard for braking energy management, three solution are proposed in the following: an electrolysis plant combined with a methanation one; a super-flywheel system; a synchronization procedure between departures and arrives.

One big hope for railway sector and related is to be able to use 100 % of the energy generated during braking. A difficult job nowadays because of the architecture of the power grid. Braking energy has few possible implementations:

- To be utilize by an accelerating train on the same catenary in the proximity with the possibility of damaging the infrastructure by overvoltage;
- To be collected by the grid if it is prepared a non-traditional reversible substation, equipped with bi-directional inverter architecture (that means the owner of the power supply system

accepts to convert all substations to buy instantaneous and random power peaks in an indefinite point of the national system, producing variations and oscillations randomly and with the probability of damaging electric components)

Traditionally, trains work with AC supply systems at medium voltage. That's due to the national grid architecture that works at high voltage alternative current (HVAC). To link with the national grid an AC subsystem is then required, but hyperloop needs a DC subsystem too. A solution can be to direct DC in a different system where it can be managed without connection to HVAC.

A smart DC grid allows to re-use the regenerated energy internally, by the same operator, in different applications. For example, directly as internal needs of the stations, where usually trains stop and regenerate the most, or to fill electric vehicles parked outside the stations. Also, an efficient energy storage and distribution can equilibrate peaks of production and peaks of consumption. Hyperloop can get also the smarter AC/DC grid, because it is an innovative network that has to be completely built.

I. Hydrogen: water electrolysis & methanation

Assuming that there are no losses for friction (both thermo-mechanical and aerodynamic, still to evaluate magnetic friction losses) the energy that can be regenerated is huge, almost 50% of total travel need for traction, compared to 15% for subways [40] and less than 5% for traditional HST.

This big amount of power is distributed in the 40 km segment close to the arrival station in few minutes, in normal condition of operation. The power peak is not manageable with traditional storages as batteries, so a more efficient thus complex system is needed, able to convert electric energy into hydrogen, then methane.

The chemical technique to produce hydrogen from water is called electrolysis. Water electrolysis occurs when a potential difference is imposed between two electrodes immersed in an electrolyte with water, generating an electric field that solicits the negative ions (anions) to move towards the anode (positive pole) and positive ions (cations) to move towards the cathode (negative pole). At the same time, the ions already present around the electrodes react in various ways: at the cathode, by absorbing electrons from the metallic circuit, and reducing at the anode giving electrons to the metallic circuit and oxidizing. Hydrogen and oxygen are obtained separately because they each grow in correspondence of one of the two electrodes; in addition, a diaphragm placed between the two compartments of the cell avoids the mixing of the gases allowing instead the passage of the ions in solution. The salts or alkalis that must be added to the water to increase its conductivity are not consumed and therefore the only substance that is consumed is water. Most commercial electrolyzers use as electrolyte a solution between 25% and 35% by weight of potassium hydroxide (KOH) [41].

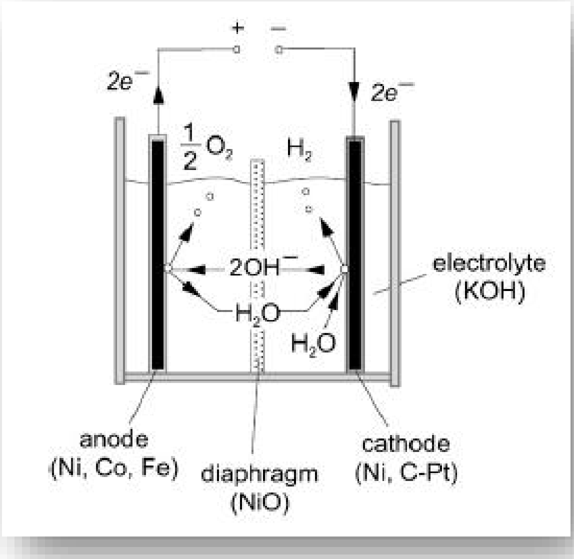


Figure 33 Water electrolysis: chemical reactions and cell structure [41]

Associated chemical reactions are:

$$4e^- + 4H_2O \rightarrow 2H_2 + 4OH^- \quad at\ the\ cathod\ (hydrogen)$$
$$4OH^- \rightarrow O_2 + 2H_2O + 4e^- \quad at\ the\ anode\ (oxygen)$$
$$2H_2O \rightarrow 2H_2 + O_2 \quad complete\ reaction$$

For the water to decompose, a voltage must be applied to the ends of the electrodes higher than the reversible voltage V^0, which corresponds to the water's free formation energy:

$$V^0 = +\frac{\Delta\bar{g}}{2 * F}$$

Where $\Delta\bar{g}$ is the molar Gibbs' free energy variation of the reaction, F the constant of Faraday (96485 C/mol) and 2 the electrons transferred in the reaction for each molecule of water. In standard conditions (25°C and 1atm) the variation of free energy of the complete reaction ΔG is equal to 237.3 kJ/mol and the minimum voltage for which the reaction takes place is therefore determinable as V^0>1.23 V. If now the global electrochemical reaction is referred to a mole of water its expression becomes:

$$\mathrm{H_2O\ (l)\ \rightarrow\ H_2\ (g)\ + 0.5\ O_2\ (g)}$$

It is possible to understand the amount of charge to be spent to split one mole of water into one mole of hydrogen and half mole of oxygen, that is 2 Faraday. 2*F corresponds to 53.6 Ah/mol. So, it is established that in order to divide a mole of water into one mole of hydrogen and half mole of oxygen it is required a charge amount of 53.6 Ah/mol. It is therefore easy to calculate that, to obtain 1 Nm^3 of hydrogen, it is necessary to spend around 2230 Ah. From the energetic simulation it is known that 394 MJ are injected in this system by every braking Pod in 4 min. From conversion it is calculated the equivalent in Wh, so $394\,MJ \rightarrow 109\,444\,Wh$. The author assumes for each cell $V_{effective} = 1.5\,V$, knowing that $Wh/V = Ah$ it is calculated that 72962.66 Ah are available, so theoretically 1.361e3 mol (about 24.5 kg) of purified water are reacted producing 32.72 Nm^3 of hydrogen every 5 minutes.

Another important aspect is the heat management during water electrolysis, due to internal resistance of cells and to the overvoltage ΔV imposed to control reaction ($V_{effective} = V^0 + \Delta V$), temperature rises. Normal operative conditions are around 60-90°C and for a safe and efficient conversion the temperature must stay in this range. Talking about efficiency, the performance of the cell is around 0.6-0.65 $\left(performance = \frac{higher\ calorif\ value\ of\ hydrogen}{electric\ energy\ consumed\ during\ process}\right)$.

The previous description refers to the so called alkaline electrolyser. Another mature and available technology is the PEM (proton exchange membrane) electrolyser, characterized by an operating temperature of 40-80°C and higher current densities, that uses a polymer electrolyte acid membrane as a medium of ion transfer. A promising technology in that domain is the SOEC (solid oxide electrolysis cells). The big difference is the operating temperature, around 700-900°C, depending on the fact that the cell works with steam and not liquid water. It is a suitable technology linkable with cogeneration plants. Of course, there are advantages and disadvantages linked to this high temperature process. For hyperloop, not directly linked to power plants, it can be just an hypothesis. In this paper no further investigation is followed to study which kind of electrolyser is the most suitable, an ad-hoc analysis must be performed at an advanced and thorough level. The author's aim is to scratch the surface of this sector to increase anticipations about hyperloop project. Once the hydrogen is produced there are three possibilities of employment:

1. Direct storage of hydrogen
2. Methanation of hydrogen
3. Direct use of hydrogen into fuel cells

Starting from the last point, it is a stupid thing to process electricity into hydrogen just to produce directly electricity with a performance lower than 0.6, so this point will no more be discussed. A discussion about direct use of electricity from arrivals to departures is addressed in "Departure-arrival synchronization".

The direct storage of hydrogen is not so easy with nowadays technologies. Hydrogen is a dangerous gas at atmospheric conditions that can explode in contact with oxygen at certain concentrations. Storages (for liquid, gaseous or solid phase) are to be completely sealed and they must guarantee high resistance to corrosion, high pressure and they must be put in circumscribed areas. The direct use of hydrogen is performed by industries and by special electric cars, so the market for a product of a great energetic value exist and it is developing, but it is still confined.

Point two takes a great interest, transforming a hard to manage substance into a wide spread gas that can be used into cars, common houses/buildings, industrial plants: methane.
It is the expansion of the CCS, the Carbon Capture and Sequestration processes that aim to stabilize greenhouse emissions while still relying on fossil fuels. It is one of the most suitable way of storing seasonally RES and large amounts of surplus electricity even for long periods.

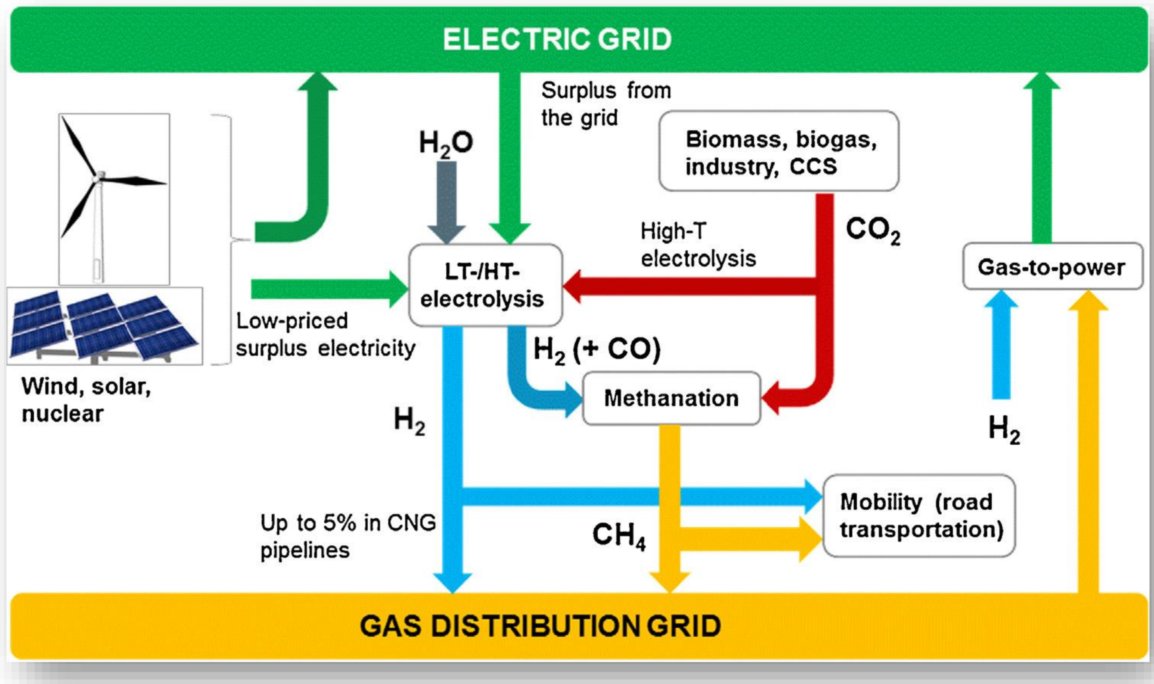


Figure 34 "Power-to-Gas" pathway: Smart interaction between the electric and the gas distribution grids [42]

For methanation two ingredients are required, hydrogen and carbon monoxide [43]. The last one must be captured, preferably at the chimney of power and heating plants by separation processes and then processed (by compression and dehydration) to be stored and finally conveyed at the methanation plant. Obviously, a little amount of CO will be processed, if the combustion occurs in a proper way, and a big amount of carbon dioxide will be sequestered. This process needs also heat power and a catalyst in order to generate SNG (Synthetic Natural Gas). The reaction is:

$$CO + 3H_2 \leftrightarrows CH_4 + H_2O \qquad with \;\; \Delta H^0_{298} = 206\ kJ/mol$$

Not only methane is safer than hydrogen, it is also more "compact".

Just for completeness, two other reactions will occur, methanation of CO_2 and water-gas shift:

$$CO_2 + 4H_2 \leftrightarrows CH_4 + 2H_2O \;\; with \;\; \Delta H^0_{298} = 165\ kJ/mol$$

$$CO + H_2O \leftrightarrows H_2 + CO_2 \qquad with \;\; \Delta H^0_{298} = 41\ kJ/mol$$

Just to remember, from electrolysis it is obtained pure oxygen that can be employed in several activities and that has also a developed market, so it can be produced and sold. It is not a waste.

There are other disrupting technologies coming out, like the direct capture of CO_2 in the air that can be synthesizes into clean, affordable transportation liquid fuel (always processing hydrogen), a concept implemented since 2015 by *Carbon Engineering,* to name one. There is great interest on those "renewable" fossil fuels because some sectors of transportation will always be reliant to, like the aircraft sector.

Another solution can be the cultivation of specific micro-algae, combining air, light from the sun, nutrients and, optional, carbon dioxide in a confined environment. From micro-algae are processed drugs, cosmetics, reinforced foods, feeds, fuels, biodegradable plastics, there are also kinds of algae that produce bio-hydrogen. This sector must be evaluated to fit with hyperloop realization.

Methanation plant seems the best solution to the author, because controlling the burning phase, in particular the flow of fumes, it is possible to recollect carbon dioxide, while cleaning smoke. Methane is easily transportable and gas turbines have reached a high performance; those plants have to be distributed wisely all the long of the infrastructure, mostly where it is needed a thermal source. In fact, they are co-generative (electric and thermal) plants. Some of the abovementioned solutions, where carbon dioxide is processed, act in the air cleaning context. This is exploitable for mitigation works that will follow the hypothetical realization of the work.

II. Super flywheel, renewable energy storage at a national level

There is one point not addressed, until now: what is the best solution to store energy produced during braking outside the braking zone (40 km near hyperloop stations) and energy from the PV system diffused all over the infrastructure.

In fact, direct use of PV is not desirable because of lack in guaranteeing availability, reliability and the total necessary power, also due to intermittent nature of the source and the users. If it is assumed that:

- 4 over 13/14 vacuum systems per km are switched on to maintain 100 Pa conditions;
- There are 9/10 vacuum pumps available per km;
- The owner of the system has great confidence and experience in magnetically levitated items;

It is clear, a local storage must be done using “super flywheels”.

This technology is based on the principle of storing electric energy in the form of kinetic energy by rotating a flywheel in a vacuum vessel using magnetic (contactless) bearings. There are several advantages:

- No deterioration due to chemical reactions;
- Infinite possibility of charge and discharge in normal conditions;
- Lower in loss than conventional flywheels;

This technology has been developed further after innovation in reversible electric machines, technology that enable to switch from generator to motor quickly and easily, and thanks to the work of researchers in the field of material science, founding new composite materials that can resist better to centrifugal forces. The energy that a flywheel contains is expressed as

$$E_{cin} = \frac{1}{2} I_z \omega^2 \text{ with } I_z = \int r^2 \rho dV$$

For a common cylindrical structure $I_z = \frac{1}{2} M r^2$. It is then underlined that angular velocity, mass and radius of the flywheel handle the capability of the storage directly. An example can be the “Flywheel Energy Storage System using Superconductive Magnetic Bearing” [44], that is made of Carbon-Fiber-Reinforced-Plastic. The radius of the CFRP flywheel rotor is 1 meter, with a weight of 4000 kg. It can store up to 25 kWh with a maximal rotational speed of 3018 rpm, the output power is of 330 kW. The team investigating its functionality guarantee high reliability. This solution needs a cryocooler, whose consumption is less than 1% of the output. This example is part of a project known as “the Technical Development for Safe, Low-Cost, Large-Capacity Battery System – the Development of the Next-Generation Flywheel Power Storage System” sponsored by the New Energy and Industrial Technology Development Organization (NEDO).

For its characteristics, this system is suitable for storing big amounts of energy, for moderating fluctuations from renewable energy sources and for absorbing regenerative braking energy available far from the stations (outside the 40 km braking zone for hyperloop).

This system is not just suitable for hyperloop system, it can become a *huge energy storage for both private renewable energy producers and for national grid surplus*, from now on *HYPER-GRID*, implementing a smart grid management at a national level, integrated into the infrastructure. Private renewable energy producers can connect directly to *hyper-grid* and so bypass the national grid, avoiding losses for DC⇆AC conversions and losses due to energy transportation. National grid can manage peaks of production injecting energy into *hyper-grid* and, vice versa, absorbing from storages in case of deficiency.

At this point it is more comprehensible the choice of the author to put a vacuum system every 75 meters. Probably, this is too much, and a proper installation of vacuum pumps must be judge. It is an extra cost during installation, but consider these advantages:

- In case of malfunction of a vacuum system there are two others available into 75 m radius, permitting constant function of hyperloop during reparation and maintenance;
- There is the possibility of install a "super flywheel" system every 75 m, employing vacuum pumps in a secondary beneficial use and creating "energy spots";
- Close to them there is the opportunity for industries to grow up, finding shareable services they can buy at a lower price than if they must install by themselves.

III. Departure-arrival synchronization

As a last consideration in the domain of regenerative braking, direct use of electric energy produces less losses avoiding conversion's irreversibilities. A synchronization process is developed, opening to a different perception of the hyperloop station.

When a Pod enter the braking zone it produces DC electric current in a dedicated grid. It is suitable that this energy is addressed to a Pod that is starting is journey. The simplest way is to connect the tubes by a net of conductors, having in mind that after 30 km the power injected is no more effective and that the most interesting is to use peak from braking (so, when Pod is 40 km from the arrival station) to cover peak from departure (so, when Pod is in the departure station).

The possibility of using high temperature super conductors is interesting, but expensive and hard to maintain with nowadays technology. A help can come from design, as showed in the following figure.

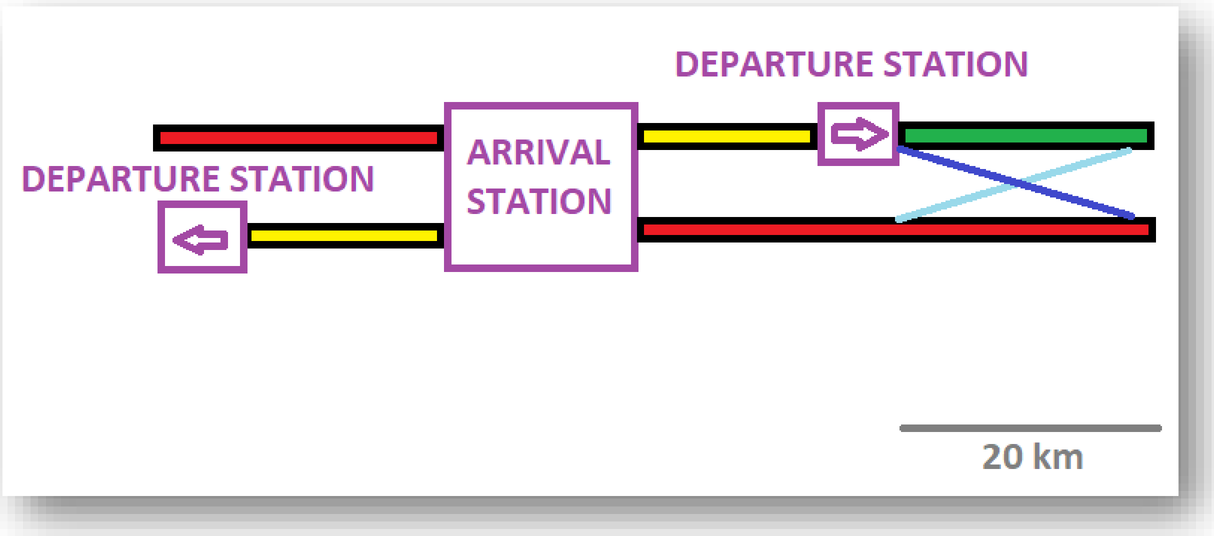


Figure 35 Station design to synchronize arrival-departure energy

To put the departure station 20 km away from the arrival station is something distant from normal people experience, even if there are advantages not only from the energetic point of view.

Advancing in order, the synchronization is now possible coupling braking peak power to departure's one into the 20 km (blue line in figure). Connections between the two ways are possible and desirable until the middle point is reached (light blue line in figure). The remaining 20 km in acceleration must be powered by use of the previously presented *hyper-grid* or by substations linked with national grid. The remaining 20 km braking energy can be managed by a smart grid in the arrival station for: lightening, air climatization, escalators, lifts, shops, electric low speed vehicles for public or private transport, energy storages, wheel-based PPT modules and so on.

Another important advantage from distant stations is the distribution of a considerable number of people over the territory, avoiding congestions and hot spots. This dislocation will help security sector and reduce the check-in phase, halving people in two 40 km distant departure stations.

To conclude with figure 35, the yellow section of 20 km will be a "low speed" transit for Pods, whose use must be depth. If it is at atmospheric condition, the tube can be in glass or some transparent material to permit the view of vehicles from outside. It can be used as transfer link between arrival and departure stations for hyperloop users, or for the paying public that can see it like a train service. It can be also the segment where industries can manage their goods.

6.2.4. Renewable thermal (re)sources

Thermal energy impacting hyperloop varies as sunny hot days and cold nights in every season. External temperature can vary a lot in short period, deforming the sealed iron tube and provoking cracks, impairment from creeping, then the malfunction of the entire system. It is important to maintain a constant internal temperature, to do what an efficient thermal management plant must be optimized.

For the characteristics of hyperloop, thus a confined and controlled environment inside a metallic sealed tube of hundred kilometers, inner temperature must vary in a very little range. To control temperature when variable external conditions varies a lot due to atmospheric conditions (as solar radiation, rain, wind, snow, seasonal fluctuations), different landscapes (from mountains to sea) and varying latitudes, a *geothermal sink* every pillar is suggested in combination with different technologies. There is also the need of evacuating heat produced by hyperloop propulsion system, in fact windings, when powered by an electric current, produce thermal losses.

The big deal, there is an absence of air into the tube, so the main goal is to control tube surface temperature to manage thermal deformations.

Geothermal can help to maintain a stable temperature. This technology exploits properties of the ground, that is characterized by stable temperature during all year long, at a certain depth. Injecting heat during summer and extracting it during winter can be an example, at latitudes where seasons vary. If an aquifer resides underground, it can be exploited as well, with different structural precautions. This solution is proposed because anyway, for every pillar, a survey of the subsoil must determine the foundations of the whole transportation system. The geothermal system can be easily implemented into pillars.

A cooling system is then needed in most cases, but instead of processing directly the flow coming from hyperloop, let's see possible implementations.

If the heat produced inside the tube is too much for the underground sink, alternatives like the implementation of *anaerobic digestion plants* near hyperloop structure can be addressed, producing bio-gas, bio-hydrogen and compost. The raw materials are crops wastes, black water depuration plants' sludges, farm wastes and organic wastes in general. For those plants a constant temperature of about 40°C is needed while bacteria, in absence of oxygen, digestate organic matter farting bio-gases.

Another alternative can be a *PCM storage (Phase Change Material)* that can store thermal energy for a long time. PCM are solid at normal atmospheric condition, when they are discharged. Once they store heat they become liquid. Every PCM has its proper phase change temperature. It is not employed for seasonal storage because the heat it can preserve per volume is not competitive. It is interesting in domestic applications, because for a fixed volume PCM can store up to 50% extra energy compared to a traditional water tank. Thus, where hyperloop crosses villages or passes through cities, a possibility is to charge domestic PCM for house heating or for domestic hot water.

By mean of the chapter 6.2 the author gives an idea of an eco-friendlier system, that saves typical energy losses, from braking to propulsion heat generation, increasing the performance of the whole system.

6.3. Sustainability, a larger view

When talking about sustainability, it means also evaluate the fact that actual societies don't want to lose "privileges" obtained. To make an example, nobody can renounce to have a fridge in its house, but he can buy a fridge made of recyclable materials, he can change some habits using different techniques to keep the food and pollute/consume less. That's the point, a service never has to be degraded, but improved in order to offer a better performance with a lowered impact on environment. To be competitive offering a door-to-door integrated service is mandatory, that is PPT. To offer an alternative to actual energy market, to commercialize precious goods displacing from high concentration to lower, hyperloop is designed for.

Hyperloop multitasking concept connects, in a unique infrastructure, benefits from high-speed travel in a controlled environment where no pollution is produced, to renewable generation and energy storage from distributed and intermittent sources. The overhead structure permits the passage of people, vehicles and animals with continuation during all the way. It can be juxtaposed to existing highways to reduce impact. Where fields are crossed, cultivation can receive benefit from geothermal systems that monitor the inner tube temperature and heat generation, with no damages at all to the harvest. If the case, the tube can pass underground without adding troubles but increasing the cost of installation.

6.3.1. Personal Public Transit (PPT)

"[…] the parameters through which a transport system is evaluated by the consumer is its *inclusive speed* (in the same spirit of the inclusive fitness of Darwinian biologists). To clarify with an example, the great success of cars is due to the fact that their inclusive speed is high (if one can find a parking space) in spite of the fact that their operational speed is mediocre (40 km/hr mean, since Ford's time!)" [45]. By car is the only way people can have a door-to-door experience of travel having the feeling that no time is lost. With others means of transport it always exists the exigence to go to stations, stops, ports, airports, with another vehicle or by feet, and wait for the departure.

This concept is *multimodality*, namely the utilization of, at least, two different mean of transport to cover the entire journey. The more direct example can be the way people reach and move away from hyperloop' stations: by car, by bus, by train, by subway, by bike, by helicopter. Stations must be designed to accord with all possible solution to offer the best travel experience to users. This concept is well known, and it is developed the most in airports.

There is another important point linked to multimodality, that is *intermodality*: the possibility for people or goods to experience multimodality remaining in the same "container". This concept has been extended to hyperloop case, finding a compromise between first class needs and PRM ones (Passengers with Restricted Mobility).

Even if essential, with one seat, personal luggage nook and a place for a wheelchair, it contains some extra comforts as a screen, a personal climate conditioner and, in case there is no need for the wheelchair, the possibility to turn the seat towards straight direction and to lengthen the seat having a kind of deckchair. The configuration of the module is based on the need of charging it into Pods and at the same time permit intermodality. To visualize, imagine a cylinder splitted in half on the vertical diameter, line that represents the back of the PPT module. The back-to-back configuration is evaluated as the more suitable for a compact and still comfortable high-speed travel.

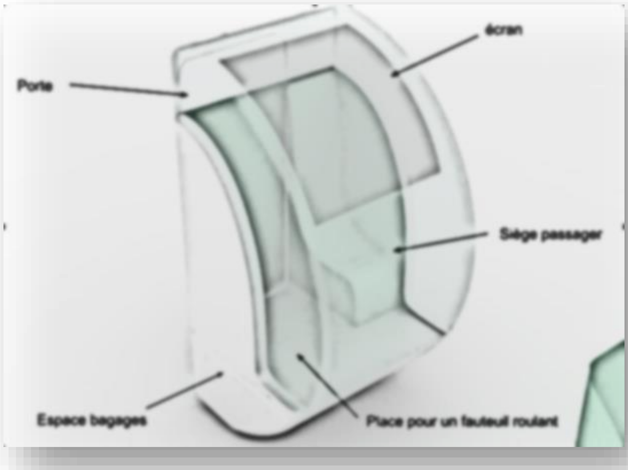


Figure 36 PPT module, concession from Ikos

The interest to maintain a low price impose the split of a normal Pod in two: a shared area and a PPT area. Lower price will be in the shared zone, where comfort is guaranteed but shared with other passengers. For business class, first class and PRM, PPT permits a workable travel time, confidential private calls or meetings. PPT capsules, in addition, benefit of an automatic process in stations that allows them to be directly charged over an autonomous wheel-based system that can travel everywhere inside and outside the station. Specific transit corridors assure no waste of time in queuing when boarding or disembarking, so a fast check-in at the departure and a fast exit when arrived contribute to the pursuit of the fastest mean of transport.

In this way PPT voyagers don't have to worry about their baggage, they don't have to stand up and get out of Pod, they just continue to enjoy the movie they are watching on the screen, or the skype meeting, for example. If it is the case of a PRM, then architectural obstacles are completely erased. Clients just need to call for the PPT service and, like a taxi, it will pick up at the door and serve until the end of travel hundreds of kilometers away. In a visionary experience, those PPT capsules should be compatible with drone-based system for a fast and direct crossing in cities. The same concept can be applied for transportation of goods, of course with modified interior design, completing the user's pool exigences.

The impact due to a door-to-door mean of transport like PPT, completely electric and autonomous, is appreciable also in terms of sustainability reducing all fossil fueled vehicle. Finally, inclusive speed can have an important upgrade, stable since Ford's time. Intermodality is of strategical importance for the development of hyperloop project.

6.3.2. Transportation of precious goods

To link distant places in a fast and sustainable way has advantages in sharing precious goods from rich to poor zones. The author wonders if a Fairtrade is implementable and he imagines possible products to be commercialized. There are precious goods for which there is interest in a fast displacement, more important, of an eco-friendly energy and transportation network.

From results of the critical analysis of vacuum system, around 200 Pods are sent every day from each station. So, a maximum capability is individuated of 5400 passengers per day. Nothing compared to the average 4 500 000 people taking the metro in Paris. But, as the author already told, hyperloop has a different public. Imagine now that 100 Pods are sent for commercial reasons, so just 2700 people can take hyperloop during a day. On the other side, 1000 ton of materials and products can be displaced on the territory quickly.

Zeolite, as Thermal Energy Storage (TES), is a solid example in European economy of benefits from this extended market zone. Zeolite is a ceramic material that has the characteristic to transfer energy to the fluid when in contact with water, under certain conditions. The reaction that made possible the storage of the heat by a ceramic material can be described as follow:

$$product + heat\ (from\ solar\ system) \rightarrow zeolite + water\ \ [charge\ TES\ when\ T > T_{inv}]$$
$$zeolite + water \rightarrow product + heat\ (for\ heating\ needs)\ \ [discharge\ TES\ when\ T < T_{inv}]$$

Where *product* means the combination of zeolite with water. Without entering in the detail, zeolite is a material that stores by absorption, a physical-chemical reaction. When exposed to a hot environment with temperature higher than the temperature of inversion it “stores thermal energy” separating zeolite from water. When dry zeolite enters in contact with a wet environment at a temperature lower than the inversion one, it releases energy. The storage is isothermal with the environment, thus at ambient temperature condition, with no losses during storage phase. The only condition is to store zeolite in a dry place or tank. This cycle can be repeated a lot of times with little alteration of the ceramic material.

The impact on a European scale is evident, charging zeolite in the sunny south of Europe and transporting it to the cold north, with a constant recirculation. This solution has been developed from professors Chiavazzo E., Asinari P. at Polytechnic of Turin, and they outlined as one of the main obstacles the cost of transportation. Hyperloop technology opens, hence, a profitable, ecologic, renewable market that may connect in an effective way Europeans.

Water is the most important good for living beings. A structured and equal repartition is suitable and hyperloop concept can increase this homogeneity. Even better if hyperloop network connects to high tech desalination plants close to the sea, transporting pure water. To remember that, for regenerative braking management, in case of realization of the electrolysis process, a huge quantity of pure water must be employed by all the system.

Information, in the age of internet and big data, is a precious good. The IoT age is starting with robotics, smartphones, driver-free vehicles, smart-glasses, augmented-reality devices and so on. Being always connected is our future, technology will grow faster, and humanity will depend more and more on this service. Hyperloop can be a bridge between major cities integrating in its infrastructure optical fibers of new generation, protected from the environment and incorporated in a mammoth work. Finally, to connect people also in reality on a large territorial scale will be the best way information can travel and society can expand.

A future into which realities as Amazon are affirmed on a global level, to guarantee a cleaner transportation service is mandatory. Not only, there is a special market connected with hyperloop solution, an energetic market, that can be built and exploited, with benefit for the industry, for the environment, for the community.

7. Conclusion

Keeping grounded in reality, hyperloop seems the next generation high velocity system for ground continental travels. It consumes less than any other in traction, it presents the more sustainable infrastructure, it is faster than airplanes. All the problems linked to vacuum, levitation, propulsion, infrastructure, energy, reliability, availability, safety, they can be managed by actual technology and expertise. The objective of the thesis is reached, hyperloop system can be considered the best HST system, even if it still needs to be proven. In this final chapter a focus on more interesting technical results is followed by a more general conclusion.

7.1. Technical conclusion

1. *Hyperloop consume 72,6% of total travel need during the first phase of constant acceleration* until top speed is reached, then maintained. Therefore, there is no need for a huge power supply sub-system like for other technologies. Only 27,4% of total energy (220 MJ over 806 MJ) is consumed over 420 km of travel, thus $0.524\,{}^{MJ}/_{km}$. This fact is very interesting, because it permits to the PV system to completely supply for the distributed need during travel. In fact, assuming PV system produces $PV_{power} = 125\,{}^{kW}/_{km}$, considering a passage every 3 min, it can accumulate $PV_{energy} = 22.5\,{}^{MJ}/_{km}$ in the same period.
2. Hyperloop has to be privileged when *crossing mountains and hills.* In fact, it can easily climb 10% slopes with an increase in energy consumption from flat condition ${}^{E_{10\%}}/_{E_{0\%}} = 1.94$. This characteristic is attributable to the agility of Pods, due to a reduced mass compared to other HST;
3. *Regeneration during braking,* so when arriving at the station, *can produce up to 48% of total travel energy consumption*. In other words, just 52% of the total traction energy is "lost" in the service. To the author, it *is desirable to manage this energy by mean of a water electrolysis and methanation plant connected to the guideway* near arrival stations. This solution proposes a safer operative condition, a developed but concentrated electrolysis plant and, mostly, it doesn't affect the weight of the POD *(a future research can develop this point, if it is better to have a unique structure to absorb, transform and store regenerative braking, or a system that every Pod can mount onboard);*
4. *For storing renewable energy production and energy regeneration* from braking outside the braking zone, *a super-flywheel storage system is recommended.* Not only it is more performant and it presents more capacity than other similar systems, it has advantages also against other forms of electric storage like batteries, capacitors, compressed air storage systems, and so on. The easy principle and implementation, the simplicity in charging and discharging thanks to commutable electric motor/generator, the use of contactless technologies as magnetic bearings, all of that made the super-flywheel the most suitable energy storage for developing an extended electric smart storage system.
5. To invest in hyperloop technology *it must be handle the integration of services from many and different domains*. From a *thermal exchange market with zeolite*, passing through *intermodality with PPT*, for *redistribution and purification of water*, as *carbon capture and methanation sub-plant*, as *energy endemic operator*, as *connector*, hyperloop should have a major role in the future.
6. In the field of safety, it is important to consider cyber security as a fundamental brick of the project. Every information around hyperloop, controlling the technology, has to be protected from infiltrations and breaches in the system. The platform must be isolated, possibly integrated in the structure, and autonomous.

7.2. General conclusion

The possibility to displace people in a confined environment, so even when natural phenomena are adverse, may be increasingly requested in an age where global warming is transforming the environment producing disasters.

Hyperloop is not suitable for short distance displacements, so it will never take the place of actual HST and the ERTMS project must go on, to harmonize power supply and signalization in Europe. It cannot replace airplane for transcontinental journeys. Its role is to complete the scene taking the place actual intercontinental airplanes have, changing not only the way we travel, but the way we keep in contact and we connect to each other. A big personality like Cesare Marchetti, whose vision has been presented also in the introduction of this paper, describes in his reports [45] a clear idea of evolution of transport talking about Maglev system in 1994. He considers that levitation is profitable for so many reasons, that, in this paper's author opinion, to persist in not actuating this technology is considerably harmful. Marchetti proposes the *side-wall suspension* as the more promising, he suggests *long-term R&D plans working on a certain hyperloop concept, focusing on compatibility and straightness.* He underlines the peculiar characteristics of linear motors *(pulling on the train independently of speed).* He talks about an *energy storage system distributed along the line* and he underlines the linked aspect of *digitalization.* He is a precursor of NOAH concept, even if with a different aim. In fact, he suggests the use of this high-speed technology to create megalopolis connecting cities about 100 km distant, into a time of 20 min. He proposes a metro system rather than an intercontinental mean of transport. The author of this paper makes an investigation that leads partially to Marchetti conclusions. Marchetti is a visionary and a genius, not pretending that this work is at his level, and his solution is suitable for growing cities rather than for growing countries. Integrating the two visions is possible, with benefits from both sides, the same network can operate as high-speed metro and as high-speed train with no change in structure. It is just a matter of power supply.

The renewable energy production, storage and smart-grid connection possible thanks to this infrastructure is potentially the response to a more safe and equilibrated energy market for Europe and should motivate the European Council to invest in this solution. In fact, this is a political choice towards the future of this Continent that is growing. In the age where everything passes through the smartphone and where virtual connectivity is at a level never seen before, a real and concrete fast interconnection between major cities can reorganize society. Not that the poor get rich, the rich become even richer, but a worker that lives in his city and work in another (hundreds of kilometers away, maybe in another country), getting in touch with a different reality/society, he can adapt his lifestyle taking all benefits from different places, mixing cultures and habits. He can understand and so be part of an effective union. Also, the market will open to an unimaginable level, bringing finally out of the permanent crisis that stagnates in Europe. The potential directly connected to this disruptive technology is enormous, a continent like the Eurasian can be connected with an upgrade also in terms of security and solidarity, because a fast displacement of people and basic necessities where catastrophes occur should be just normal, if the infrastructure is not affected. In terms of energy dependency, a must to face for European government, it should be a possibility to finally rely mostly on renewables energies.

Finally, a little remark on the proper scale for hyperloop integration. It is not at national investment level (except for USA, Canada, Russia, China, India), but a continental level engagement. Hyperloop factually links several states, in the European Union a project like this should be the investment for the future. This project has great similarities with the "train fever" that around 1869 led to the completion of the transcontinental railway creating the USA. The secession war was a big promoter for the completion of the railway, showing the real potentiality of a well-established network. Hoping that nor a war neither a new crisis will promote the construction of hyperloop, but just the good sense of our ruling classes. An example of good sense is showed by the town council of Limoges, that will host a three-kilometer-long test line in collaboration with TransPod from 2019. There are advantages for the image of the region all around the world, for the local university, a new R&D center will grow up, people can work in the realization phase. TransPod will pay for everything, something like 21 million €, 100% from private investments. The CEO of TransPod, Sebastien Gendron, affirms that without an indulgent political class, open to new technologies and prepared to collaborate, even indirectly, this should not be possible. To remember that in first approach, having the reference shareholder in Italy, Angelo Investments, TransPod asked to Italian “Ferrovie dello Stato” without a positive answer and with the change of government and the resetting of the vertices of the institution, the negotiation has fallen [46]. In 2030 TransPod affirms the first commercial line will be available, so what is the position of European countries to this new technology? Should the community invest in it? That’s pure politics. For the near term, the author thinks that some test lines should rise in other Countries to test this technology in different environments. He suggests the realization of a test line Torino-Courmayeur thinking about a possible connection Torino-Paris, to test the infrastructure in winter in a mountainous territory.

The PHA of the traction system reveals that the work to obtain a safe mean of transport is long, but achievable. Hyperloop gives a smart network, it helps having a safer energy grid, it produces work, it connects the north to the south, the east to the west, it is more ecofriendly than any other high-speed vehicle. It is the future of high-speed ground transportation. It is the way the energy market can evolve. It is the link for a European Union. It is not perfect, just the best.

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9. Attached

9.1. The AGV MATLAB code for simulation

Total flat travel:

```
clear all
close all
clc

%% dati AGV 550
passeggeri=1*460*75; %kg persone+bagagli

massa=380000+passeggeri; %kg
ratio_peso=passeggeri/380000;
gg=9.81; %m/s2
V_max=360; %km/h
wheel=0.92; %m
beta=0.08; %stima, ho preso il max valore che si può avere per un treno completo
dv=0.1; %km/h
tratta=500000; %m
s_fren=15000-2000; %m
rend_glob=0.94*0.98*0.99*0.95*0.98;

TV=@(v)(273).*(v>=0 & v<77)+... %kN
    ([0.000663953737416945]*v.^2+[-
1.81317198543584].*v+[408.677661169415]).*(v>=77 & v<135)+... %y
    ([1.12856626941153e-05]*v.^2+[-
0.285538551823764].*v+[214.342023293608]).*(v>=135 & v<206)+... %yy
    ([0.00109516399449993]*v.^2+[-
1.02191461723471].*v+[319.983997626702]).*(v>=206 & v<=360);  %yyy
R=@(v) ([0.000531250000000000].*v.^2+[0.00874999999999998]*v+[5]).*(v>=0 &
v<=360); %kN
vvv=[0:0.2:370]; %km/h

watz=0;
trip=0;
tempo=0;
vel=0;
j=0;
dv=0.1; %km/h
% per grafici
speed(1)=[0];
time(1)=[0];
line(1)=[0];
axel(1)=[0];
energy(1)=[0];



    while trip<(tratta-s_fren)
        j=j+1;
        if vel<V_max-10*dv
            %accelero
[s,t,v,a,Pot,Ene,cum_ene]=accelerazione(TV,R,dv,vel,V_max,massa,beta);

            prodotta(j)=0;
            consumata(j)=cum_ene(end);
```

```
            risparmiata(j)=0;
            trajet(j)=s(end)/1000;
            durata(j)=t(end);
            trip=trip+s(end);
            tempo=tempo+t(end);
            vel=v(end)*3.6;
        elseif vel>=V_max-10*dv
            %crocera
            [s,t,v,a,Pot,Ene,cum_ene]=crocera(TV,R,dv,vel,V_max,massa,beta);

            prodotta(j)=0;
            consumata(j)=0;
            risparmiata(j)=cum_ene(end);
            trajet(j)=s(end)/1000;
            durata(j)=t(end);
            trip=trip+s(end);
            tempo=tempo+t(end);
            vel=v(end)*3.6;
        end
        clear s t v a Pot Ene cum_ene
    end
    dec(j)=0;
    while trip<tratta & vel>0
        if dec(j)<0.62
            j=j+1;
            %frenata rigenerativa
            [s,t,v,a,Pot,Ene,cum_ene]=frenata(TV,R,dv,vel,massa,beta);

            prodotta(j)=cum_ene(end);
            consumata(j)=0;
            risparmiata(j)=0;
            trajet(j)=s(end)/1000;
            durata(j)=t(end);
            trip=trip+s(end);
            tempo=tempo+t(end);
            vel=v(end)*3.6;
            dec(j)=a(end);
        else
            %arresto con dissipazione termica (dec=0.3 [m/s2])
            j=j+1;
            [s,t,v,a,Pot,Ene,cum_ene]=arresto(TV,dv,vel,massa,beta);
            prodotta(j)=0;
            consumata(j)=0;
            risparmiata(j)=0;
            trajet(j)=s(end)/1000;
            durata(j)=durata(j-1)+t(end);
            trip=trip+s(end);
            tempo=tempo+t(end);
            vel=v(end)*3.6;
            dec(j)=a(end);
        end
    clear s t v a Pot Ene cum_ene
end
fasi=[1:j];
cum_denerg(1)=consumata(1)/rend_glob-prodotta(1)/rend_glob;
% rend_glob=0.94*0.98*0.99*0.95*0.98;
en_km(1)=consumata(1)/rend_glob/trajet(1);
en_p_km(1)=prodotta(1)*rend_glob/trajet(1);
for bb=[2:1:length(fasi)]
    cum_denerg(bb)=cum_denerg(bb-1)+consumata(bb)/rend_glob-
prodotta(bb)/rend_glob;
    en_km(bb)=consumata(bb)/rend_glob/trajet(bb);
```

```
    en_p_km(bb)=prodotta(bb)*rend_glob/trajet(bb);
end
tot_prod=sum(prodotta)*rend_glob;
tot_cons=sum(consumata)/rend_glob;
perc_recupero=tot_prod/tot_cons;
ratio_energia=passeggeri/(tot_cons-tot_prod);
%% plot

figure
bar(fasi,trajet,'r')
title('Distance crossed per phase');
xlabel('phase')
ylabel('distance [km]')
grid on
box on
axis([-20 874 0 36])


figure
plot(fasi,durata/60)
title('Time spent per phase');
xlabel('phase')
ylabel('time [min]')
grid on
box on
axis([-10 874 0 9])


figure
plot(fasi,cum_denerg)
title('Diagramma energia cumulata');
xlabel('tratta')
ylabel('energia [MJ]')
grid on
box on

figure
hold on
plot(fasi,prodotta,'g')
plot(fasi,consumata,'r')
title('Diagramma energia');
xlabel('tratta')
ylabel('energia [MJ]')
legend('prodotta','consumata')
axis([-10 874 0 4250])
grid on
box on

figure
hold on
bar([1],[sum(prodotta)],'g')
bar([2],[sum(consumata)],'r')
title('Total traction energy diagram');
xlabel('produced & consumed')
ylabel('energy [MJ]')
legend('produced','consumed','Location','northwest')
grid on
box on

figure
hold on
```

```
bar(en_p_km,2,'g')
bar(en_km,2,'r')
title('Kilometric energy consumption');
xlabel('phase')
ylabel('specific energy [MJ/km]')
legend('produced','consumed')
axis([-10 874 0 150])
grid on
box on
```

Function “accelerazione”:

```
function [s,t,v,a,Pot,Ene,cum_ene]=accelerazione(TV,R,dv,vel,V_max,massa,beta)
i=1;
dt=0;
%dv km/h
% vel=0; %km/h
s(1)=0; %m
t(1)=0; %s
v(1)=0; %m/s
a(1)=0; %m/s2
Pot(1)=0; %kW
Ene(1)=0; %kJ
cum_ene(1)=0; %MJ
while vel<=(V_max-dv/2) %km/h
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(TV(vel+dv/2)-R(vel+dv/2))/1000; %s
    t(i)=t(i-1)+dt; %s
    if vel==0
        v(i)=(i-1)*dv/3.6; %m/s
    else
        v(i)=vel/3.6+dv/3.6;
    end
    s(i)=s(i-1)+dt*v(i); %m
    a(i)=dv/3.6/dt;
    Pot(i)=TV(v(i)*3.6)*v(i); %[kN] * [m/s] = [kW]
    Ene(i)=Pot(i)*dt; % [kW] * [s] = [kJ]
    cum_ene(i)=cum_ene(i-1)+Ene(i)/1000; %MJ
    vel=vel+dv; %km/h
end
end
```

Function “crocera”:

```
function [s,t,v,a,Pot,Ene,cum_ene]=crocera(TV,R,dv,vel,V_max,massa,beta)
i=1;
dt=0;
%dv km/h
%vel km/h
s(1)=0; %m
t(1)=0; %s
v(1)=vel/3.6; %m/s
a(1)=0; %m/s2
Pot(1)=0; %kW
Ene(1)=0; %kJ
cum_ene(1)=0; %MJ
while vel>V_max-11*dv
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(R(vel-dv/2))/1000; %s
    v(i)=vel/3.6-dv/3.6; %m/s
    Pot(i)=R(v(i)*3.6)*v(i); %[kN] * [m/s] = [kW]
```

```
    t(i)=t(i-1)+dt; %s
    s(i)=s(i-1)+dt*v(i); %m
    a(i)=dv/3.6/dt;
    Ene(i)=Pot(i)*dt; % [kW] * [s] = [kJ]
    cum_ene(i)=cum_ene(i-1)+Ene(i)/1000; %MJ
    vel=v(i)*3.6; %km/h
end
end
```

Function “frenata”:

```
function [s,t,v,dec,Pot,Ene,cum_ene]=frenata(TV,R,dv,vel,massa,beta)
i=1;
dt=0;
velo=vel-dv; %km/h
s(1)=0; %m
t(1)=0; %s
v(1)=vel/3.6; %m/s
dec(1)=0; %m/s2
Pot(1)=0; %kW
Ene(1)=0; %kJ
cum_ene(1)=0; %MJ
while dec(i)<0.62 %km/h
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(TV(velo+dv/2)+R(velo+dv/2))/1000; %s
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)-dv/3.6; %m/s
    s(i)=s(i-1)+dt*v(i); %m
    dec(i)=dv/3.6/dt;
    Pot(i)=TV(v(i)*3.6)*v(i); %[kN] * [m/s] = [kW]
    Ene(i)=Pot(i)*dt; % [kW] * [s] = [kJ]
    cum_ene(i)=cum_ene(i-1)+Ene(i)/1000; %MJ
    velo=velo-dv; %km/h
end
end
```

Function “arresto”:

```
function [s,t,v,dec,Pot,Ene,cum_ene]=arresto(TV,dv,vel,massa,beta)
i=1;
dt=0;
%dv km/h
velo=vel-dv; %km/h
s(1)=0; %m
t(1)=0; %s
v(1)=vel/3.6; %m/s
dec=0.3; %m/s2
Pot(1)=0; %kW
Ene(1)=0; %kJ
cum_ene(1)=0; %MJ
while v(i)>0 %m/s
    i=i+1;
    dt=dv/3.6/dec; %s
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)-dv/3.6; %m/s
    s(i)=s(i-1)+dt*v(i); %m
    Pot(i)=TV(v(i)*3.6)*v(i); %[kN] * [m/s] = [kW]
    Ene(i)=Pot(i)*dt; % [kW] * [s] = [kJ]
    cum_ene(i)=cum_ene(i-1)+Ene(i)/1000; %MJ
    velo=velo-dv; %km/h
end
end
```

From zero to maximum speed:

```
clear all
close all
clc

% moto uniformemente accelerato
passeggeri=1*460*75; %kg persone+bagagli
% passeggeri=0; %kg
massa=380000+passeggeri; %kg
gg=9.81; %m/s2
V_max=360; %km/h
V_max2=260; %km/h
V_max3=174; %km/h
wheel=0.92; %m
rend_glob=0.94*0.98*0.99*0.95*0.98;
%pan_dis*convert*invert*motor*trasmiss
TV=@(v)(273).*(v>=0 & v<77)+... %kN
    ([0.000663953737416945]*v.^2+[-
1.81317198543584].*v+[408.677661169415]).*(v>=77 & v<135)+... %y
    ([1.12856626941153e-05]*v.^2+[-
0.285538551823764].*v+[214.342023293608]).*(v>=135 & v<206)+... %yy
    ([0.00109516399449993]*v.^2+[-
1.02191461723471].*v+[319.983997626702]).*(v>=206 & v<=360);  %yyy
pm0=@(v) ([0.000531250000000000].*v.^2+[0.00874999999999998]*v+[5]).*(v>=0 &
v<=360); %kN
pm20=@(v) ([0.000576923076923077].*v.^2+[0.0192307692307692].*v+[84]).*(v>=0 &
v<=260); %kN
pm35=@(v) ([0.000723983010769958].*v.^2+[-
0.0118333467177058].*v+[145.099539577589]).*(v>=0 & v<=174); %kN
vvv=[0:0.2:360]; %km/h
vv20=[0:0.2:260]; %km/h
vv35=[0:0.2:174]; %km/h
figure
hold on
plot(vvv,TV(vvv))
plot(vvv,pm0(vvv))
plot(vv20,pm20(vv20))
plot(vv35,pm35(vv35))
axis([0 360 0 280]);
grid on
box on

beta=0.08; %stima, ho preso il max valore che si può avere per un treno completo

%% diagramma di avviamento
% diagramma di avviamento in piano
i=1;
dt=0;
dv=0.1; %km/h
vel=0; %km/h
s(1)=0; %m
t(1)=0; %s
v(1)=0; %m/s
a(1)=0;
Pot(1)=0; %kW
Ene(1)=0; %kJ
cum_ene=0; %kJ
while vel<=(V_max-dv/2) %km/h
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(TV(vel+dv/2)-pm0(vel+dv/2))/1000; %s
    t(i)=t(i-1)+dt; %s
```

```
    v(i)=(i-1)*dv/3.6; %m/s
    s(i)=s(i-1)+dt*(v(i)+dv/2); %m
    a(i)=dv/3.6/dt;
    Pot(i)=TV(v(i)*3.6)*v(i); %[kN] * [m/s] = [kW]
    Ene(i)=Pot(i)*dt; % [kW] * [s] = [kJ]
    cum_ene=cum_ene+Ene(i); %kJ
    vel=vel+dv; %km/h

end

% diagramma di avviamento in salita al 2 per cento
i=1;
dt=0;
dv=0.1;
vel=0;
s2(1)=0;
t2(1)=0;
v2(1)=0;
a2(1)=0;
Pot2(1)=0;
Ene2(1)=0;
cum_ene2=0;
while vel<=(V_max2-dv/2)
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(TV(vel+dv/2)-pm20(vel+dv/2))/1000;
    t2(i)=t2(i-1)+dt;
    v2(i)=(i-1)*dv/3.6;
    s2(i)=s2(i-1)+dt*(v2(i)+dv/2);
    a2(i)=dv/3.6/dt;
    Pot2(i)=TV(v2(i)*3.6)*v2(i); %[kN] * [m/s] = [kW]
    Ene2(i)=Pot2(i)*dt; % [kW] * [s] = [kJ]
    cum_ene2=cum_ene2+Ene2(i);
    vel=vel+dv;
end
% diagramma di avviamento in salita al 3.5 per cento
i=1;
dt=0;
dv=0.1;
vel=0;
s3(1)=0;
t3(1)=0;
v3(1)=0;
a3(1)=0;
Pot3(1)=0;
Ene3(1)=0;
cum_ene3=0;
while vel<(V_max3-dv/2)
    i=i+1;
    dt=(massa*(1+beta)*(dv/3.6))/(TV(vel+dv/2)-pm35(vel+dv/2))/1000;
    t3(i)=t3(i-1)+dt;
    v3(i)=(i-1)*dv/3.6;
    s3(i)=s3(i-1)+dt*(v3(i)+dv/2);
    a3(i)=dv/3.6/dt;
    Pot3(i)=TV(v3(i)*3.6)*v3(i); %[kN] * [m/s] = [kW]
    Ene3(i)=Pot3(i)*dt; % [kW] * [s] = [kJ]
    cum_ene3=cum_ene3+Ene3(i);
    vel=vel+dv;

end

figure
hold on
```

```
plot(v*3.6,t)
plot(v2*3.6,t2)
plot(v3*3.6,t3)
title('Velocity - From zero to maximum speed');
xlabel('velocity [km/h]')
ylabel('time [s]')
legend('flat 0%','uphill 2%','uphill 3.5%','location','northeast')
grid on
box on

figure
hold on
plot(v*3.6,Pot)
plot(v2*3.6,Pot2)
plot(v3*3.6,Pot3)
title('Power - From zero to maximum speed');
xlabel('velocity [km/h]')
ylabel('power [kW]')
legend('flat 0%','uphill 2%','uphill 3.5%')
grid on
box on

figure
hold on
plot(t,Pot)
plot(t2,Pot2)
plot(t3,Pot3)
title('Power - From zero to maximum speed');
xlabel('time [s]')
ylabel('power [kW]')
legend('flat 0%','uphill 2%','uphill 3.5%')
grid on
box on

figure
hold on
plot(t,s/1000)
plot(t2,s2/1000)
plot(t3,s3/1000)
title('Distance - From zero to maximum speed');
xlabel('time [s]')
ylabel('distance [km]')
legend('flat 0%','uphill 2%','uphill 3.5%')
grid on
box on

figure
hold on
plot(t,a)
plot(t2,a2)
plot(t3,a3)
title('Acceleration - From zero to maximum speed');
xlabel('time [s]')
ylabel('acceleration [m/s2]')
legend('flat 0%','uphill 2%','uphill 3.5%')
grid on
box on

figure
bar([0 2 3.5],[cum_ene/1000/rend_glob cum_ene2/1000/rend_glob
cum_ene3/1000/rend_glob])
```

```
title('Total energy consumption');
xlabel('gradient [%]')
ylabel('energy [MJ]')
grid on
box on

figure
hold on
title('Time based comparison - From zero to maximum speed')
yyaxis left
plot(t,a,'g')
plot(t2,a2,'r')
plot(t3,a3,'b')
xlabel('time [s]')
ylabel('acceleration [m/s2]')
grid on
box on
yyaxis right
plot(t,s/1000,'g-')
plot(t2,s2/1000,'r-')
plot(t3,s3/1000,'b-')
ylabel('distance [km]')
legend('flat 0%','uphill 2%','uphill 3.5%','location','southeast')
```

9.2. The MAGLEV MATLAB code for simulation

Total flat travel:

```
clear all
close all
clc

% moto uniformemente accelerato
passeggeri=1*460*75; %kg persone+bagagli
massa=51700*2+50600*3+passeggeri; %kg  ipotizzo 5 carrozze, 153 metri di
lunghezza
gg=9.81; %m/s2
V_max=430/3.6; %m/s
cd=0.26;
ax=0.6; %m/s2
air=1.225; % kg/m3
Af=16; %m2
Plg=7.820743126379191e+03; %W/t

%% simulazione sulla base di "Study on green characteristics of high-speed
maglev transportation"
eee=@(t) ([0.0277443910256410].*t.^2+[0.826121794871794].*t).*(t>0 & t<=200)+...
    (5.116279069767442.*(t-200)+1275).*(t>200 & t<=3978)+...
    (0.777777777777778.*(t-3978)+20604).*(t>3978 & t<=4178);
ttt=[0:1:4178];
figure
plot(ttt,eee(ttt)*3.6)
title('Real energy profile consumption');
ylabel('energy [MJ]')
xlabel('time [s]')
grid on
box on

%% simulazione fittizzia 500 km
% avviamento in piano
```

```
i=1;
dt=1;
flag=0;
v(1)=0; %m/s
s(1)=0; %m
t(1)=0; %s
ar(1)=0; %m/s2
Fd(1)=0; %N
Fr(1)=0; %N
Pot(1)=0; %W
Ene(1)=0; %J
cum_ene=0; %J
while v(i)<=V_max & flag==0%m/s
    i=i+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)+ax*dt; %m/s
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=(massa*ax+Fd(i))/massa; %m/s2
    Fr(i)=massa*ar(i); %N
    Pot(i)=Fr(i)*v(i)+Plg*massa/1000; %W
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    cum_ene=cum_ene+Ene(i); %J
end
flag=1;
% mantenimento velocità di regime
while s(i)<488000 & flag==1
    while v(i)>=V_max-(1/3.6)
        i=i+1;
        t(i)=t(i-1)+dt; %s
        Fd(i)=0.5*air*v(i-1)^2*cd*Af; %N
        ara=Fd(i)/massa; %m/s2 accelerazione della resistenza aerodinamica
        ar(i)=0;
        Fr(i)=0;
        v(i)=v(i-1)-ara*dt; %m/s
        s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
        Pot(i)=Plg*massa/1000; %W
        Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
        cum_ene=cum_ene+Ene(i); %J
    end
    while v(i)<=V_max
        i=i+1;
        t(i)=t(i-1)+dt; %s
        Fd(i)=0.5*air*v(i-1)^2*cd*Af; %N
        ara=Fd(i)/massa; %m/s2 accelerazione della resistenza aerodinamica (ara)
        ar(i)=1.5*ara; %m/s2    considero come accelerazione il 50% in più 
dell'ara
        v(i)=v(i-1)+ar(i)*dt; %m/s
        s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
        Fr(i)=massa*ar(i); %N
        Pot(i)=Fr(i)*v(i)+Plg*massa/1000; %W
        Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
        cum_ene=cum_ene+Ene(i); %J
    end
end
% decelerazione e arresto in piano
j=0;
while v(i)>=0 %m/s
    i=i+1;
    j=j+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)-ax*dt; %m/s
```

```
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=-(massa*ax-Fd(i))/massa; %m/s2
    Fr(i)=-massa*ar(i); %N
    Pot(i)=Plg*massa/1000; %W
    Pot_prod(j)=Fr(i)*v(i);
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    Ene_prod(j)=Pot_prod(j)*dt;
    cum_ene=cum_ene+Ene(i); %J
end
perf=0.85;

figure
hold on
plot(t,ar)
title('Real acceleration');
ylabel('acceleration [m/s2]')
xlabel('time [s]')
% legend('flat 0%','uphill 2%','uphill 3.5%','location','northeast')
grid on
box on


figure
hold on
plot(t,Pot/1000)
title('Power');
xlabel('time [s]')
ylabel('power [kW]')
% legend('flat 0%','uphill 2%','uphill 3.5%')
grid on
box on

figure
hold on
bar([1],[(sum(Ene_prod)/1e6*perf)],'g')
bar([2],[cum_ene/1e6/perf],'r')
title('Total energy production & consumption');
xlabel('production - consumption')
ylabel('energy [MJ]')
legend('produced','consumed','location','northwest')
grid on
box on
```

From zero to max speed:

```
clear all
close all
clc

% moto uniformemente accelerato
passeggeri=1*460*75; %kg persone+bagagli
massa=51700*2+50600*3+passeggeri; %kg  ipotizzo 5 carrozze, 153 metri di
lunghezza
gg=9.81; %m/s2
V_max=430/3.6; %m/s
ax=0.6; %m/s2
air=1.225; % kg/m3
cd=0.26;
```

```
Af=16; %m2
Plg=7.820743126379191e+03; %W/t


%% diagramma di avviamento simulazione fittizia
% diagramma di avviamento in piano
i=1;
dt=1;
v(1)=0; %m/s
s(1)=0; %m
t(1)=0; %s
ar(1)=0; %m/s2
Fd(1)=0; %N
Fr(1)=0; %N
Pot(1)=0; %W
Ene(1)=0; %J
cum_ene=0; %J
while v(i)<=V_max %m/s
    i=i+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)+ax*dt; %m/s
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=(massa*ax+Fd(i))/massa; %m/s2
    Fr(i)=massa*ar(i); %N
    Pot(i)=Fr(i)*v(i)+Plg*massa/1000; %W
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    cum_ene=cum_ene+Ene(i); %J
end

% diagramma di avviamento in salita al 2 per cento
i=1;
dt=1;
v2(1)=0; %m/s
s2(1)=0; %m
t2(1)=0; %s
ar2(1)=0; %m/s2
Fd2(1)=0; %N
Fr2(1)=0; %N
Pot2(1)=0; %W
Ene2(1)=0; %J
cum_ene2=0; %J
while v2(i)<=V_max %m/s
    i=i+1;
    t2(i)=t2(i-1)+dt; %s
    v2(i)=v2(i-1)+ax*dt; %m/s
    s2(i)=s2(i-1)+(v2(i)+v2(i-1))/2*dt; %m
    Fd2(i)=0.5*air*v2(i)^2*cd*Af; %N
    ar2(i)=(massa*ax+Fd2(i)+massa*gg*sin(0.019997))/massa; %m/s2
    Fr2(i)=massa*ar2(i); %N
    Pot2(i)=Fr2(i)*v2(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene2(i)=Pot2(i)*dt; % [W] * [s] = [J]
    cum_ene2=cum_ene2+Ene2(i); %J
end
% diagramma di avviamento in salita al 3.5 per cento
i=1;
dt=1;
v3(1)=0; %m/s
s3(1)=0; %m
t3(1)=0; %s
ar3(1)=0; %m/s2
Fd3(1)=0; %N
```

```
Fr3(1)=0; %N
Pot3(1)=0; %W
Ene3(1)=0; %J
cum_ene3=0; %J
while v3(i)<=V_max %m/s
    i=i+1;
    t3(i)=t3(i-1)+dt; %s
    v3(i)=v3(i-1)+ax*dt; %m/s
    s3(i)=s3(i-1)+(v3(i)+v3(i-1))/2*dt; %m
    Fd3(i)=0.5*air*v3(i)^2*cd*Af; %N
    ar3(i)=(massa*ax+Fd3(i)+massa*gg*sin(0.034986))/massa; %m/s2
    Fr3(i)=massa*ar3(i); %N
    Pot3(i)=Fr3(i)*v3(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene3(i)=Pot3(i)*dt; % [W] * [s] = [J]
    cum_ene3=cum_ene3+Ene3(i); %J
end
% diagramma di avviamento in salita al 10 per cento
i=1;
dt=1;
v10(1)=0; %m/s
s10(1)=0; %m
t10(1)=0; %s
ar10(1)=0; %m/s2
Fd10(1)=0; %N
Fr10(1)=0; %N
Pot10(1)=0; %W
Ene10(1)=0; %J
cum_ene10=0; %J
while v10(i)<=V_max %m/s
    i=i+1;
    t10(i)=t10(i-1)+dt; %s
    v10(i)=v10(i-1)+ax*dt; %m/s
    s10(i)=s10(i-1)+(v10(i)+v10(i-1))/2*dt; %m
    Fd10(i)=0.5*air*v10(i)^2*cd*Af; %N
    ar10(i)=(massa*ax+Fd10(i)+massa*gg*sin(0.09967))/massa; %m/s2
    Fr10(i)=massa*ar10(i); %N
    Pot10(i)=Fr10(i)*v10(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene10(i)=Pot10(i)*dt; % [W] * [s] = [J]
    cum_ene10=cum_ene10+Ene10(i); %J
end
figure
hold on
plot(t,ar)
plot(t2,ar2)
plot(t3,ar3)
plot(t10,ar10)
title('Real acceleration - From zero to maximum speed');
ylabel('acceleration [m/s2]')
xlabel('time [s]')
legend('flat 0%','uphill 2%','uphill 3.5%','uphill 10%','location','northeast')
grid on
box on


figure
hold on
plot(t,Pot/1000)
plot(t2,Pot2/1000)
plot(t3,Pot3/1000)
plot(t3,Pot10/1000)
title('Power - From zero to maximum speed');
xlabel('time [s]')
```

```
ylabel('power [kW]')
legend('flat 0%','uphill 2%','uphill 3.5%','uphill 10%')
grid on
box on

figure
bar([0 2 3.5 10],[cum_ene/1e6 cum_ene2/1e6 cum_ene3/1e6 cum_ene10/1e6])
title('Total energy consumption');
xlabel('gradient [%]')
ylabel('energy [MJ]')
grid on
box on
```

9.3. The HYPERLOOP MATLAB code for simulation

Total flat travel:

```
clear all
close all
clc

% moto uniformemente accelerato
passeggeri=1*27*75; %kg persone+bagagli per 1 POD
massa=10000+passeggeri; %kg  ipotizzo 1 POD
gg=9.81; %m/s2
V_max=1000/3.6; %m/s
ax=0.1*9.81; %m/s2
Ttube=273+50;
PMair=0.21*32+0.79*28;
RR=8314.5/PMair;
air=100/(RR*Ttube); % kg/m3 densità dell'aria
cd=1.9;
Af=((3.25/2)^2-(3/2)^2)*pi; %m2
Plg=7.820743126379191e+03; %W/t
Pcomp=500000; %W

%% simulazione fittizzia 500 km
% avviamento in piano
i=1;
dt=1;
flag=0;
v(1)=0; %m/s
s(1)=0; %m
t(1)=0; %s
ar(1)=0; %m/s2
Fd(1)=0; %N
Fr(1)=0; %N
Pot(1)=0; %W
Ene(1)=0; %J
cum_ene=0; %J
while v(i)<=V_max & flag==0%m/s
    i=i+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)+ax*dt; %m/s
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=(massa*ax+Fd(i))/massa; %m/s2
    Fr(i)=massa*ar(i); %N
    PcompR(i)=Pcomp*v(i)/V_max;
```

```
    Pot(i)=Fr(i)*v(i)+Plg*massa/1000+PcompR(i); %W
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    cum_ene=cum_ene+Ene(i); %J
end
flag=1;
% mantenimento velocità di regime
while s(i)<460000 & flag==1
    if v(i)>=V_max-(1/3.6) & s(i)<460000
        i=i+1;
        t(i)=t(i-1)+dt; %s
        Fd(i)=0.5*air*v(i-1)^2*cd*Af; %N
        ara=Fd(i)/massa; %m/s2 accelerazione della resistenza aerodinamica
        ar(i)=0;
        Fr(i)=0;
        v(i)=v(i-1)-ara*dt; %m/s
        s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
        PcompR(i)=Pcomp*v(i)/V_max;
        Pot(i)=Plg*massa/1000+PcompR(i); %W
        Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
        cum_ene=cum_ene+Ene(i); %J
    else
        i=i+1;
        t(i)=t(i-1)+dt; %s
        Fd(i)=0.5*air*v(i-1)^2*cd*Af; %N
        ara=Fd(i)/massa; %m/s2 accelerazione della resistenza aerodinamica (ara)
        ar(i)=1.5*ara; %m/s2    considero come accelerazione il 50% in più
dell'ara
        v(i)=v(i-1)+ar(i)*dt; %m/s
        s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
        Fr(i)=massa*ar(i); %N
        PcompR(i)=Pcomp*v(i)/V_max;
        Pot(i)=Fr(i)*v(i)+Plg*massa/1000+PcompR(i); %W
        Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
        cum_ene=cum_ene+Ene(i); %J
    end
end
% decelerazione e arresto in piano
j=0;
while v(i)>=0 %m/s
    i=i+1;
    j=j+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)-ax*dt; %m/s
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=-(massa*ax-Fd(i))/massa; %m/s2
    Fr(i)=-massa*ar(i); %N
    PcompR(i)=Pcomp*v(i)/V_max;
    Pot(i)=Plg*massa/1000+PcompR(i); %W
    Pot_prod(j)=Fr(i)*v(i);
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    Ene_prod(j)=Pot_prod(j)*dt;
    cum_ene=cum_ene+Ene(i); %J
end
perf=0.85;

figure %1
hold on
plot(t,ar)
title('Real acceleration');
ylabel('acceleration [m/s2]')
xlabel('time [s]')
```

```
grid on
box on


figure %2
hold on
plot(t,Pot/1000)
title('Power');
xlabel('time [s]')
ylabel('power [kW]')
grid on
box on

figure %3
hold on
bar([1],[(sum(Ene_prod)/1e6*perf)],'g')
bar([2],[cum_ene/1e6/perf],'r')
title('Total energy production & consumption');
xlabel('production - consumption')
ylabel('energy [MJ]')
legend('produced','consumed','location','northwest')
grid on
box on

figure %4
hold on
bar([1],[17*(sum(Ene_prod)/1e6*perf)],'g')
bar([2],[17*cum_ene/1e6/perf],'r')
title('Total energy for 17 PODs (459 passengers)');
xlabel('production - consumption')
ylabel('energy [MJ]')
legend('produced','consumed','location','northwest')
grid on
box on
```

From zero to max speed:

```
clear all
close all
clc

% moto uniformemente accelerato
passeggeri=1*27*75; %kg persone+bagagli
massa=(10000+passeggeri); %kg
gg=9.81; %m/s2
V_max=1000/3.6; %m/s
ax=0.1*gg; %m/s2
Ttube=273+50;
PMair=0.21*32+0.79*28;
RR=8314.5/PMair;
air=100/(RR*Ttube); % kg/m3
cd=1.9;
Af=((3.25/2)^2-(3/2)^2)*pi; %m2
Plg=7.820743126379191e+03; %W/t  sistema di levitazione simile a quello transpod
perf=0.85;


%% diagramma di avviamento simulazione fittizia
% diagramma di avviamento in piano
i=1;
dt=1;
```

```
v(1)=0; %m/s
s(1)=0; %m
t(1)=0; %s
ar(1)=0; %m/s2
Fd(1)=0; %N
Fr(1)=0; %N
Pot(1)=0; %W
Ene(1)=0; %J
cum_ene=0; %J
while v(i)<=V_max %m/s
    i=i+1;
    t(i)=t(i-1)+dt; %s
    v(i)=v(i-1)+ax*dt; %m/s
    s(i)=s(i-1)+(v(i)+v(i-1))/2*dt; %m
    Fd(i)=0.5*air*v(i)^2*cd*Af; %N
    ar(i)=(massa*ax+Fd(i))/massa; %m/s2
    Fr(i)=massa*ar(i); %N
    Pot(i)=Fr(i)*v(i)+Plg*massa/1000; %W
    Ene(i)=Pot(i)*dt; % [W] * [s] = [J]
    cum_ene=cum_ene+Ene(i); %J
end

% diagramma di avviamento in salita al 2 per cento
i=1;
dt=1;
v2(1)=0; %m/s
s2(1)=0; %m
t2(1)=0; %s
ar2(1)=0; %m/s2
Fd2(1)=0; %N
Fr2(1)=0; %N
Pot2(1)=0; %W
Ene2(1)=0; %J
cum_ene2=0; %J
while v2(i)<=V_max %m/s
    i=i+1;
    t2(i)=t2(i-1)+dt; %s
    v2(i)=v2(i-1)+ax*dt; %m/s
    s2(i)=s2(i-1)+(v2(i)+v2(i-1))/2*dt; %m
    Fd2(i)=0.5*air*v2(i)^2*cd*Af; %N
    ar2(i)=(massa*ax+Fd2(i)+massa*gg*sin(0.019997))/massa; %m/s2
    Fr2(i)=massa*ar2(i); %N
    Pot2(i)=Fr2(i)*v2(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene2(i)=Pot2(i)*dt; % [W] * [s] = [J]
    cum_ene2=cum_ene2+Ene2(i); %J
end
% diagramma di avviamento in salita al 3.5 per cento
i=1;
dt=1;
v3(1)=0; %m/s
s3(1)=0; %m
t3(1)=0; %s
ar3(1)=0; %m/s2
Fd3(1)=0; %N
Fr3(1)=0; %N
Pot3(1)=0; %W
Ene3(1)=0; %J
cum_ene3=0; %J
while v3(i)<=V_max %m/s
    i=i+1;
    t3(i)=t3(i-1)+dt; %s
    v3(i)=v3(i-1)+ax*dt; %m/s
```

```
    s3(i)=s3(i-1)+(v3(i)+v3(i-1))/2*dt; %m
    Fd3(i)=0.5*air*v3(i)^2*cd*Af; %N
    ar3(i)=(massa*ax+Fd3(i)+massa*gg*sin(0.034986))/massa; %m/s2
    Fr3(i)=massa*ar3(i); %N
    Pot3(i)=Fr3(i)*v3(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene3(i)=Pot3(i)*dt; % [W] * [s] = [J]
    cum_ene3=cum_ene3+Ene3(i); %J
end
% diagramma di avviamento in salita al 10 per cento
i=1;
dt=1;
v10(1)=0; %m/s
s10(1)=0; %m
t10(1)=0; %s
ar10(1)=0; %m/s2
Fd10(1)=0; %N
Fr10(1)=0; %N
Pot10(1)=0; %W
Ene10(1)=0; %J
cum_ene10=0; %J
while v10(i)<=V_max %m/s
    i=i+1;
    t10(i)=t10(i-1)+dt; %s
    v10(i)=v10(i-1)+ax*dt; %m/s
    s10(i)=s10(i-1)+(v10(i)+v10(i-1))/2*dt; %m
    Fd10(i)=0.5*air*v10(i)^2*cd*Af; %N
    ar10(i)=(massa*ax+Fd10(i)+massa*gg*sin(0.09967))/massa; %m/s2
    Fr10(i)=massa*ar10(i); %N
    Pot10(i)=Fr10(i)*v10(i)+Plg*massa/1000; %[N]*[m/s]=[W]
    Ene10(i)=Pot10(i)*dt; % [W] * [s] = [J]
    cum_ene10=cum_ene10+Ene10(i); %J
end
figure
hold on
plot(t,ar)
plot(t2,ar2)
plot(t3,ar3)
plot(t10,ar10)
title('Real acceleration - From zero to maximum speed');
ylabel('acceleration [m/s2]')
xlabel('time [s]')
legend('flat 0%','uphill 2%','uphill 3.5%','uphill 10%','location','northeast')
grid on
box on


figure
hold on
plot(t,Pot/1000)
plot(t2,Pot2/1000)
plot(t3,Pot3/1000)
plot(t3,Pot10/1000)
title('Power - From zero to maximum speed');
xlabel('time [s]')
ylabel('power [kW]')
legend('flat 0%','uphill 2%','uphill 3.5%','uphill 10%')
grid on
box on

figure
bar([0 2 3.5 10],[cum_ene/1e6/perf cum_ene2/1e6/perf cum_ene3/1e6/perf
cum_ene10/1e6/perf])
```

```
title('Total energy consumption');
xlabel('gradient [%]')
ylabel('energy [MJ]')
grid on
box on
```

9.4. PHA worksheet

SUB-	PHASE	HAZARD ID	HAZARD MANIFESTATION	HAZARD SCENARIO CAUSE	HAZARD SCENARIO EVENTS	HAZARD SCENARIO CONSEQUENCE	SEVERITY	LIKELIHOOD	RISK	HAZARD REDUCTION MEASURES
PS1	AB	1	no motion at low speed	loss of wheel's traction	inability to start/stop travel	loss of mission	3	D	MEDIUM	maintenance just before the departure
	AB	2	pod impact the guideway	landing gear does't handle landing stress	loss of structural support after impact with the guideway	fatality	1	E	MEDIUM	redesign of the landing gear, when in operation continuos stress test and substitution after expiration time
	AB	3	pod impact the guideway	landing gear fail to open	loss of structural support, impact with the guideway	fatality	1	D	SERIOUS	maintenance just before the departure, provide emergency tools
	AB	4	loss of stability, augmented air friction, noise and vibrations	landing gear fail to close	landing gear fail to close when pod levitate, no contact with the guideway	loss of performance, degradation of comfort	4	D	LOW	redesign of the landing system, avoid high-velocity contact between wheels and guideway
	AB	5	loss of stability, augmented friction, noise and vibrations	less than half of the wheels are buckled or explosed	wheels highly damaged at low speed configuration	delay, degradation of performance	3	D	MEDIUM	check before departure, pressure test and monitoring before use, manutention
	AB	6	heavy degradation of stability, augmented friction, noise and vibrations	more than half of the wheels are buckled or explosed	wheels highly damaged at low speed configuration	loss of mission	2	E	MEDIUM	check before departure, pressure test and monitoring before use, manutention, esploration of guideway condition in the low speed sections
	BP	7	uncontrolled mobilitation of pod while boarding	Inadvertent Activation of PS	boarding ports spoil and passengers are exposed to inner tube conditions (p,T,B)	damages to structure and people illness	2	D	SERIOUS	software control and cyber security upgrade, automatic isolation of traction system when boarding
	MN	8	high friction and noise	bad manutention on bearings	degraded performance, block of rotation	delay and degradation of comfort	4	C	MEDIUM	increase manutention performance, time and quality
	MN	9	loss of stability	unstable or deflated wheels	augmentation of vibrations and low degradation of performance	delay and degradation of comfort	4	C	MEDIUM	increase manutention performance, time and quality; install pressuresensors on wheels
	IC	10	electric motor under exepted performance	bad choice of electric motor mechanical power output or typologye, possible interaction with magnetic fields	overheating of the motor, degradation of performance	shorter life of the motor, higher energy consumption	4	D	LOW	redesign electric motor traction needs and investigate different typologyes; isolate magnetically from the environment
	EM	11	fail of backup wheels emergency system	backup wheels emergency system is involved in the sinistro, it is electrically isolated, it has not enought time to finalize its actions	emergency system on, but he system doesn't react properly; backup wheels can not land the pod, that crash	fatality, loss of pod and tube section involved	1	D	SERIOUS	redesign of the emergency configuration, apply redundancy
	PE	12	incomplete traction system running still controllable	expulsion of fragments, loss of not essential equipment	contour elements fail, the ride can continue but with degradation of control and safety	delay, degradation of performance	4	D	LOW	maintenance

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PS2	AB	1	loss of braking system	braking system electrically isolated; malfunction of components	loss of brakes at low speed	crash, fatality	2	D	SERIOUS	emergency low speed braking, redundancy
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PS3	AB	1	propeller blade release	failure of mechanical transmission to propeller	propeller release, motor still running, augmentation of drag frontal surface	degradation of performance, vibration and instability, reduction of speed, delay	3	C	SERIOUS	maintenance
	MN	2	degradation of mechanical in contact parts	insufficient lubrification of gear-box	higher friction, noise and dissipation	degradation of performance and shorter components life, degradation of comfort	4	C	MEDIUM	maintenance
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PS4	IC	1	inadequate traction system	bad choice of compressor/propeller	low energetic, traction and comfort performances	substitution of componenets	2	D	SERIOUS	redesign compressor, taking in account sound speed limit, vibration and air ejection; to complete see also PS5 REDUCTION MEASURES

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PS5	AB	1	system out of normal operation	important air density variation, problem with the near vacuum system	tube at higher pressure than normal, augmented flow into compressor and on the sides	augmented vibrations, injuries to system and passengers, loss of stability, possible fatality	1	B	HIGH	improvement of pod stability, redesign of vacuum system, perform high communication of emergency situations
	AB	2	failure leading to propeller protection activation	loss of ability to support the propeller	degradation of performance, vibration and instability, delay	degradation of performance, vibration and instability, reduction of speed, delay	2	D	SERIOUS	redesign of propeller, maintenance
	AB	3	engine shut down, possible damage to surrounding parts	loss of ability to support loads	loss of propeller, augmented air friction	mission degradation, injury to passenger	2	C	HIGH	redesign of propeller, maintenance
	AB	4	major reduction of axial thrust	degraded ability to trasform potential energy into mechanical energy	increase of vibrations and degradation of energy performance	mission degradation	3	D	MEDIUM	procedure change
	AB	5	high vibrational stress	loss of ability straighten the exhaust flow	turbulence effects on the back of the pod	mission degradation, possible contact pod-guideway, possible fatality	1	C	HIGH	redesign, maintenance
	AB	6	vibrational resonance of pod structure	compressor vibration propagate to pod structure	destructive resonance	fatality	1	E	MEDIUM	redesign
	MN	7	block of compressor	external object into compressor	maintenance team forgetfulness, damage to compressor	loss of mission	1	B	HIGH	special training for maintenance team
	IC	8	compressor consumption higher than expected	inappropriate number of stages	more stages than necessary, higher propeller mass	degradation of performance	3	E	LOW	redesign and substitution of the propeller
	IC	9	low efficiency at cruise speed	propeller optimized for acceleration operation	larger energy consumption at cruise speed	degradation of performance	3	B	SERIOUS	redesign and substitution of the propeller
	IC	10	malfunction of propeller	inadequate load and flow coefficients, design deficiency	vibration injury, performance decrease	degradation of mission	2	D	SERIOUS	redesign
	IC	11	non optimized compressor work	inadequate choice on the stator and rotor blades number, design deficiency	degradation of potential air flow energy	degradation of performance, higher energy consumption	4	A	SERIOUS	redesign
	IC	12	non optimized compressor work	inadequate air gap between ranks	high vibration and low performance	degradation of performance, degradation of comfort	3	B	SERIOUS	redesign
	PE	13	high noise and vibrational effects	air flow at supersonic speed	increase of pod instability, supersonic waves shock in the tube	degradation of guideway, degradation of comfort, possible injuries to passengers and onboard material	2	D	SERIOUS	redesign

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PS6	AB	1	PCM leakage	breach in tank	discharge of chemical substance at high temperature	loss of PCM storage, corrosion and toxicity	2	C	HIGH	confine the tank and dispose a drainage; dispose mitigation actions for chemical reactions
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PS7	AB	1	PMC can not be regenerate	block of the recharge port	maintenance team extra time intervention	loss of time, substitution of components	4	D	LOW	maintenance and if necessary redesign of the recharge system
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PS8	PE	1	no coolant flow	pumps brake	engines can not be cooled, degradation of performance and material, overheating, possible fail of traction system	possible fail of traction system, loss of mission, degradation of comfort, substitution of componenets	1	B	HIGH	redundant pumps, emergency cooling system and emergency special operations
	PE	2	loss of coolant	breach in coolant system	discharge of chemical substance, loss of pression in cooling system	overheating of engines, corrosion and toxicity	2	C	HIGH	maintenance and protection equipement for passengers
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PS9	IC	1	overheated engines	underestimation of thermal needs	unability to exchange with profit	degradation of performance and material	2	D	SERIOUS	redesign and substitution, upgraded maintenance
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PS10	AB	1	pod doesn't slow	loss of high speed brakes	braking signal is received but no action	pod violent impact with the guideway when enter the slow speed zone	1	D	SERIOUS	emergency high speed braking system, diversification of braking modes
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PS11	AB	1	no power onboard	underestimation of electric power needs	loss of electric components	loss of mission / injuries	1	E	MEDIUM	redesign with a safety coefficient higher
	MN	2	maintenance operator fatality	component in tension when supposed not to be, high voltage arc-flash	operator in contact with live equipment, fatality on working place	fatality to operator, judicial persecution	1	B	HIGH	special equipment and training to operators, automatic detachment of high voltage tension
	IC	3	loss of power	interruption of power connection	3rd rail contact fail, loss of sub-station power line	emergency batteries start emergency routine, loss of mission	2	B	HIGH	power pickup redundance, increase batteries capacity, increase number of sub-stations
	IC	4	high electrostatic potential	insufficient electrical & mechanical clearances around high voltage equipement	equipement failure, severe injury	interruption of power connection, loss of pod control, possible loss of emergency system, injury to passengers and possible fatality	1	C	HIGH	redesign
	PE	5	high structural stress, intermittent power pickup, sparks	intermittent contact with the guideway (at high-speed)	electric equipment overexited at high voltage, no continuos power	explosion of electric equipment, loss of mission	1	B	HIGH	redesign
	PE	6	structure electrified	electric short-circuit	passenger cabine electrified	fatality	1	C	HIGH	electric isolation, sensors and mitigation plans

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PS12	AB	1	loss of traction	loss of electric components	traction electric components fail, emergency traction control system stop the pod close to emergency exit	loss of mission	1	C	HIGH	redoundancy and maintenance
	AB	2	no useful power	converter fail	converter overheating, fail of component, no usefull power, degradation of electric system	loss of mission	1	C	HIGH	redundancy and maintenance, redesign
	AB	3	fire, explosion, toxic smoke and loss of power	degradation of the MT electric circuit, overload of transformer	degradation of electric circuit, loss of power, emergency traction system stop the pod, evacuation with possible fire, toxic smoke, explosion	loss of mission, injury to passenger	1	C	HIGH	maintenance and fire fighting system
	AB	4	material fast degradation	overloaded electrical components	degradation of electric circuit, degradation of performance	loss of components, increase of maintenance	3	C	SERIOUS	redesign
	MN	5	maintenance operator fatality	component in tension when supposed not to be, high voltage arc-flash	operator in contact with live equipment, fatality on working place	fatality to operator, judicial persecution	1	B	HIGH	special equipment and training to operators, automatic detachment of high voltage tension
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PS13	AB	1	loss of LIM	loss of magnetization	interruption in LIM circuits, loss of high speed traction/brake	degradation of mission, possible activation of the emergency braking system	2	E	MEDIUM	redundancy and redesign, constant inspection and maintenance
	AB	2	runaway acceleration	fail of VFD LIM control	loss of acceleration/brake control, increased vibration and mechanical stress at high speed	degradation of comfort, passengers illness, degradation of mission	2	D	SERIOUS	redesign with emergency shot-down system
	MN	3	degradation of performance	degraded components, superficial maintenance	higher energy consumption, pod LIM check up	detection and substitution of components, increased maintenance operative time	4	B	MEDIUM	special maintenance team training
	IC	4	non optimized LIM work	bad LIM design	LIM traction doesn't reach expected performances, investigation of problems	redesign of LIM structure	2	E	MEDIUM	investigate interaction with electric motors, compressor, power lines, PV panels, materials, electric circuit
	PE	5	materials and components degradation	Thermo-Magnetic-Mechanical components fatigue	loss of mechanical robustness, loss of safe operation condition	system verification, materials and components replacement	4	A	SERIOUS	fatigue test and research on specific hyperloop conditions, maintenance
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PS14	AB		PS catastrophic explosion	terroristic attack	external component into the PS system generate explosion	fatality	1	C	HIGH	security measures, smart verification of PS elements before departure
	MN		injury of maintenance personnel	loss/problem of communication	remote operation of equipement without coordination with maintenance activities	judicial persecution, degradation of reputation	1	C	HIGH	instauration of strict protocols, validation of activities, increase communication
	IC		corrosion and oxidation	chemical reaction	embrittlement of structure due to stress, time and environment	end of life then substitution of pod	4	D	LOW	maintenance and specific treatments, recycle materials
	IC		toxic contamination	battery leakage	loss of battery potential, contamination of environment	passengers illness, loss of emergency power source	1	C	HIGH	sensor disposition, constant use of batteries even in normal conditions, maintenance
	IC		loss of software control	terrorist cyber attack	loss of pod control	possible fatality, degradation of reputation	1	B	HIGH	cyber security dispositions, "fail safe" communication interruption
	IC		fail of software control room	blackout, fire/explosion/catastrophic event in control room	loss of system activities	loss of mission, loss of control, possible injury, loss of trust and reputation	1	C	HIGH	decentralization of control rooms, high security defence, fire fighting system, "plan B" operational control