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Transferability and roadmap beyond HYPERNEX

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Abbreviations and acronyms

Abbreviation / Acronyms	Description
AB	Advisory Board
CA	Consortium Agreement
DMP	Data Management Plan
DoA	Description of Action
DTO	Driverless train operation
DX.Y	Deliverable X.Y
EB	Executive Board
GoA	Grade of Automation
JU	Shift2Rail Joint Undertaking
MAAP	Multi-Annual Action Plan
QAPlan	Quality Assurance Plan
S2R	Shift2Rail
SC	Steering Committee
SIL	Safety Integrity Level
SMP	Strategic Masterplan
STO	Semi-automated train operation
TX.Y	Task X.Y
UTO	Unattended train operation
WPX	Work Package X

NOTE Consider that participant's short name will be used in this document as specified in the proposal document.

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1 Executive summary

This deliverable D4.1 is the third deliverable produced under the HYPERNEX project. In the first deliverable, D2.1, it has been prepared the state of the art of the hyperloop system and the technologies in progress. In the second deliverable, D3.1, a first approach to the safety case, the architecture and the concept of operation has been performed. This last deliverable, D4.1 has the objective of mapping the existing and potential synergies between the hyperloop system and the existing transport modes. In a first approach, the main interrelation can be focussed on the railway transport, nevertheless, the analysis shall be extended also to other transport systems. For doing so, an analysis of the taxonomy of the different transport modes has been prepared to serve as initial reference point to the subsequent study.

In a second sept, an analysis in relation to the existing European programmes, in particular the alignment, synergies and opportunities within Shift2Rail programmes is presented.

This deliverable D4.1 also describes the needs in terms of standardization and regulation that hyperloop systems will require in order to be a reality. A first approach has been made in deliverable D1.2. In this document a more comprehensive analysis specific for hyperloop is presented.

The document is organized in three main sections:

- Transferability under S2R roadmap, focused on identify the synergies of this research with railways in the frame of S2R, enhancing those areas where investigation activities can be beneficial for both parties.
- Transferability and cross fertilization to non-guided modes, describing the synergies with other areas and programs, including non-railway modes.
- Standardization and regulation, focused on the applicability of current regulatory practices in Europe to hyperloop certification scheme. This analysis includes the roles for Assessment and Notified Bodies, the applicability and roadmap for standardization of hyperloop.

2 Transportation modes taxonomy

2.1 Introduction

At present, there are four primary modes of transport: road, rail, waterborne and air transport. They all are based on consolidated concepts, focusing on delivering safe, efficient, reliable and accessible transport.

In the last decade, several disruptive transportation concepts and technologies, like information and communication technologies (ICT), the Internet of Things (IoT), or the hyperloop concept, have been identified as very promising. In the near future, hyperloop could become the fifth mode of transport. Its concept shares some aspects with each of the four existing transportation modes but differs from them in other aspects. One way to improve our knowledge and understanding of the hyperloop concept is to compare it with the knowledge and experience from the other transportation modes. In particular, an efficient and effective way of consolidating knowledge is to create a taxonomy. In this line, this work aims to identify a taxonomy of current transportation modes to frame the hyperloop among them, paying attention to different features. Different taxonomies have been proposed by researchers with different backgrounds, though most of them have a common base.

From a linguistic point of view, a taxonomy is a kind of controlled vocabulary consisting of categories and subcategories connected in a hierarchy that is used to classify information. Taxonomies can have a single or a limited number of top terms. They can be used as an aid to classify, categorize and organize concepts when designing a search structure. Users can browse and navigate the taxonomy from broader to narrower terms.

As an example, (National Academies of Sciences, Engineering, and Medicine, 2017), the next Figure 1 shows a taxonomy of transportation modes, adapted from the Transportation Research Thesaurus (TRB). It has five top level modes, each of them broken down into a more detailed set of categories.

From a scientific point of view, taxonomy can also be defined as the science that studies the principles, methods and aims of classification. Taxonomic analysis is used to reveal natural clustering inside a set of objects, not evident at first sight (Segaran, 2007), so that the objects inside a same cluster have similar features. These classification techniques are based on clustering algorithms, whose particularities are described next.

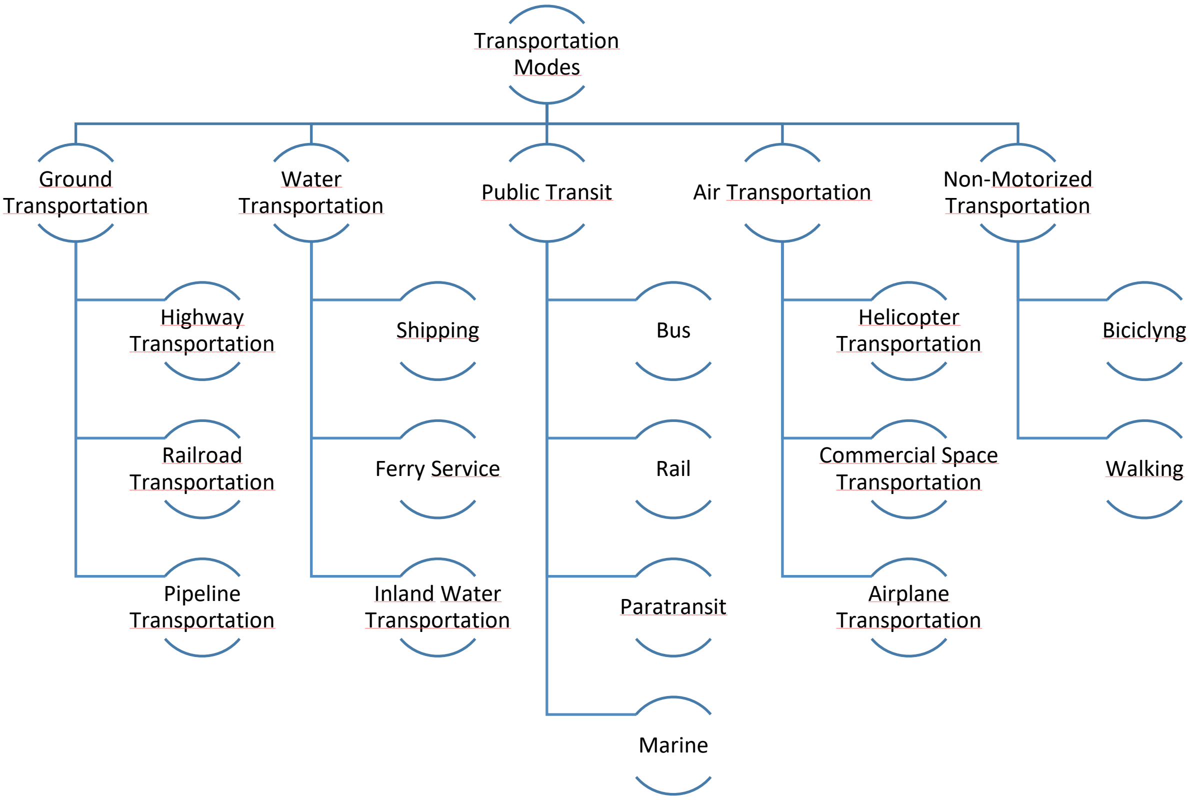


Figure 1. Taxonomy of transportation modes [adapted from the Transportation Research Thesaurus (TRB)]

2.2 Clustering algorithms

Clustering algorithms allow breaking a set of objects, characterised by the value of various variables, into several separate classes (Chrobak, Prieto, Prieto, Gaido, & Rotella, 2006). The classes obtained should be reasonably homogeneous, and should be externally isolated from the other ones, so that the degree of similitude between objects inside a same class is greater than between objects of different classes. From all the different clustering methods, in this work hierarchical agglomerative classification was chosen.

2.2.1 Hierarchical agglomerative classification

The hierarchical agglomerative classification process comprises the following stages (Segaran, 2007), (Gondar Nores, 2001) and (Meneses & de Sesma, 2000):

1. Select the variables in which clustering is based.

2. Choose the measure to assess the distance between any two objects. The problem should be normalized in this stage, as the different variables used can represent characteristics of a different nature, and so be measured on different scales, which could distort proximity measures between objects. One way to use a proportional scale for the set of variables that characterise each object is to

subtract from each one its mean value, and to divide the result by its standard deviation. The most common distance measures between two objects are (Quintín, Cabero, & Paz (de), 2008):

- the Euclidean distance;
- the Euclidean distance square; and
- the Manhattan or urban streets distance, which is computed adding the absolute value of the differences between the values of each variable.

3. Choose a linking method. These methods differ in the way they are used to define the distance between two groups of objects (Grupo InfoStat, FCA, 2004), (Vicente Villardón):

- simple link: the distance between two groups is the least distance between one object from the first group and another for the second one;
- complete link: the distance between two groups is the greater distance between one object from the first group and another for the second one;
- mean link: the distance between two groups is the mean value of the distances between all the object couples formed by one object from each group;
- centroid link, which is the most robust algorithm in the face of extreme values, and the distance between two groups is the distance between the centroid of each group; and
- Ward link, or minimum variance method, based on the fact that the global heterogeneity grows when two groups are joined, so increasing the variance. This method evaluates the value that the variance should take in the event that any two groups are joined, finally joining those groups with the smallest variance. This method usually provides groups with equal size and is little sensitive to the presence of outliers.

4. Run the clustering algorithm, following the subsequent steps:

- assign each object from the original set to a different group;
- assess the similarity or dissimilarity between each couple of groups. To that end, the distance between all groups is computed, in accordance with the distance measure and to the linking method previously chosen. In this way the distances matrix, which stores in its (i, j) position the distance between groups i and j, is built;
- examine the distances matrix, and join the two closest groups in a new group of bigger size, so reducing the number of groups in one unit;
- compute the distance between the new group and the others;
- repeat the process, joining in turns the existing groups in others of larger size, until all the objects are included in a single group.

2.2.2 Graphic representation of the hierarchical classification process

Once the classification process if finished, it is very useful to graph the clusters obtained. This graphical representation, called a dendrogram or classification tree, shows the way in which the objects have been grouped as the degree of similitude between them decreases (Chrobak, Prieto, Prieto, Gaido, & Rotella, 2006). The root of the tree represents the group formed by all the objects, while the leaves of the tree represent the groups formed by single objects. Between both extremities of the tree, a set of intermediate nodes can be found, representing the links made between groups throughout each stage of the classification process. The branches of the tree connect the nodes of adjacent levels to each other, their length being proportional to the distance between the joined groups. Therefore, the dendrogram should not be considered as a simple set of clusters, but as a hierarchical classification with several levels, where the taxonomic groups of a given level are linked to each other in the immediately upper level, forming new taxonomic groups.

As an example, the next Figure 2 shows a graphical representation of the clustering process concerning 6 objects defined by the variables collected in the next table, the final picture (stage 5) being the corresponding dendrogram. In this graphical representation, connections between the different groups are represented as an inverted U, whose height is proportional to the distance between the joined groups.

Object	Var. 1	Var. 2
1	1	3
2	3	2
3	6	1
4	7	4
5	10	1
6	10	8

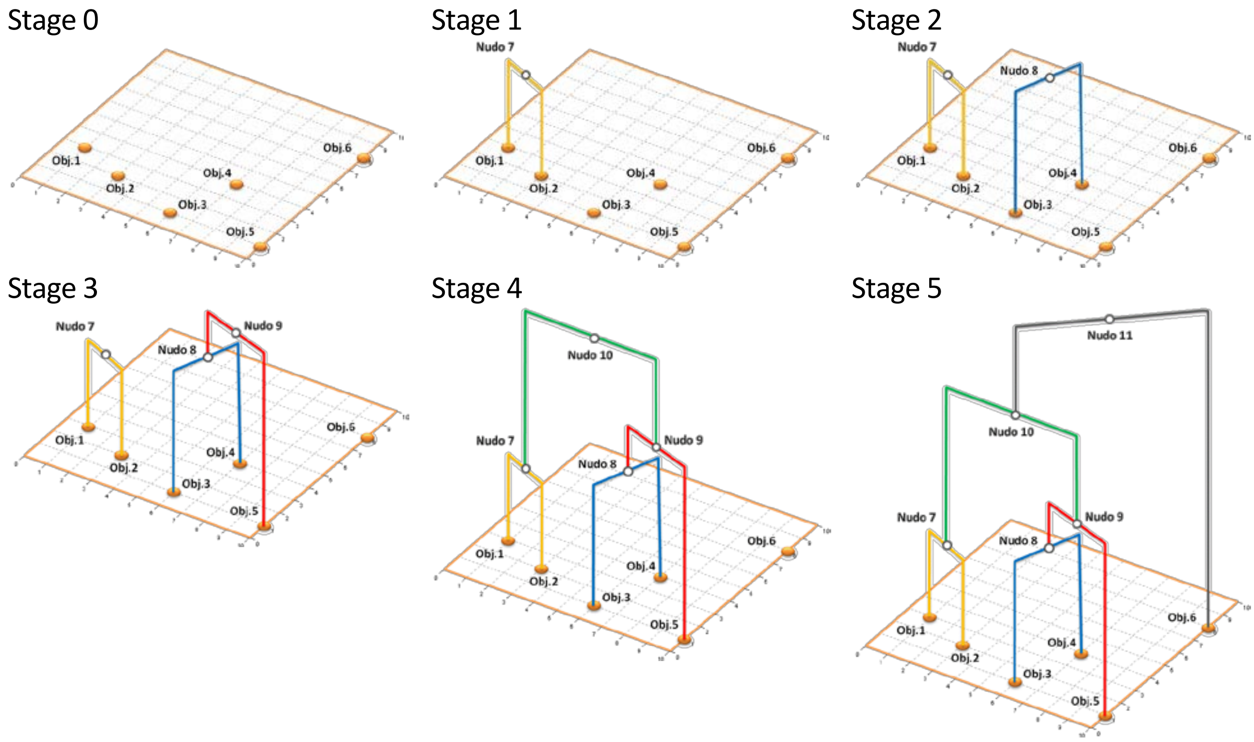


Figure 2. Dendrogram. Connections between different groups

The next Figure 3 shows the most common representation of the dendrogram.

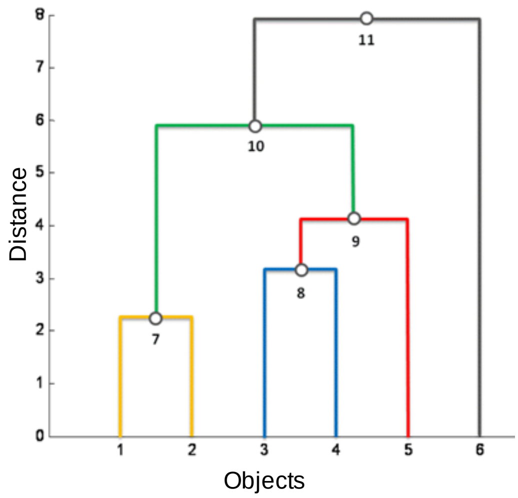


Figure 3. Common representation of dendrogram

2.2.3 Obtaining classes

From the dendrogram, it is possible to find a partition of the initial set of objects into different classes or clusters. To that end, the tree is cut at a particular level, and all the objects placed below each cut are assigned to a same cluster, thus obtaining the searched classification.

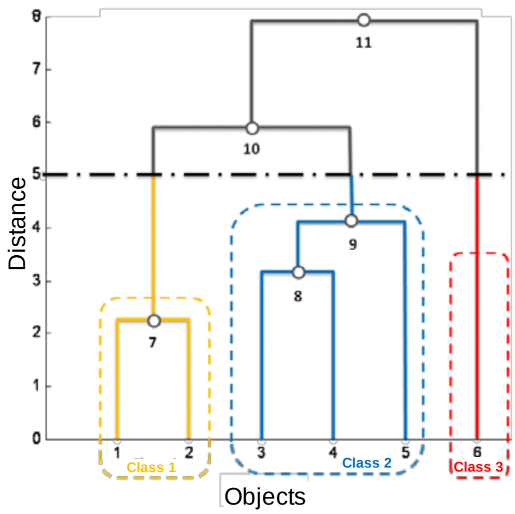


Figure 4. Partition of the initial set of objects in the dendrogram

Continuing with the previous sample, when cutting the tree as shown in the previous Figure 4, three classes are obtained. By cutting it at different heights, different classifications would be obtained. In accordance with (Forina, Armanino, & Raggio, 2002), a good practice would be to cut the tree at the level with the longer branches, in order to find apparently significant groups.

The final decision concerning the optimum number of classes is subjective and depends on the analyst's criterion. If few classes are selected, these can be heterogeneous and artificial, while if too many are selected, their interpretation could be complex. This aspect should be very carefully dealt with in order to get a true classification and not a dissection of the original set into groups without a real meaning. So, the final decision of the analyst is essential to determine if the classes obtained are relevant or not.

2.3 How we move

As a first step, we can classify transportation modes focusing on the way people move. The following figures show a taxonomy of transportation modes based on these concepts, taken from (The Urbanist, 2019). It classifies different transport systems based on how many people can travel at the same time (one person or many people) and how they are powered by (human or non-human), also distinguishing between land, air and water transport (Figure 5 and Figure 6). This taxonomy tries to show similarities of use and form by grouping comparable modes into families. As example, shoes, roller skates and snowshoes represent an evolution of the human foot to move faster and easier over a variety of terrains, so they can be grouped into a same family.

The next Figure 7 shows a similar classification for surface passenger transportation (Levinson, 2013). In this case, the first cut of the hierarchical graph is related with time, concerning whether a reservation is required or not, i.e. if some advance planning is required. The second cut is also related with time, concerning whether the service is scheduled or dynamic. The third cut is related with space, concerning whether the routes are fixed or dynamic. Next, for fixed routes, a distinction is made regarding whether stops are fixed (the vehicle stops at every stop) or not (the vehicle only stops when called, like a bus). Other traditional distinctions, like access mode versus primary mode, such as walk to transit versus drive to transit, are not considered in this schema.

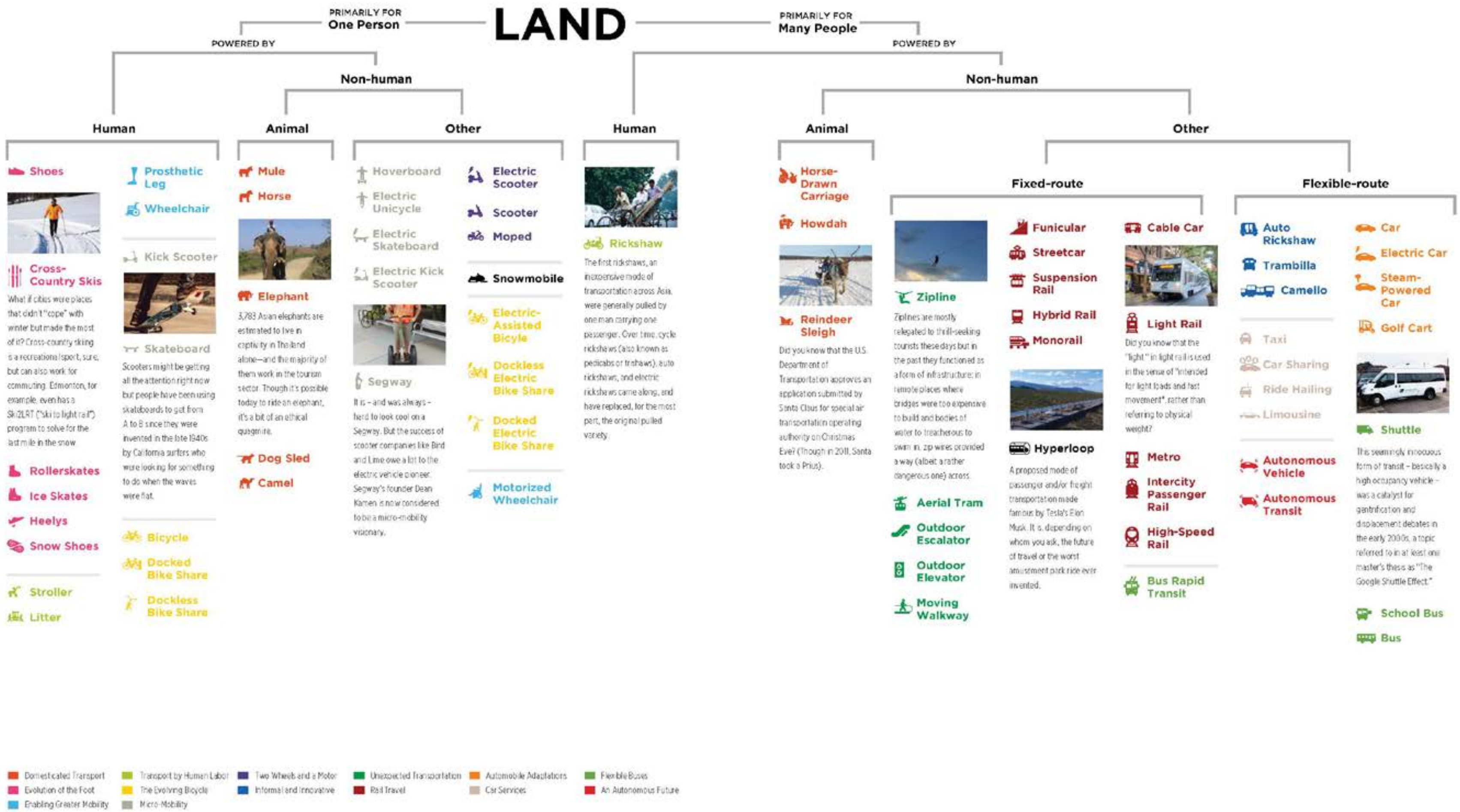


Figure 5. Classification according to the way people moves on land (Source: The Urbanist, 2019)

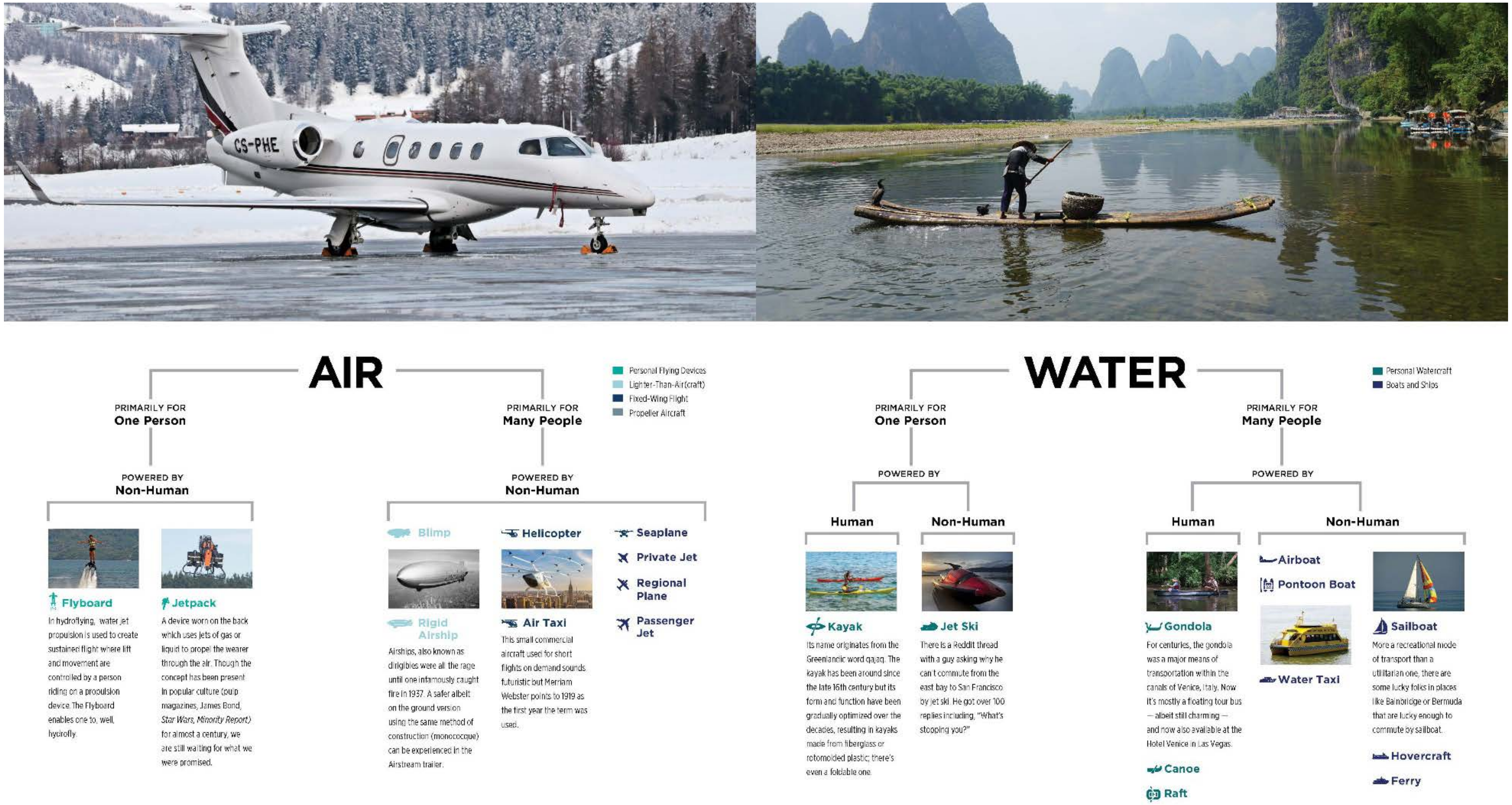


Figure 6. Classification according to the way people moves in air and water (Source: The Urbanist, 2019)

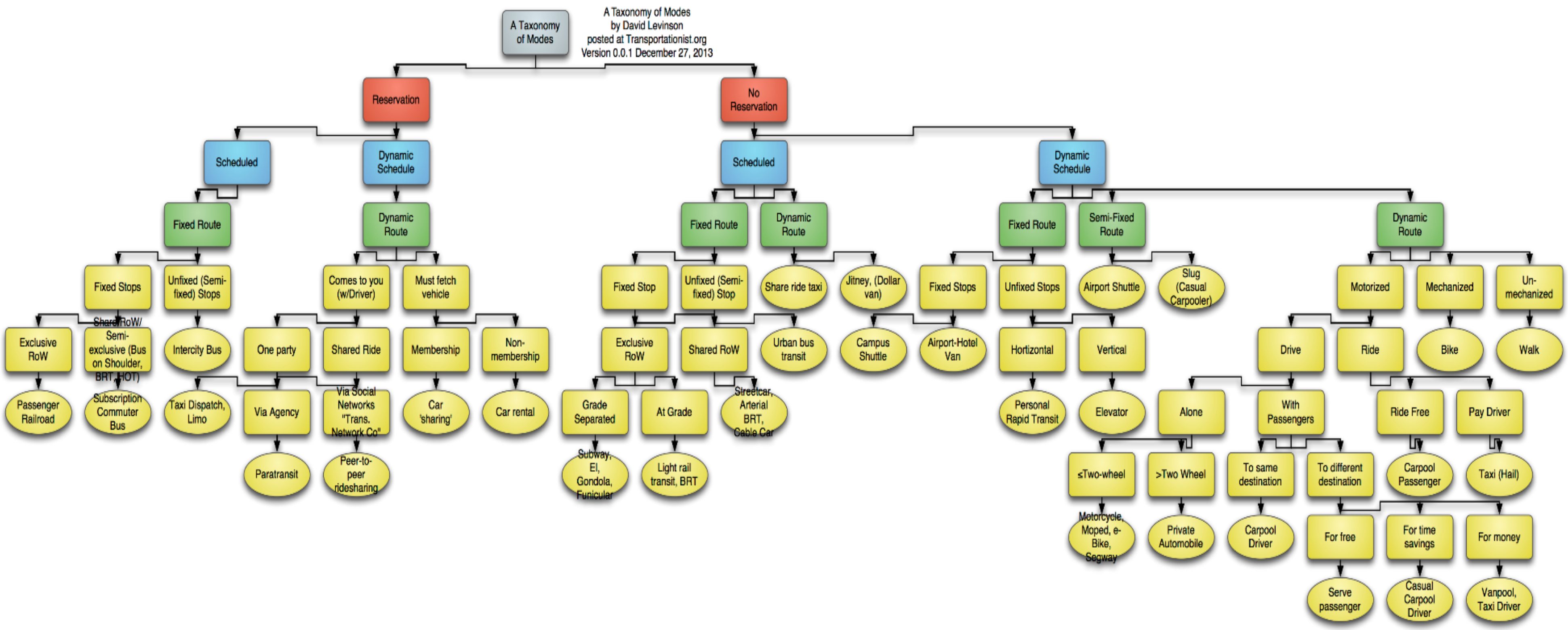


Figure 7. Classification according to surface passenger transportation

2.4 Operational features of transportation modes

2.4.1 Introduction

The next Figure 8 shows the maximum speed of the four existing transportation modes, together with the expectations of the hyperloop system.

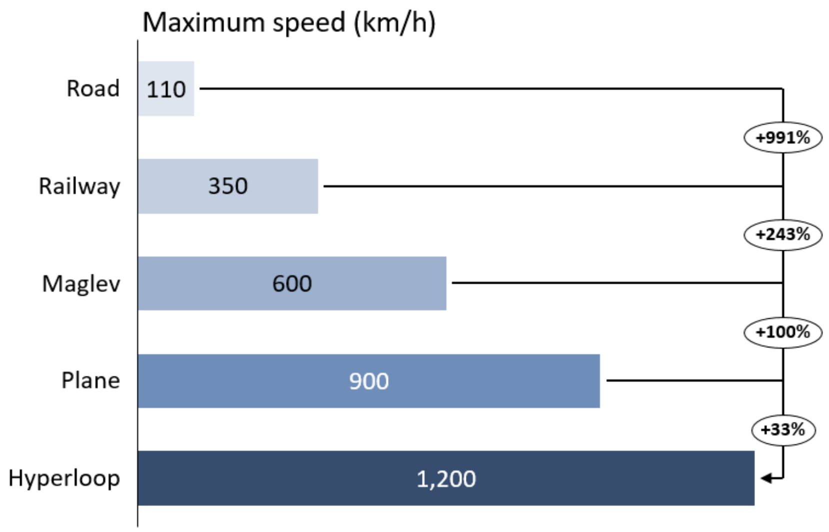


Figure 8. Maximum speed for the existing transport modes and hyperloop

The next Figure 9 shows the mean speed of the four existing transportation modes, together with the expectations of the hyperloop system.

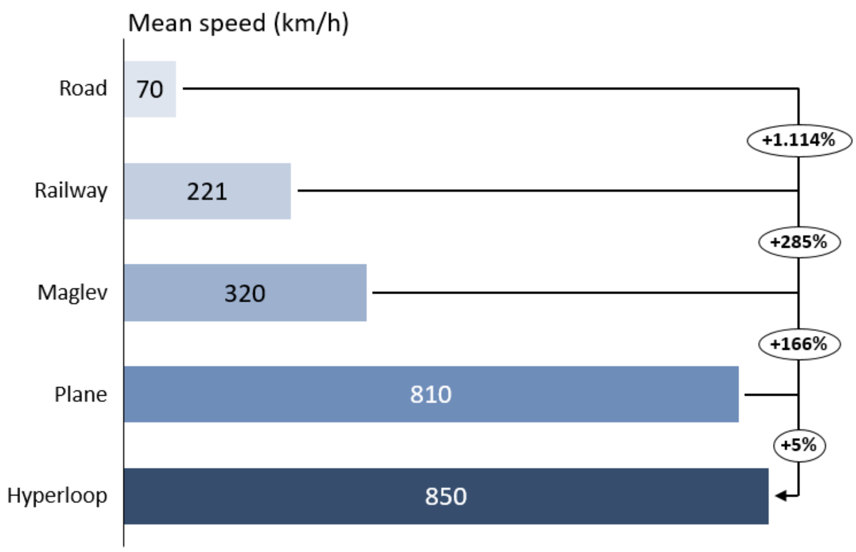


Figure 9. Mean speed for the four existing modes

The next Figure 10 shows the passenger capacity per vehicle of the four existing transportation modes, together with the expectations of the hyperloop system.

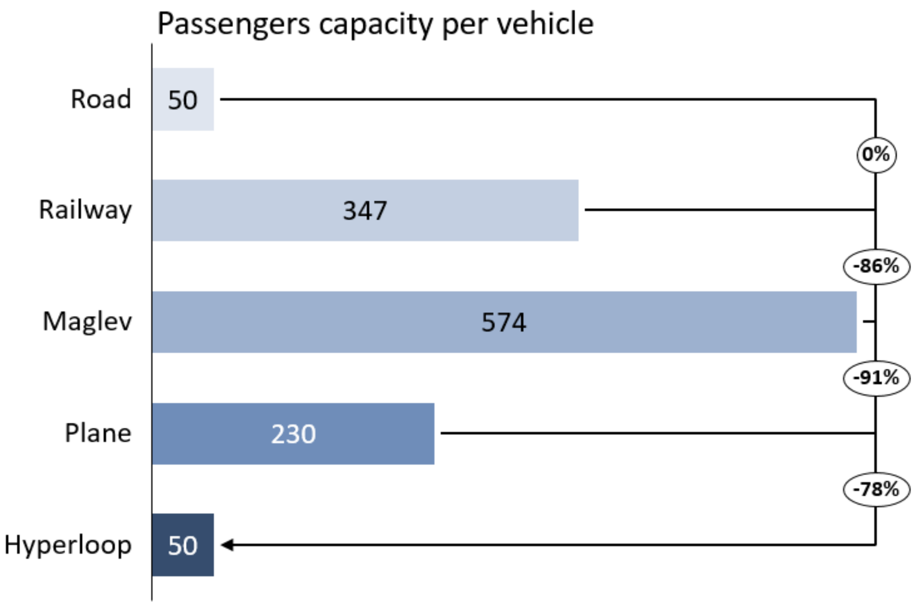


Figure 10. Passenger capacity per vehicle of the four existing transportation modes

The next Figure 11 classifies the four existing transportation modes, together with the expectations of the hyperloop system, attending to the type of energy needed to operate them.

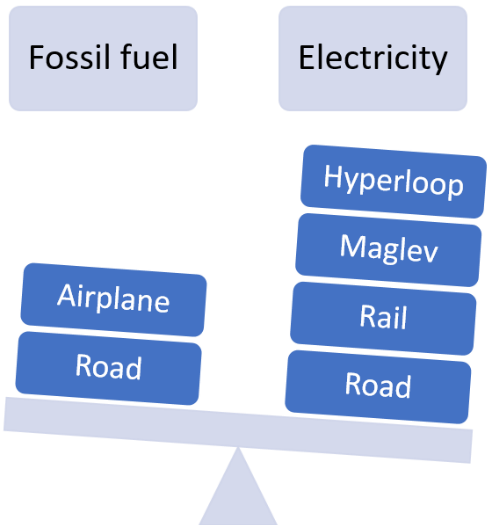


Figure 11. Classification according to the type of energy to operate

The next Figure 12 shows the Energy consumption, in kWh s/km, of the four existing transportation modes, together with the expectations of the hyperloop system.

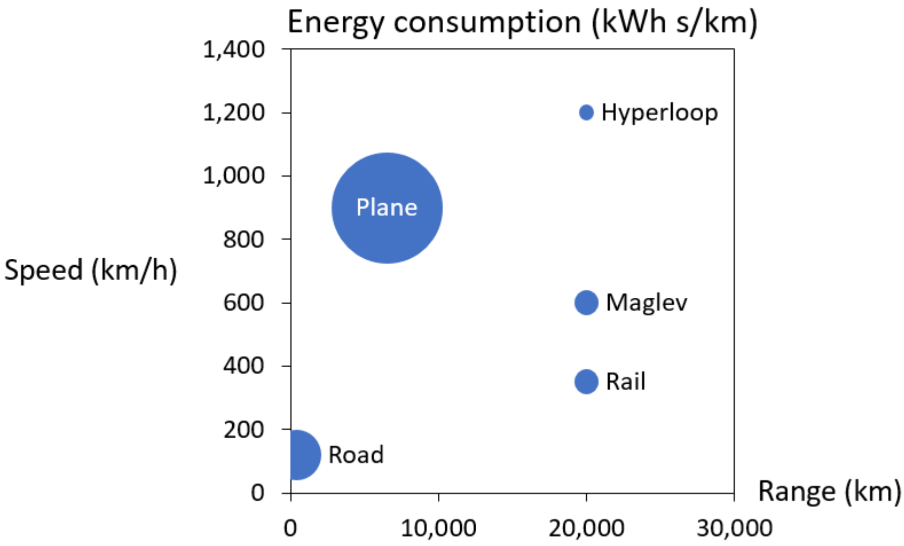


Figure 12. Energy consumption, in kWh s/km, of the four existing transportation modes (the bubble size indicates the energy consumption)

The next Figure 13 shows the grade of automation (GoAx) of the four existing transportation modes, together with the expectations of the hyperloop system.

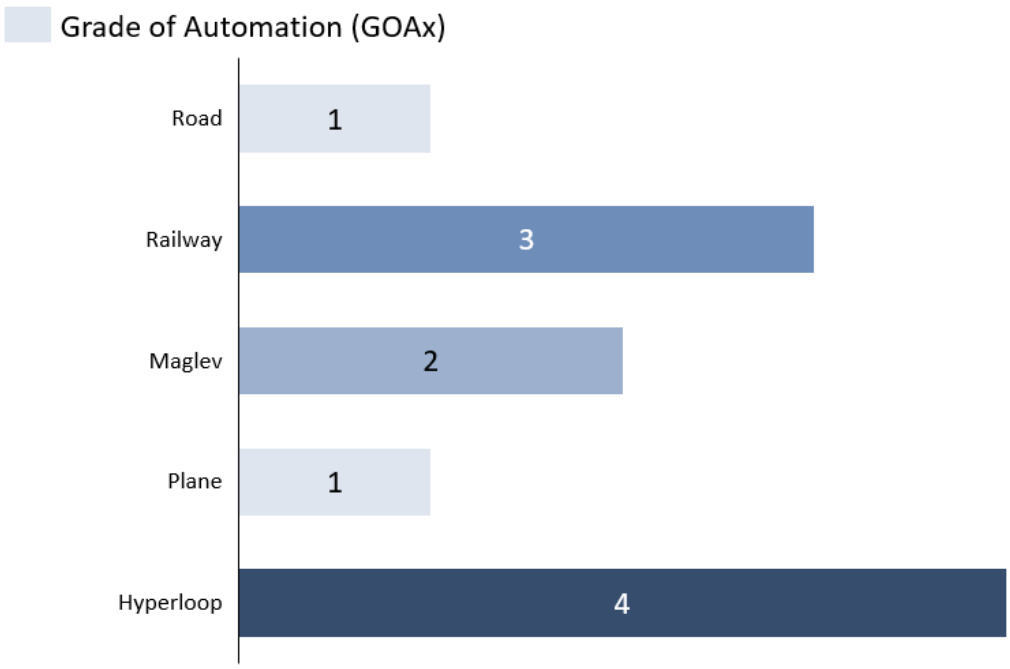


Figure 13. Grade of automation (GoAx) of the four existing transportation modes

The next Figure 14 shows the range of the four existing transportation modes, together with the expectations of the hyperloop system.

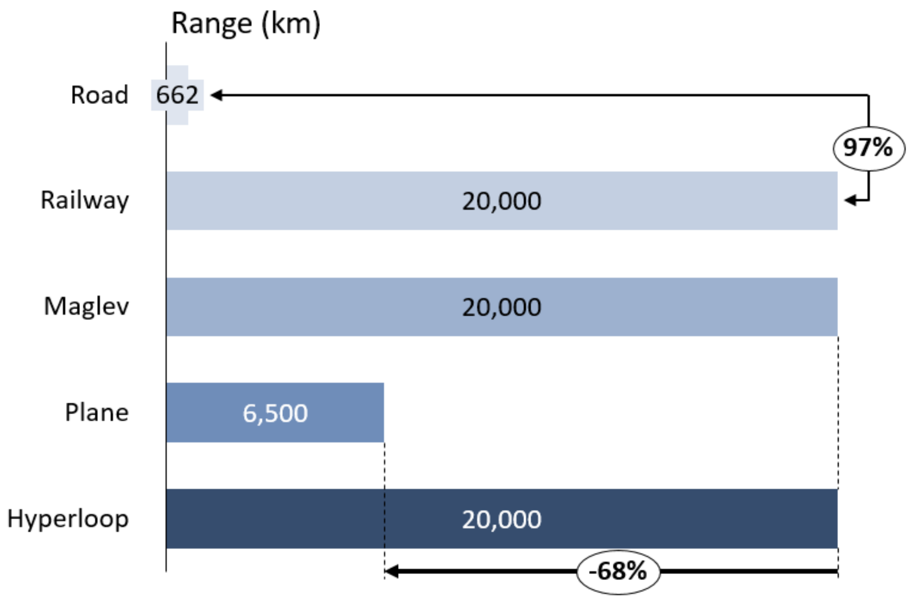


Figure 14. Range of the four existing transportation modes

2.4.2 Taxonomic analysis

The next Table 1 gathers together the above operational data.

Table 1. Operational data

	Maximum speed (km/h)	Mean speed (km/h)	Passenger capacity	Range (km)	Grade of automation
Road	90	70	50	400	1
Railway	350	221	347	20,000	3
Maglev	600	320	574	20,000	2
Plane	900	810	230	6,500	1
Hyperloop	1,000	850	50	20,000	4
Mean value	588	454.2	250.2	13,380	2.2
Standard deviation	378.1	354.7	220.7	9,317.8	1.3

To compare these data, we have normalized them by subtracting to each value by the mean value of its category, and then dividing by the standard deviation of its category. The next Table 2 shows the normalized values so obtained.

Table 2. Normalized values

	Normalized maximum speed	Normalized mean speed	Normalized passenger capacity	Normalized range	Normalized grade of automation
Road	-0,76	-0,80	-0,77	-0,96	-0,23
Railway	-0,07	-0,38	0,57	1,15	1,30
Maglev	0,59	-0,10	1,60	1,15	0,53
Plane	1,38	1,28	0,04	-0,30	-0,23
Hyperloop	1,64	1,40	-0,77	1,15	2,07

We have used these data to generate a dendrogram. To this end, we have used the following Matlab code:

```
X =  [-0.76	-0.80	-0.77	-0.96	-0.23;
-0.07	-0.38	0.57	1.15	1.30;
0.59	-0.10	1.60	1.15	0.53;
1.38	1.28	0.04	-0.30	-0.23;
1.64	1.40	-0.77	1.15	2.07];
tree = linkage(X,'average');
dendrogram(tree);
```

This way, we obtained the dendrogram shown in the next Figure 15:

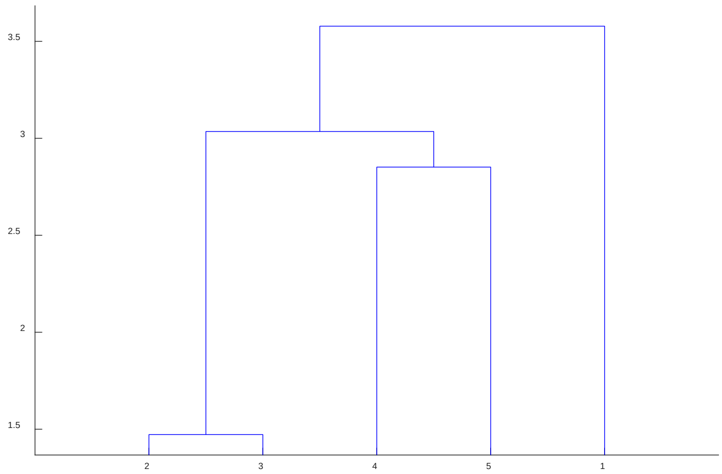


Figure 15. Dendrogram obtained with the normalized data

In this Figure 15, the labels in the x-axis correspond to the order of the transportation modes in the above data tables: 1 = Road; 2 = Railway; 3 = Maglev; 4 = Plane; 5 = Hyperloop. From the dendrogram we can see that the closest transportation modes are railway (2) and maglev (3), then plane (4) and hyperloop (5) and, finally, the road transportation mode (1) is the most different one in comparison with the other four.

2.5 Vehicle system classification

We can use transportation systems to move from one place to another. Different kinds of vehicles are based on various principles, travel at different speeds, and operate in different environments. They can be classified by their support and propulsion principles. The support mechanism balances the gravity force, while the propulsion generates the forward speed.

In this section, based on the work of Dukkipati (Dukkipati, 2000), we provide a review of the classification of vehicles based on the support and propulsion principles, a review of the classification of guided ground transportation concepts with respect to support configuration, means of support and propulsion and braking systems, and a review of the classification of vehicles according to the different means of generating the levitation and guidance forces.

2.5.1 Vehicle system classification

The next figures show a classification of vehicles based on the support and propulsion principles. Ground vehicles are supported by the reaction forces generated by the wheels, air cushions or magnets, and are driven by friction, flow, or magnetic forces.

Non-guided ground vehicles can be classified into road vehicles, off-road vehicles and air-cushion vehicles.

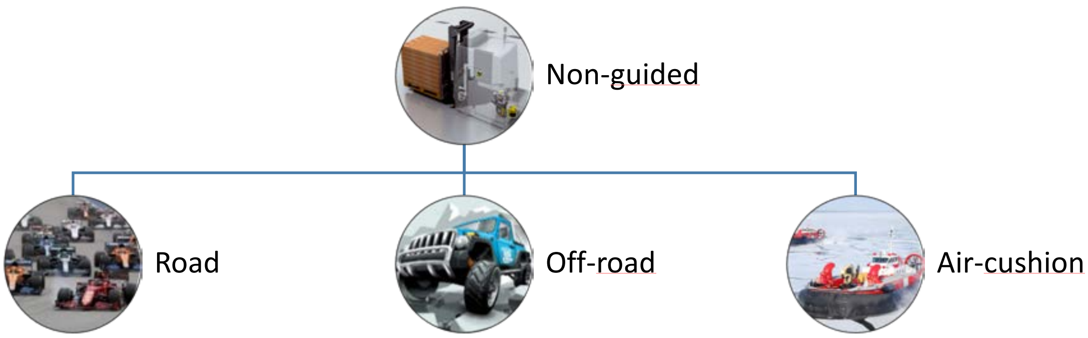


Figure 16. Classification of vehicles based on the support principles

Guided ground vehicles can be classified into railway vehicles, tracked air-cushion vehicles and magnetically levitated vehicles. The hyperloop pods can also be included into this category.

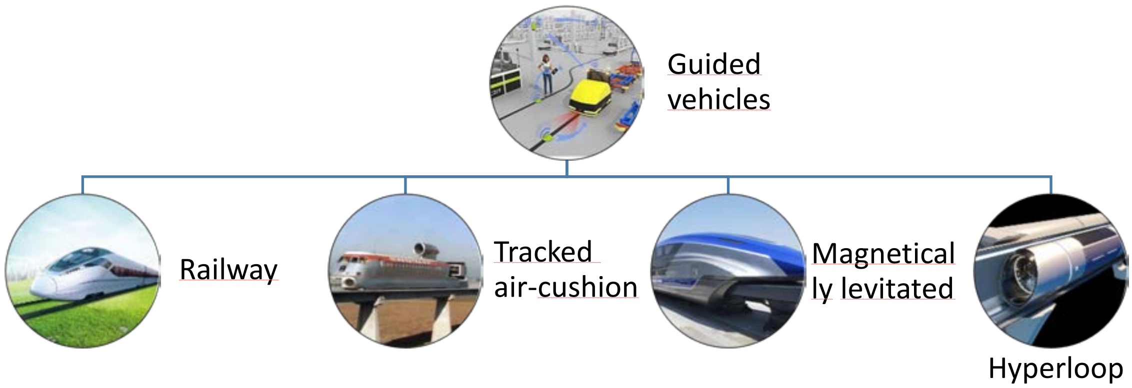


Figure 17. Classification of vehicles based on the propulsion principles

Fluid vehicles can be classified into marine crafts and aircrafts. Hyperloop could also be considered as a third class of fluid vehicle. Marine crafts can also be classified into hydrofoils and ships, while aircrafts can also be classified into airplanes, airships and helicopters.

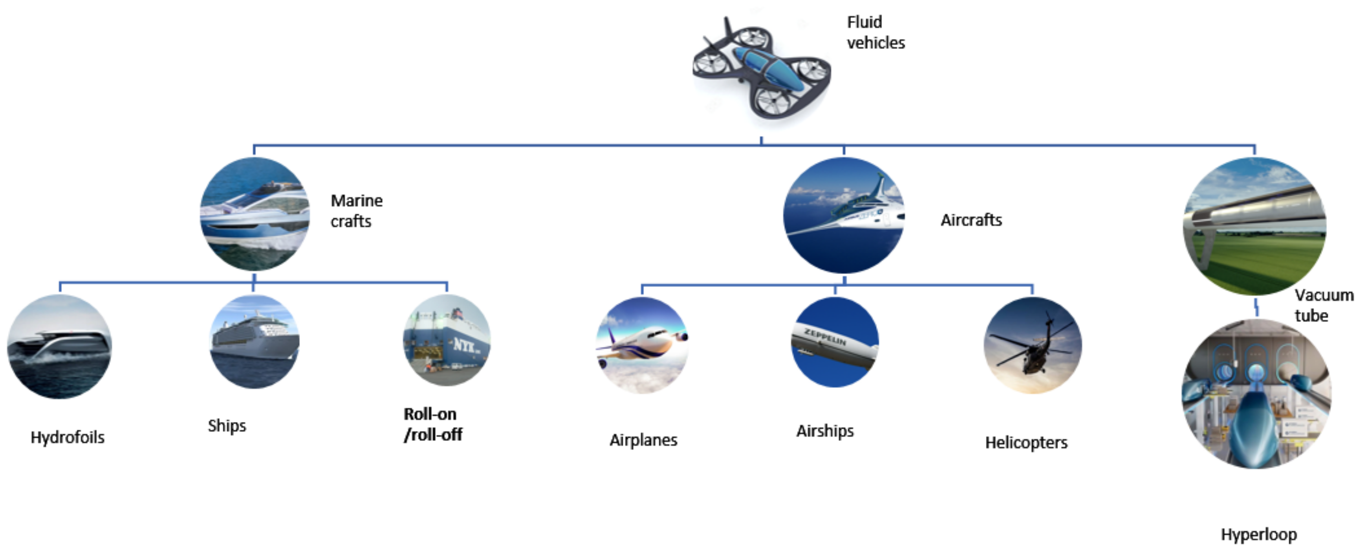


Figure 18. Classification of fluid vehicles

Inertia vehicles can be classified as aircrafts and spacecrafts. The former category is composed just by airplanes, and the latter by launch vehicles and satellites.

The next Figure 19 gathers all the former classifications together.

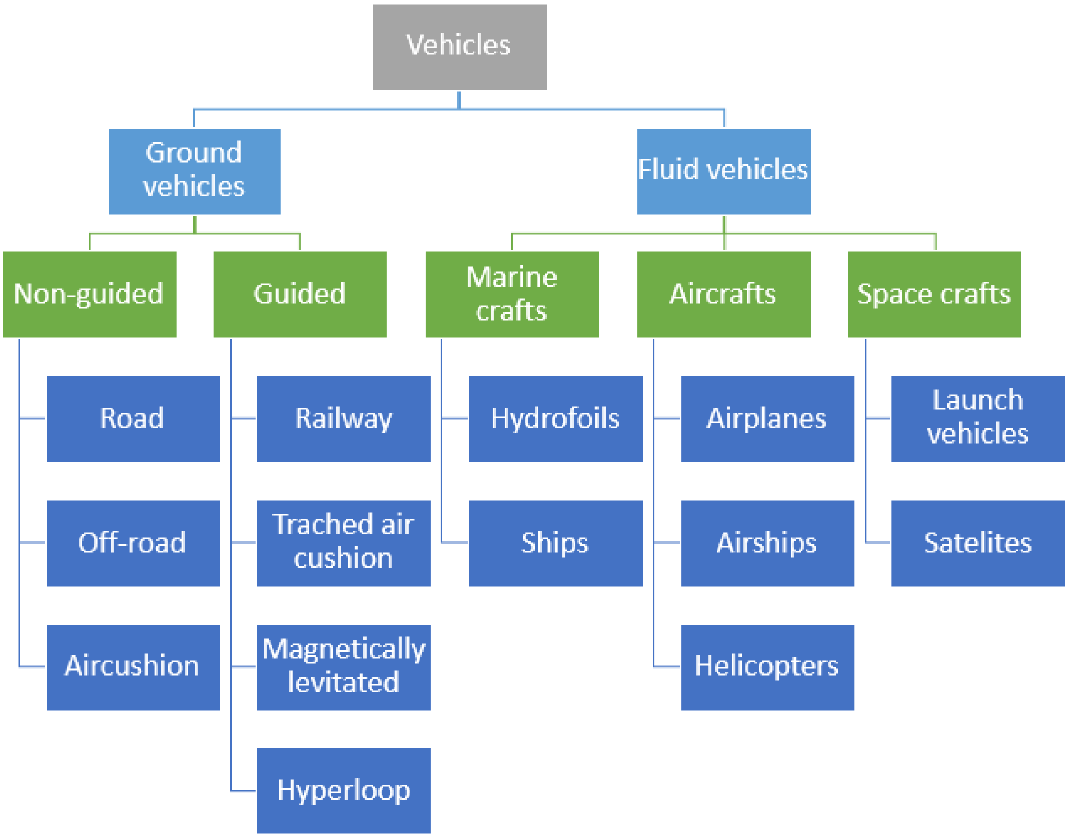


Figure 19. Global classification of vehicles

Fluid vehicles are supported by static or dynamic lift forces generated by water or air, and usually propelled by flow forces. Inertia vehicles are supported by dynamic lift or inertia forces generated by air, jet propulsion or orbital motion, and just inertia forces accelerate them.

The maximum travelling speeds of these classes of vehicles are very different due to their diverse support and propulsion principles. Current ground vehicles can reach maximum speeds of 600 km/h, fluid vehicles can reach 3,000 km/h and inertia vehicles can reach 50,000 km/h.

2.5.2 Guided ground vehicle system

Guided ground transportation associated with control of the vehicle may be characterized by its degrees of freedom. While an aircraft is characterized by three translational degrees of freedom, a steerable ground vehicle has two degrees of freedom and a guided ground transportation (GGT) vehicle just one. Steerable and guided ground vehicles comprise the ground transportation field. Besides, multi-modal systems is an hybrid class which falls into both of these categories.

2.5.3 Vehicle support classification

In the following, we present a classification of guided ground vehicles based on their support configuration, means of support, and propulsion and braking systems.

The next Figure 20 shows the classes of supporting devices. Only the steel wheel, the pneumatic tire and the air cushion have important applications in modern transportation, with the steel wheel being the dominant guided ground transportation device.

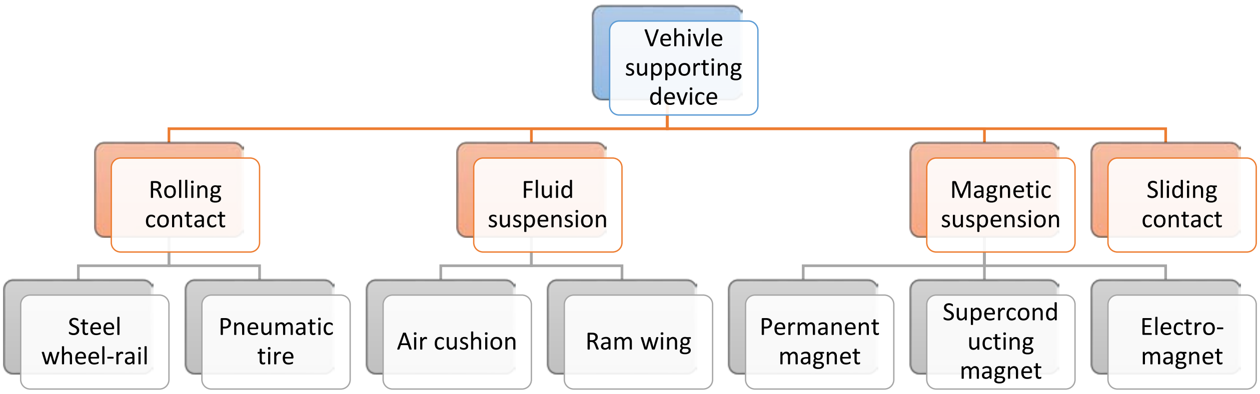


Figure 20. Classes of supporting devices

The next Figure 21 shows the classification of support configurations for guided ground vehicles. If the vehicle and supporting devices are symmetrically arranged respect to a vertical plane, the support configuration is symmetrical, and asymmetrical in other case. Symmetric configurations may be classified again as suspended or supported. They are supported if the support plane between the vehicle and the guideway lays below the vehicle body and suspended if the supporting plane is above the vehicle. Most concepts have a symmetric support configuration. Nevertheless, some present an asymmetric configuration, like the asymmetrically suspended monorail or the side-riding beam-way concept. For asymmetric configurations, the distinction between suspended or supported vehicles is not always clear.

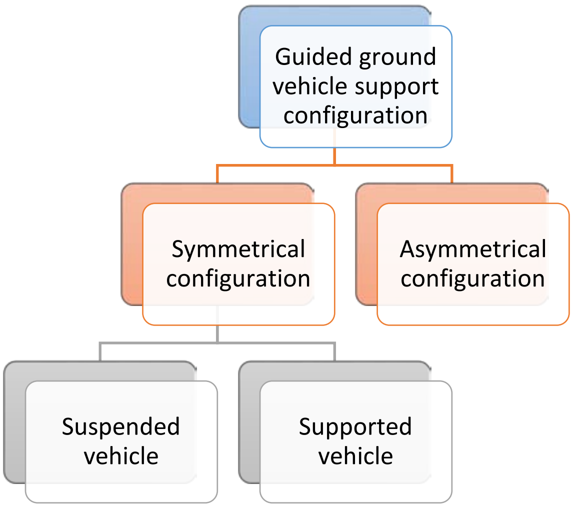


Figure 21. Classification of support configurations for guided ground vehicles

The contact pressure presents high variations from one support device to another. It ranges from less than 7,000 N/m^2 for the air cushion to 7,000·105 N/m^2 for the steel wheel. It has important implications for the track structure, determining the requirements for the track material in contact with the supporting device and the design of the load-carrying structure.

The next Figure 22 shows a classification of propulsion systems for guided ground transportation (GGT) vehicles.

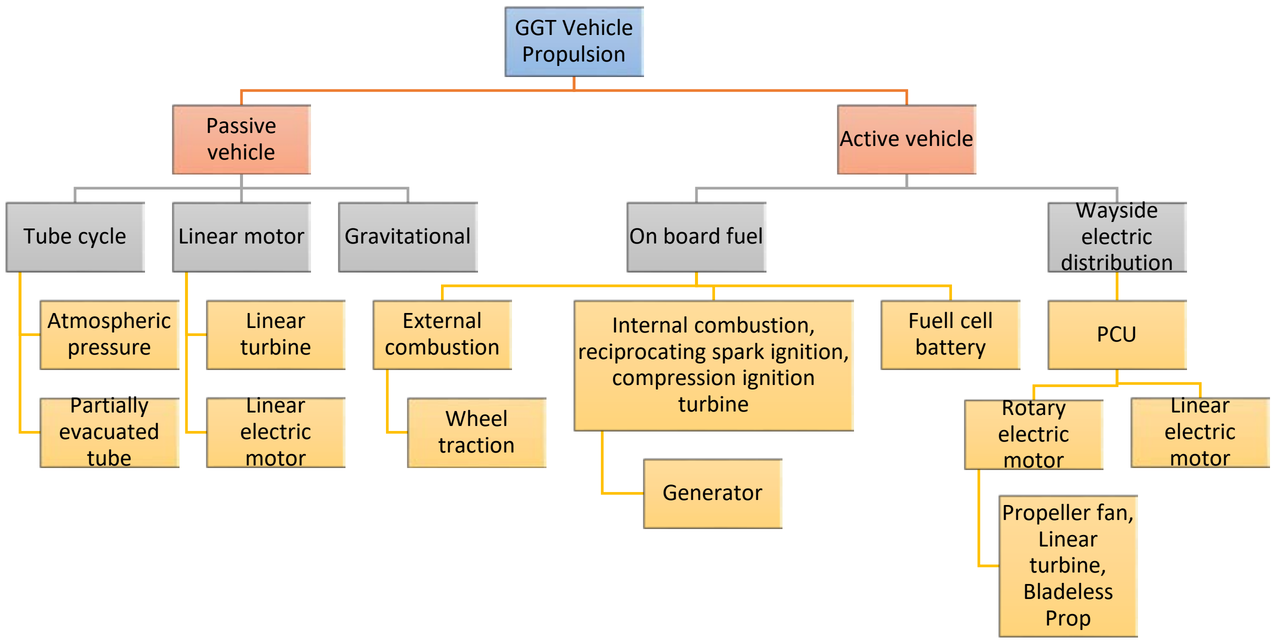


Figure 22. Classification of propulsion systems for guided ground transportation (GGT) vehicles

The next Figure 23 shows a classification of braking systems for guided ground transportation (GGT) vehicles.

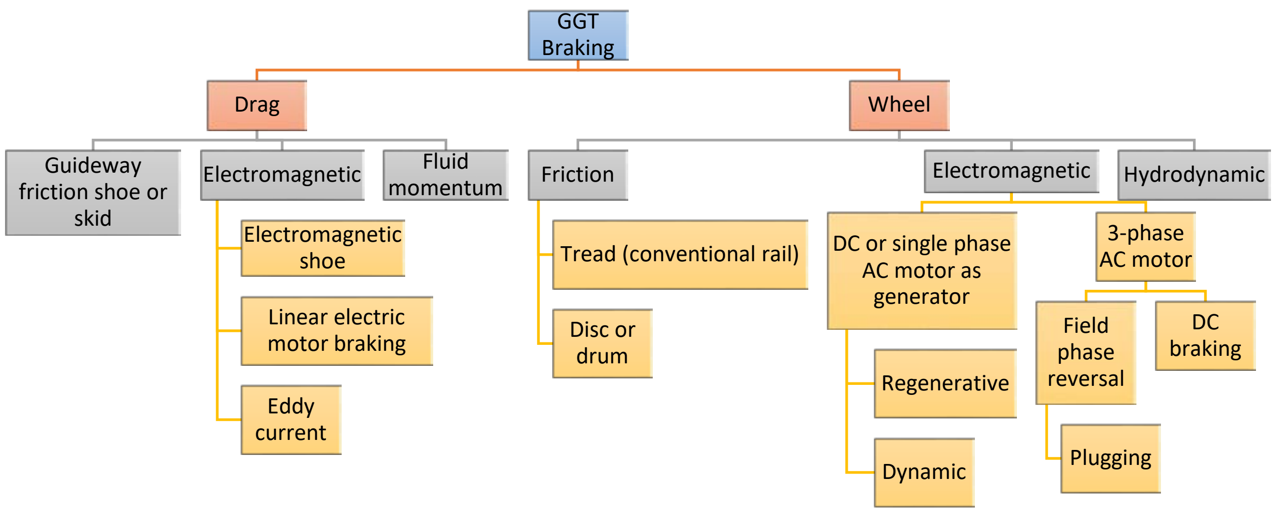


Figure 23. Classification of braking systems for guided ground transportation (GGT) vehicles

2.5.4 Transportation concepts

Transportation concepts can be classified into six broad categories, as shown in Figure 24:

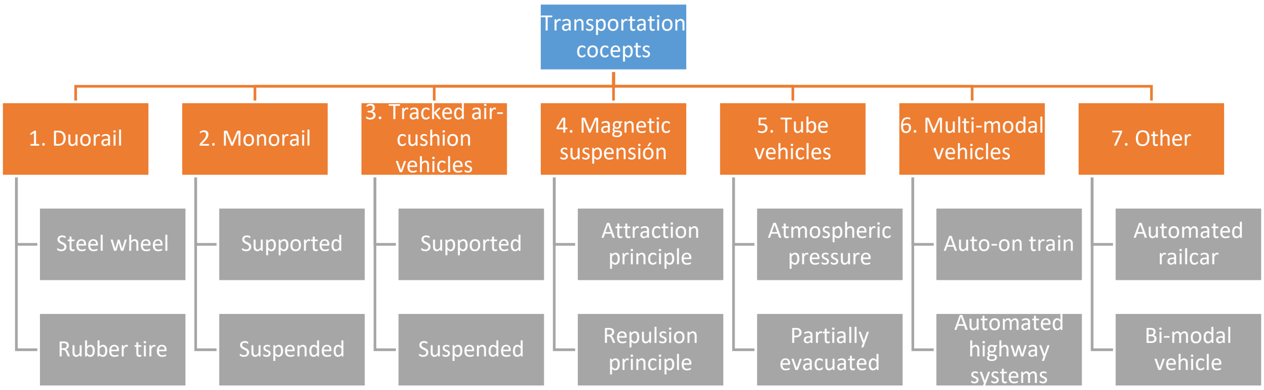


Figure 24. Transportation concepts

In the above classification, the first four categories are distinguished by their support method. The fifth category is based on those propulsion systems having a tubular enclosure that plays a fundamental role. Moreover, the first five categories may also be considered as station-to-station systems, while the sixth category can be regarded as a door-to-door transportation, reflecting the need for a transportation system combining the convenience of the automobile with the safety, speed, capacity, and low pollution levels of modern guided ground transportation.

2.5.4.1 Duorail

The term duorail refers to a configuration with a supported vehicle running on two supporting rails. The rails are spaced to provide stability against over-turning. The conventional railway system is an example of the steel-tired duorail concept.

Rubber-Tired Duorail

The rubber-tired duorails have found application in urban underground systems like Paris, Montreal and Mexican City Metros, among many others recently evolving. Like in steel-wheeled systems, the bogies of these rubber-tired underground vehicles is used to support the carbody. Like for steel-wheeled systems, rubber-tired bogies also have two wheelsets, thus having four support wheels running on guiderails located on each side of a concrete supporting track. They also have additional steel wheels mounted on the same axle as each supporting wheel, which can run above a steel duorail track. The inner steel wheels would support the vehicle if a rubber tire blows out the axle. In switches, the guiderails are discontinued, and the concrete track is lowered, so that the bogies can run on the steel wheels, using conventional railway switches.

The Westinghouse Transit Expressway is a variant of the rubber-tired duorail system. It has single-axle bogies, steered by guidance wheels running on a central I-beam rail.

2.5.4.2 Monorail

Monorail systems can be classified into suspended and supported. The next Figure 25 shows a classification of monorail systems.

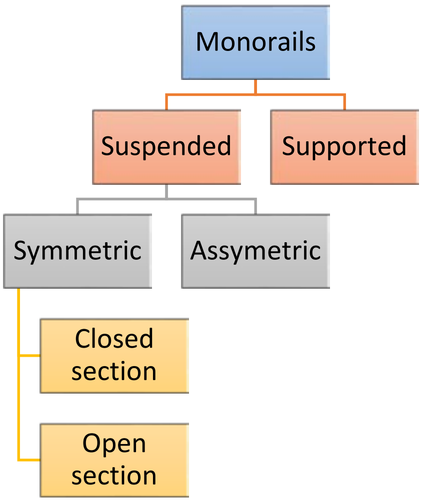


Figure 25. Classification of monorails

The German Wuppertal system, in operation on a 12.8 km line for over seventy-five years, is a good example of an asymmetrically suspended monorail. It has steel wheels and has a maximum speed of 40 km/h. A peculiarity of this system is its supporting structure, composed by an A-frame supported from each bank of the Wupper River.

SAFEGE, with a 1.6 km experimental track in operation at Chateauneuf, France, is an example of a symmetrically suspended monorail. It has a rubber-tired bogie. In the USA, we can find the General Electric Aerial Transport System. The URBA air cushion suspended monorail also belongs to the symmetrically suspended monorails category.

The Aerial Transport System also lays into the symmetrically suspended category. Though its main feature is its cable-tension guideway structure, its I-beam track represents a basic variant of the symmetrically suspended monorail. Its configuration is similar to that commonly used in industrial monorails.

The ALWEG system is the only developed version of the supported monorail. The vehicle has pneumatic tires and rides on a box beam track. Its supporting tires ride on top of the beam, while its guiding and balancing tires ride along the beam sides. Its maximum design speed is 100 km/h.

2.5.4.3 Tracked air-cushion vehicles

The next Figure 26 shows a classification of the best-known support configurations developed for Tracked Air-Cushion Vehicles (TACV).

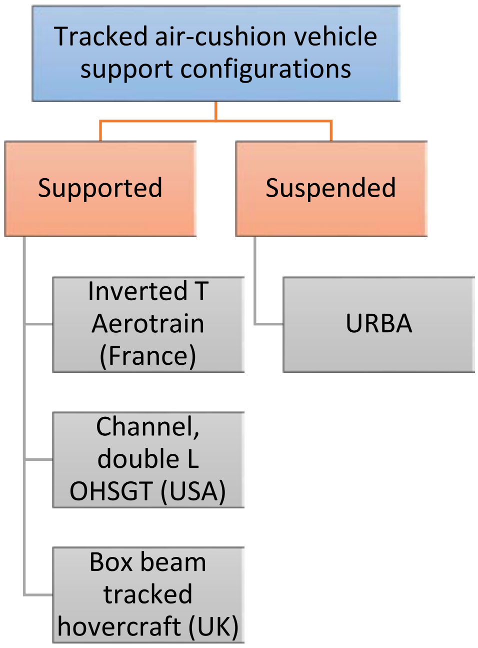


Figure 26. Classification of the best-known support configurations developed for Tracked Air-Cushion Vehicles (TACV)

However, the propulsion systems of TACV have few principal variations. The linear induction motor (LIM) is the most important propulsion system, which is used in all the existing TACV developments. Two distinct lines of LIM are the single-sided motor and the two-sided motor. Aerotrain has also developed a ducted propeller version, though it would seem to favour the pressed wheel for its commercial application.

As their name suggests, the URBA concept, previously included as an asymmetrically suspended monorail, is conceived for urban and suburban application. The design speeds for the projected URBA 30 and URBA 100 vehicles are 80.5 km/h and 120.7 km/h, respectively.

2.5.4.4 Magnetic suspension

Some experimental vehicles with suspensions based on magnetic attraction have been tested in Germany. In 1971, the Messerschmidt-Bolkbow-Blohm (MBB) vehicle and another vehicle developed by Krauss-Maffei were unveiled. These vehicles use the attraction principle. It is based on the attraction between a magnet in the vehicle and a magnetic material on the track. To overcome the unstable nature of the attraction, these vehicles use electromagnets to control the flux, by varying the current in the magnet coils.

The repulsion principle can be achieved by bringing together like poles of two bar magnets. The repulsive force increases with proximity, providing a statically stable force variation. It can be used to lift the vehicle by creating permanent repulsion fields on both the vehicle and the guideway. Another way is to induce a repulsion field using the relative velocity of vehicle and guideway fields. This second approach allows either the vehicle or the guideway to be passive. However, it requires a relative velocity between the vehicle and track fields before generating the lift. If an alternating current is used on the active side, the lift generation does not require motion of the vehicle. However, if a direct current is used, the vehicle does not lift until a certain velocity is achieved.

The next Figure 27 shows a classification of magnetic suspension types.

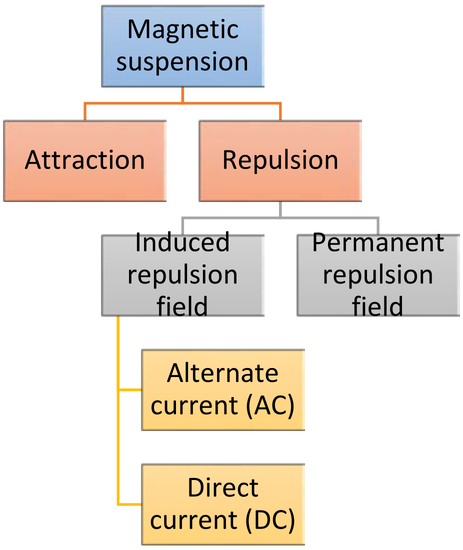


Figure 27. Classification of magnetic suspension types

2.5.4.5 Tube vehicle systems

Several tube vehicle system concepts have been proposed and some concepts have been tested using small-scale models. In the recent years, some full-scale system has also been developed.

The tube is the guideway for the vehicle, and may be classified according to its internal environment, as shown in the next Figure 28.

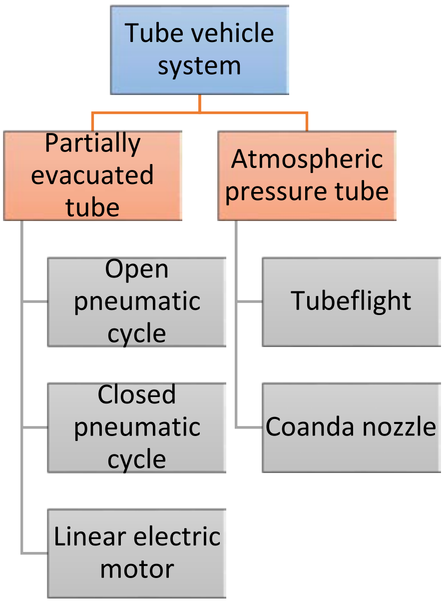


Figure 28. Classification of the tube according to its internal environment

Tube vehicle systems are designed for very high speeds. The Gravity Vacuum Transit (GVT) concept, for distances up to 40 km, provides just about the maximum conceivable speed. However, it requires a relative velocity between the vehicle and track fields before the former can lift within passenger comfort limitations on acceleration. Concepts proposed for inter-city distances are conceived for maximum speeds of 500 to 800 km/h.

2.5.4.6 Partially evacuated tube systems

The partial evacuation of the tube allows to achieve high speeds with low drag. Several concepts of this type have been proposed. The gravity vacuum transit (GVT) system is an open system that uses pneumatic and gravitational propulsion to propel a wheel-supported vehicle with a high blockage ratio. The controlled environment gravity tube system (CEGTS) is a closed system that uses pneumatic and gravitational propulsion to propel wheel-supported vehicles with a high blockage ratio. The LIM-evacuated system is a railway vehicle propelled by a linear induction motor (LIM) which runs in a partially evacuated tube.

2.5.4.7 Atmospheric tube systems

Examples of atmospheric pressure tube systems are the tube-flight concept, and another system developed by the Illinois Institute of Technology Research Institute (IITRI).

The tube-flight concept is based on the hypothesis of matched internal propulsion, which states that vehicles with low blockage ratio can be propelled in a non-evacuated tube by transferring air around a vehicle requiring less energy than other methods of atmospheric propulsion.

The tube system concept of the IITRI is based on a passive vehicle that is propelled through a tube using a series of nozzles spaced along the tube. The nozzles use the Coanda effect to inject air along the tube wall. The vehicle is propelled along the tube by properly staging the action of the nozzles.

2.5.4.8 Multi-modal systems

It is not easy to provide a definitive classification of the multi-modal concept due to its generality. The classification shown in the next Figure 29 reflects those concepts identified so far.

Bi-modal vehicles are classified into automated highway systems, auto/rail systems, and other systems. The latter refers to those systems involving air-cushion or magnetic suspension. Some concepts regarding tri-modal vehicles have been discussed in the literature, but they have not been implemented. In terms of their configuration, propulsion or braking, multi-modal systems are not distinct from other guided ground transportation (GGT) classes. In fact, most multi-modal vehicles can be considered a particular class of one of the previous concepts. Two specific cases of the multi-modal concept are the auto-on-train system and the automated highway system.

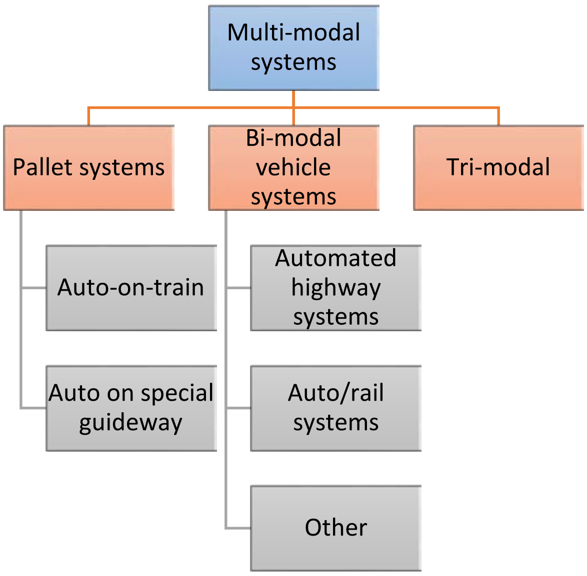


Figure 29. Classification of multi-modal systems

The auto-on-train system uses existing railways to transport both cars and passengers. For example, it is in regular service in France, connecting Paris and the English Channel ports with tourist cities in the south of Europe. They offer services where the passengers and their cars are carried on the same train. However, passengers and cars travel on separate trains on longer journeys, the latter being transported in conventional car-carrier freight cars. A somewhat different approach consists in carrying the car and its passengers on one train, while the passengers remain in their own cars, driving on and off the train by themselves.

The automated highway systems are based on vehicles similar to conventional automobiles but capable to operate on automated highways as guided vehicles where the driver renounces to control the car. This way, the steering function is taken over by an automatic control system, giving the car the single control freedom characteristic of a GGT system. The speed of the vehicle would also be automatically controlled. Another multi-modal system is the auto/rail bi-modal vehicle, which is similar to a bus that can operate either on a conventional railway track or on a road.

Other bi-modal vehicles have been suggested, like the Alden Starrcar and the Cornell Aeronautical Laboratories Urbmobile. Palletized systems use small, steel duorail cars that operate on fully automated guideways transporting automobiles and their occupants, being a highly specialized version of the auto-on-train concept.

2.5.5 Vehicle – guideway system classification

The interaction between vehicles and guideways is a broad topic that may include multiple types of vehicles and guideways. For vehicle systems operating on dedicated guideways, the following Figure 30 shows three primary classes of guideway systems. They can be classified in rigid surfaces, such as grade pavement and rail track; elevated systems or bridge structures, such as simple spans or continuous spans discretely supported by pylons or cable-stayed; and continuously supported surfaces, such as at grade highway or rail systems with rail or pavement flexibility. It should be considered that any real guideway is composed of combinations of all these three categories.

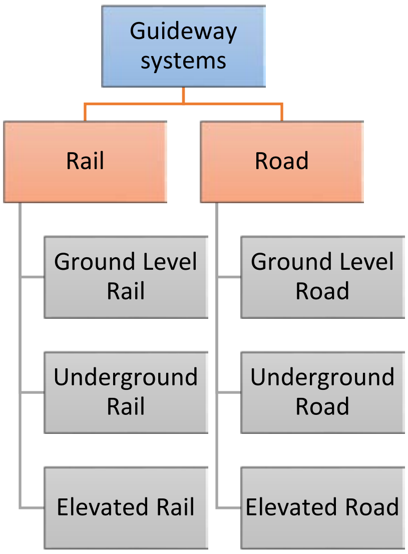


Figure 30. Primary classes of guideway systems

Vehicles can be classified according to the different means of generating the levitation and guidance forces. The following Figure 31 shows a classification of these forces, which interact with the guideway, and are usually known as primary suspension forces. They include: tracked levitated systems, such as magnetic and air-cushion vehicles; conventional steel wheel/rail; and pneumatic or rubber-tired vehicles.

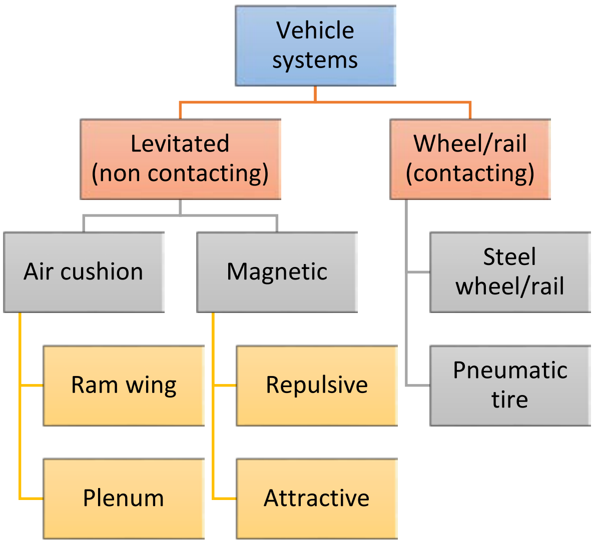


Figure 31. Classification of primary suspension forces

2.6 Sustainable investment taxonomy

Europe elaborated a finance taxonomy initiative that guides financial markets towards investing in sustainability and supports closing the private investment gaps to deliver on the EU's environmental ambitions. There are four criteria under the Taxonomy Regulation that any investment must meet to be labelled as "environmentally sustainable".

Figure 32. Criteria for being a sustainable investment

<u>Steps 1 and 2</u>

The six environmental objectives are the following:

1. climate change mitigation;

2. climate change adaptation;

3. sustainable use and protection of water and marine resources;

4. transition to a circular economy;

5. pollution prevention and control; and

6. protection and restoration of biodiversity and ecosystems.

For the hyperloop case, the most relevant objectives are one and two, however, the deployment of this solution will have a smaller impact in objectives 2

These six objectives can be exemplified as:

1. Hyperloop will reduce the GHG emissions of the transport sector. It is a zero direct emissions solution given that it is foreseen to be powered by electricity generated by sustainable sources only. The manufacturing of the infrastructure is considered as GHG-intensive. Materials such as cement or steel are assumed to be highly demanded for the infrastructure, thus the decarbonisation of these industries (cement or steel) should be closely monitored and lower carbon intensive materials should be also studied, if the sustainable investment label wants to be achieved.

2. Hyperloop will anticipate the adverse effects that might arise from climate change, such as: extreme weather conditions. Its sealed and confined operating environment makes it the most weather-robust transport mode.

3. Hyperloop will not intend to invade or use water nor marine resources.

4. Hyperloop should be an electronic intensive sector, aspects such as battery/electronics second life or reuse strategy, as well as the raw materials contained, are critical when qualifying for the sustainable investment label.

5. Hyperloop works in a closed environment, specifically created for its operation. This closed environment will grant a minimum noise impact both external and internally, contributing to the objective of noise pollution reduction.

6. Hyperloop, as a new infrastructure, will impact the biodiversity and ecosystem.

<u>Step 3</u>

For hyperloop to be a sustainable investment it should comply with the minimum safeguards implemented by an undertaking that is carrying out an economic activity to ensure the alignment with the OECD Guidelines for Multinational Enterprises and the UN Guiding Principles on Business and Human Rights, including the principles and rights set out in the eight fundamental conventions identified in the Declaration of the International Labour Organisation on Fundamental Principles and Rights at Work and the International Bill of Human Rights. 2.

<u>Step 4</u>

Hyperloop's qualification for sustainable investment will be agile and highly reactive thanks to the early phase of the project. Research should be focused on meeting the technical screening criteria proposed in Regulation (EU) 2020/852 to facilitate sustainable investment.

One of the important and challenging aspects of hyperloop development is being able to recognize and identify the points to work on in order to be environmentally sustainable. It is not an easy task and it must be iterative. Hyperloop success will depend, among others, on the European investment for testing and deployment. To do so, hyperloop must meet the guidelines offered by the European Commission to become a sustainable investment solution, however, such work is out of the scope of this document, and will be proposed as future work.

3 Circular economy in hyperloop

The Circular Economy or regenerative economy should affect all sectors of the industry.

The industry related to hyperloop cannot be considered as a separate case and not follow the recommendations of the European Green Deal[1] or those corresponding to the circular economy[2].

The design of both the vehicles and the necessary infrastructures (tubes, stations, etc.) must work with their life cycle in mind (extraction of materials, assemblies, placing on the market, and end of life) from the moment of initial design.

Different approaches in the railway world have been made to increase sustainability in the design of the different parts and elements of the rolling stock. SUSTRAIL[3] project shift to design a sustainable freight vehicle.

The REUSE[4] project, led by UIC, sought to provide with an inventory of practices related to sustainable use of resources and circular economy, limiting the raw materials extraction and decreasing the pollution of water and the waste generated due the transformation of those resources.

The HS2 Project[5] is the largest railway infrastructure project of the UK railways and has left great lessons on the implementation of circular economy principles in the railway sector. These principles must be incorporated into the development of the European hyperloop, as it is explained below.

The hyperloop sector will have an infrastructure that should be based on a very long life cycle; they will be designed to last a long time, but eventually should be replaced. Infrastructure design must be completed using a systematic approach (Figure 33) and Life Cycle Assessment methodologies. Its design and use must be observed during the manufacturing phase, the use phase, and the withdrawal phase. The vehicle should not be treated differently. Potentially, their treatment is simpler since they could be designed as more accessible elements. The first two phases can be improved thanks to eco-design (ISO 14006[6]); manufacturing with more environmentally efficient materials and incorporating recycled materials where possible. Similarly, the extraction and manufacturing using green energies must be taken care of. For its replacement, modification, or disassembly, it is necessary to think about possible remanufacturing, alternative uses, etc. thanks to, for example, modular designs[7] or the use of materials that can be recycled or biomaterials. It is also important to incorporate a design designed for easy disassembly; minimizing the joining elements and the variety of materials used. It is extremely important that any element that complies with the hyperloop should be properly documented with the composition of the

[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[2] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_420
[3] https://cordis.europa.eu/project/id/265740
[4] https://uic.org/projects/article/reuse
[5] Homepage - High Speed 2 (hs2.org.uk)
[6] ISO 14006 Environmental management systems — Guidelines for incorporating eco-design
[7] https://www.arup.com/projects/copenhagen-metro

materials and their origin, which will allow upcycling or recycling. The incorporation of IOT technologies will also allow knowing relevant information about the components such as the hours of use and being able to make decisions with regard to possible maintenance, improving safety.

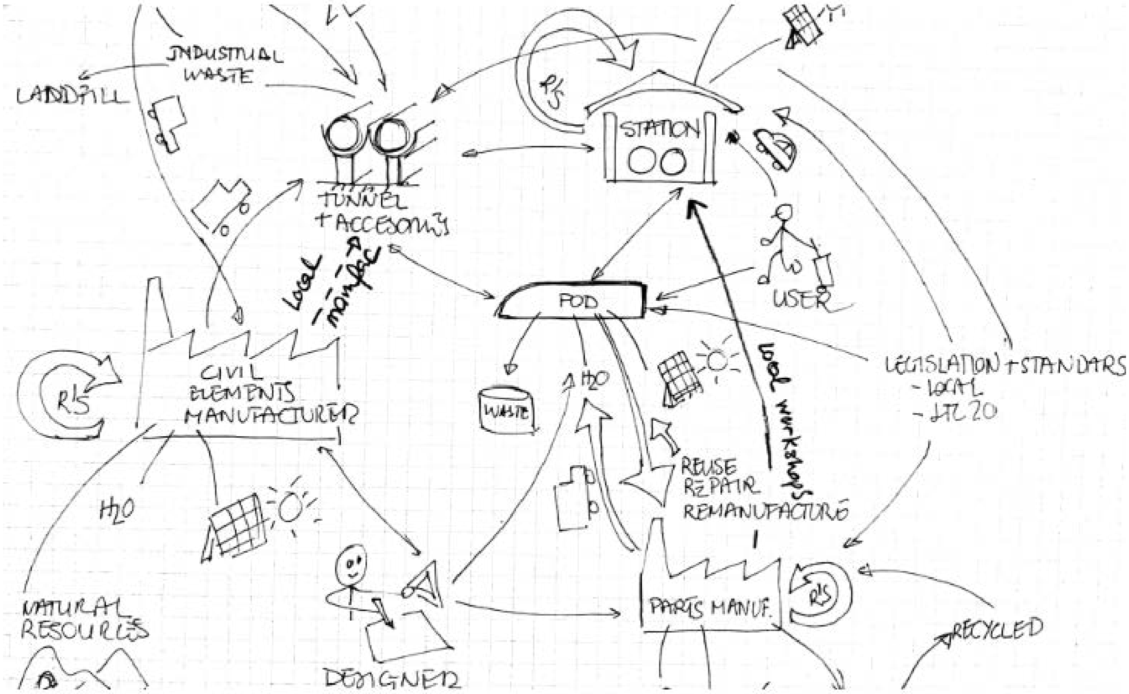


Figure 33. Sketch of the hyperloop systemic approach (source: UPM)

The new implementations of civil infrastructures should be documented and managed by means of BIM (Building Information Modelling) methodology avoiding undocumented elements.

Implementing circular economy principles will benefit the hyperloop sector in:

- These principles add higher whole life value
- Reduce of oil derived energy
- Reduce of non-renewable materials
- Reduce CO2 impact
- Reduce water use
- Will offer new opportunities of employment
- Will boost collaboration and alliances between different sectors
- Will develop new business models
- Hyperloop sector will have a higher knowledge of the systems and better decisions taken
- Circular economy will enable less capital and operational costs

- Circular economy should apply the following principles to implement in hyperloop activities:
  - keep resources in use for as long as possible
  - recover and regenerate resources at the end of each use
  - keep resources at their highest quality and value at all times
  - Safety must not be affected

Figure 34 shows this circular economy framework for hyperloop implementation in Europe.

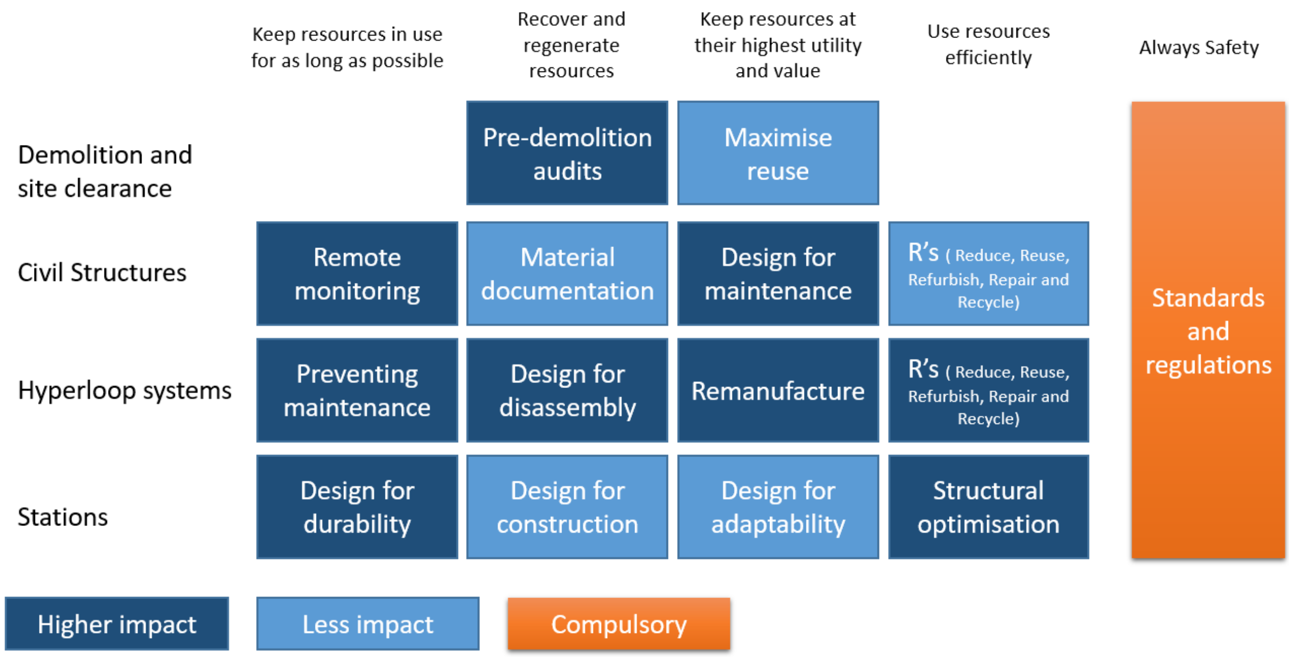


Figure 34. Circular economy framework for hyperloop (based in www.hs2.org.uk)

4 Guided transport

4.1 Current and future trends

4.1.1 Guided transport systems technical and regulatory overview

It is important to understand the regulatory framework of the commonly utilised guided transport systems before defining rules aimed at ensuring coherency between transport means and transport infrastructure for the new fifth mode of transportation based on the hyperloop concept. Therefore, the following subsections present a comprehensive approach to technical solutions and the regulatory framework for trams, metro, railways and unconventional guided transport systems (UGTS). The aim of the analyses conducted by authors within the HYPERNEX project was to find conditions that should be taken into account during creation of a new guided transport mode based on hyperloop concept. The four subchapters dedicated to findings in relations to trams, metro, railways and UGTS (Unconventional Guided Transport Systems) are followed by hyperloop's technical and legal challenges.

Before presenting individual guided transport systems it is important to subdivide all transport systems into three main parts:

- transport means, i.e. trams, metro, railway and unconventional vehicles which carry passengers and goods between different locations (including transport means maintenance procedures);
- transport infrastructure, i.e. routes along which transport means are moving (including transport infrastructure maintenance procedures); and
- operational and emergency transport procedures, which are used in normal operation and in degraded circumstances.

4.1.1.1 Trams technical solutions and regulatory framework overview

Trams – short technical overview

Tram infrastructure is composed of: tracks, tram stops, traction power supply systems and overhead contact line installations as well as elements of signalling. These signals are usually added to road signalling systems as most of the trams are running within roads or along the roads passing many crossroads.

Trams as transport means are light in comparison to transport means utilised by other guided transport systems (metro trains or railway vehicles). At the same time, trams are much heavier than passenger cars, and therefore individual cities in which trams are used in most cases decided to introduce signalling system to respect traffic regulations.

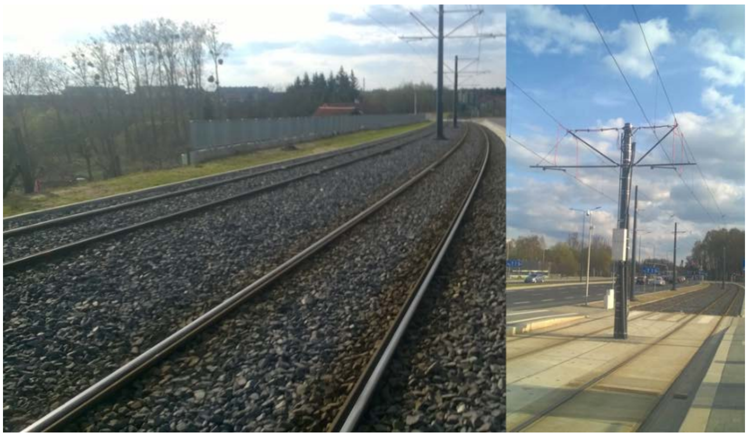


Figure 35. Trams infrastructure in Olsztyn, Poland (photo MPawlik)

Trams – short legal overview

Tramways and trams are in most cases under construction regulations dedicated for roads. That seems reasonable as tram movements take place partly on the roads. The number of requirements and their verifications significantly differ between countries and partly between cities. This situation is acceptable as long as there are no connections between tram systems between different cities, which is usually the case. And that is the case in most places. Individual construction products are under Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonized conditions for the marketing of construction products.

Trams – short info about current and future trends

1. More and more high speed trams are being introduced. They typically run along dedicated infrastructure, which is fully, or almost entirely, separated from the roadway. In the case that the tram is not separated from the roadway, legal challenges can arise due to road regulation no longer being easily applicable.

2. Moreover, in some places trams started to use railway infrastructure. As a result, it was important to take into account huge differences in crashworthiness between trams and railway vehicles. As a result a new category of vehicles is emerging – a tram-train.

3. Trams have become increasingly tailored to the needs of serving cities taking into account persons with reduced mobility. That includes low flooring, small gaps between platforms and door steps, places for wheelchairs, etc.

4.1.1.2 Metro technical solutions and regulatory framework overview

Metro – short technical overview

Metro infrastructure is composed of: engineering structures including tunnels, slab track structures, underground stops, traction power supply systems and third rail power supply installations, dedicated trackside signalling plus in many cases track-train transmission based control command systems supervising metro train runs against given permissions as well as communication systems ensuring operational communication between metro train drivers and dispatchers.

Metro trains are usually used to ensure homogenous or nearly homogenous traffic. Metro trains homogeneity is important to ensure similarity between speed-up and braking characteristics of the trains which is a prerequisite for control command systems ensuring short headways between metro trains. Passengers do not check, what time there is a train as headway between trains is usually about 2 min.

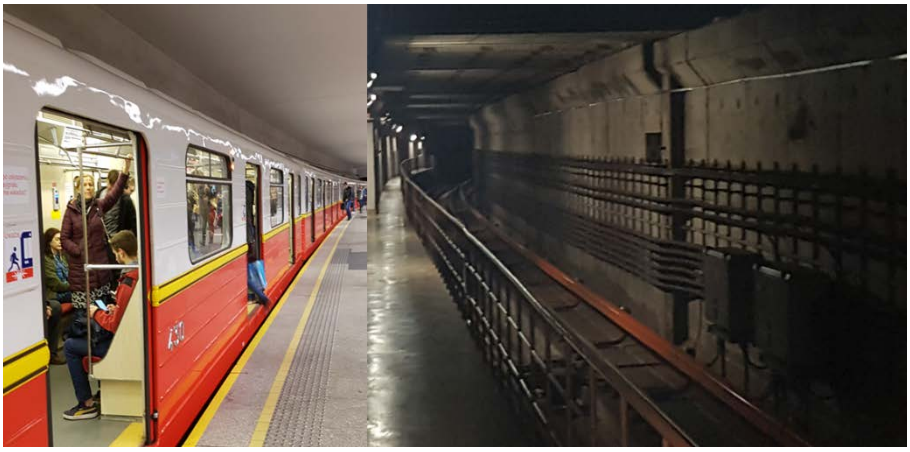


Figure 36. Metro system in Warsaw, Poland (photo MPawlik)

Metro – short legal overview

Metro systems are in some cases under construction regulations dedicated for metro and in some cases under railway related regulations. Of course, individual construction products are under Regulation (EU) No 305/2011.

Metro – short info about current and future trends

More and more metro systems are equipped with automatic systems ensuring safe driverless operation. An IEC 62267:2009 Railway applications - automated urban guided transport (AUGT) - safety requirements standard defines grades of automation. The GoA already introduced in metro homogenous systems are at the moment being introduced in railway system – see Table 3.

4.1.1.3 Railways technical solutions and regulatory framework overview

Railway – short technical overview

Railway infrastructure is composed by: engineering structures & tracks (bridges, viaducts, tunnels) utilising both ballasted and slab tracks, stations composed by sets of interlinked tracks with platforms and dedicated buildings ensuring necessary services for passengers and freight forwarders, traction power supply and overhead contact line installations as well as trackside signalling plus in many cases track-train transmission based control command systems supervising train runs against given permissions as well as communication systems ensuring operational communication between train drivers and dispatchers as well as between adjacent dispatchers, plus telematics systems for freight and for passenger services ensuring seamless exchange of information between infrastructure managers, train operators, freight forwarders (e.g. shippers) and individual clients. Telematic applications were introduced by EU regulations to facilitate using railway connections for logistic networks at the time of split of national railways into infrastructure managers and railway undertakings.

Trains are composed out of railway vehicles, which are frequently significantly heavier than in case of metro. Usual axle load is 22.5 ton per axle. Usually there are four axles under single vehicle, but special vehicles for heavy cargo are also utilised e.g. twenty axle vehicles for transport of transformers. Trains are composed by electric/diesel multiple units or by locomotives and coaches for passengers or by locomotives and wagons for freight.

Both infrastructure and trains, in case of passenger trains, are required to be prepared to serve persons with reduced mobility including different kinds of disabilities as well as persons traveling with infants and/or small children as well as persons having communication challenges.

Figure 37. Railway infrastructure in Gdansk, Poland (photo MPawlik)

Railway – short legal overview

Requirements for railways are defined by two dedicated directives:

- railway interoperability directive (presently (UE) 2016/797) with which eleven Technical Specifications for Interoperability (TSIs) are associated – see chapter 5.1.2, and

- railway safety directive (presently (UE) 2016/798) with which six Common Safety Methods (CSMs) are associated – see chapter 5.1.3.

The TSIs as well as the CSMs are binding directly, however general rules which are defined in the quoted directives are implemented in each Member State of the EU in a national regulatory framework. Usually in a form of Railway Transport Act.

However, construction works are to be performed under general construction regulations and individual construction products have to respect rules established under Regulation (EU) No 305/2011.

Railway – short info about current and future trends

1. Railways are introducing new propulsion solutions e.g. hydrogen cells.

2. Railways are trying to dedicate lines for high speed passenger traffic and for freight traffic.

3. Railways are speeding up – more and more lines are constructed for 350 km/h. This is a maximum speed for which railways can claim that all the requirements are already defined by the directives, TSIs and CSMs and railway standards.

4. Railway traffic is not homogenous. However automatic train operation is being introduced. Currently utilised ETCS on-board installations (baselines 2.3.0.d, 3.4.0, and 3.6.0) intervene when trains are running in a way that without intervention would lead to exceeding maximum speed limit or running beyond movement authority. Works dedicated to introduction of the semi-automated train operation STO on the basis of the TSIs to be published in 2022 as well as of the unattended train operation UTO on the basis of the TSIs to be published in 2025 are ongoing. They involve the European Union Agency for Railways of the European Union as well as industrial partners associated within UNIFE as well as European railway companies. Overview of the functionalities which have to be ensured without involving railway on-board staff is shown in Table 3.

4.1.1.4 Unconventional guided transport systems (UGTS) technical solutions and regulatory framework overview

UGTS – short technical overview

Unconventional guided transport systems infrastructure frequently differs from systems to system as usually such systems serve only precisely defined relationships. UGTS infrastructure is composed by engineering structures & tracks (bridges, viaducts, tunnels) utilising both ballasted and slab tracks frequently with steel ropes or sprocket wheels, stations with platforms, escape paths and corridors, trackside mounted propulsion, simplified signalling especially when vehicles going in different directions use the same track which is rather common, emergency communication including equipment available for passengers along escape routes.

UGTS systems frequently have propulsion trackside. Moreover, they are frequently serving significant vertical differences. Therefore, such systems utilise dedicated vehicles which fit only to precisely defined infrastructure. However also such vehicles frequently need to be prepared for persons with reduced mobility. Usually, UGTS systems serve relatively short distances. Toilets may be accessible only trackside, but emergency push button certainly should be accessible for short person and/or person on a wheelchair.

Table 3. Grades of automation

Basic functions of train operation		On-sight train operation TOS	Non-automated train operation NTO	ETCS baseline 2.3.0.d 3.4.0/3.6.0	Semi-automated train operation STO	ETCS system TSI 2022	Driverless train operation DTO	Unattended train operation UTO	ETCS specifications to be ready in 2025
		GoA0	GoA1		GoA2		GoA3	GoA4	
Ensuring safe movement of trains	Ensure safe route	X (points command/ control in system)	S	S	S	S	S	S	S
	Ensure safe separation of trains	X	S	S	S	S	S	S	S
	Ensure safe speed	X	X (partly supervised by system)	S	S	S	S	S	S
Driving	Control acceleration and braking	X	X	braking S accelerating X	S	S	S	S	S
Supervising guideway	Prevent collision with obstacles	X	X	X	X	X	S	S	S
	Prevent collision with persons	X	X	X	X	X	S	S	S
Supervising passenger transfer	Control passengers doors	X	X	X	X	X	X or S	S	S
	Prevent injuries to persons between cars or between platform and train	X	X	X	X	X	X or S	S	
	Ensure safe starting conditions	X	X	X	X	X	X or S	S	S
Operating a train	Put in or take out of operation	X	X	X	X	X	X	S	S
	Supervise the status of the train	X	X	X	X	X	X	S	S
Ensuring detection and management of emergency situations	Perform train diagnostic, detect fire/smoke and detect derailment, handle emergency situations (call/evacuation, supervision)	X	X	X	X	X	X	S and/or staff in OCC	S and/or staff in OCC

NOTE
X = responsibility of operations staff (may be realised by technical system).
S = realised by technical system.

NOTE Table taken from IEC 62267:2009 with added columns describing different ETCS (European Train Control System) baselines associated with non-automated train operation NTO, semi-automated train operation STO and unattended train operation UTO.

Figure 38. Unconventional transport system infrastructure in Napoli, Italy (photo MPawlik)

UGTS – short legal overview

Legal framework is system type and country dependent. Disregarding requirements and verifications regarding transportation capabilities, construction works are to be performed under general construction regulations and individual construction products have to respect rules established under Regulation (EU) No 305/2011.

UGTS – short info about current and future trends

Some UGTS systems require drivers, however new solutions being constructed are more and more supervised by operator located trackside or autonomous. At the same time social changes more and more show, that security related equipment e.g. for detection of: left luggage, which might be full of explosives, presence of unauthorised persons in restricted areas, which might be associated with terrorist attack or suicide. Such systems have to be analysed also against cyberattacks taking into account that availability of different technologies is changing over time and transport systems which were accepted as properly protected may be in danger after few years as transport systems are frequently constructed for thirty years or longer while electronic programmable solutions are changing every few years.

4.1.1.5 Hyperloop obvious challenges

Hyperloop obvious technical challenges can be summarised as follows:

1. tubes (incl. creation and keeping vacuum)
2. guideways (incl. degraded modes)
3. stations (entering/leaving low pressure environment)
4. traction power supply
5. vehicles/pods
6. safety, security, cybersecurity

Hyperloop obvious legal challenges can be summarised as follows:

1. interoperability approach definition and legal enforcement
2. defining appropriate amount of regulatory and standards framework
3. preparation of standards and regulations and legal enforcement

4.1.2 Railway transport system interoperability

For many years the railway systems in the various Member States of the European Union have developed independently of each other, using different technical solutions. This diversity makes it more difficult for railway undertakings to provide services and causes them to incur higher operating costs (e.g. for the purchase and maintenance of different rolling stock).

The implementation of interoperability, and therefore the harmonization of technical requirements at European Union level, is the result of the adoption of Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community, which was replaced by Directive 2016/797 of 11 May 2016. According to the provisions of this Directive, interoperability means the ability of the railway system to ensure the safe and uninterrupted passage of trains meeting the required level of performance.

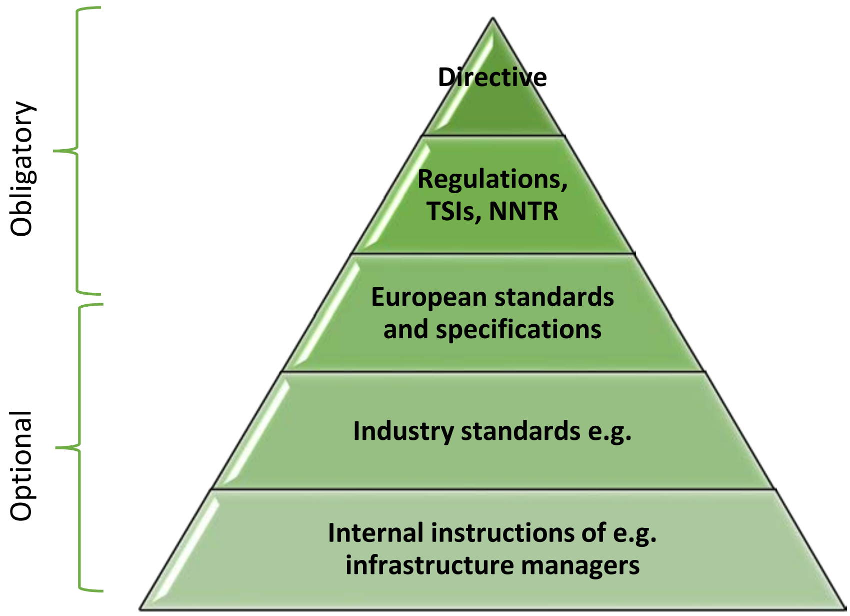


Figure 39. Relationship between different legal and formal requirements (Source: own elaboration based on the European Union Agency for Railways TSIs Guidelines)

Directive 2016/797 defines the subsystems that contribute to the railway system and defines essential requirements for them. Following structural and functional subsystems are defined in Table 4.

Table 4. Structural and functional subsystems

Structural subsystems	Functional Subsystems
Infrastructure Energy Track-side control-command and signalling On-board control-command and signalling Rolling stock	Railway traffic operation Maintenance Telematics applications for passenger and freight services

In addition, the structure of the railway system distinguishes:

- interoperability constituents,
- interfaces, which are the links between the subsystems.

The interoperability constituents are also assessed and certified. In addition, the interoperability constituents shall be verified and assessed as part of the assessment of the subsystems concerned.

The detailed requirements for each subsystem are defined in the so-called Technical Specifications for Interoperability (TSIs). These documents define not only the requirements for the subsystem in question, but also the requirements related to the interfaces to the cooperating subsystems and the requirements for interoperability constituents. The first set of TSIs defining the requirements for the European high speed rail system was published in 2002. Since January 2005, specifications defining the requirements for rail subsystems have been in force without distinguishing between the high-speed and conventional networks and without distinguishing between the European network. TSIs apply to the whole railway system and consequently to all rail investments made and all types of rolling stock purchased. The Technical Specifications for Interoperability are characterised by a common structure. Each specification has seven chapters and annexes. The requirements for subsystems are defined in Chapter 4 and for interoperability constituents in Chapter 5. The TSIs also describe so-called 'open points', areas that should be regulated for the single market but are not yet. Therefore, national requirements apply to open points.

According to the general approach of the European Union, products must meet the essential requirements specified for them. This approach is also applied in the railway sector. The fulfilment of the essential requirements by railway products (including interoperability constituents) and subsystems guarantees their interoperability. The following essential requirements apply to rail transport:

- Safety
- Reliability and availability
- Health
- Environmental protection
- Technical compatibility
- Availability

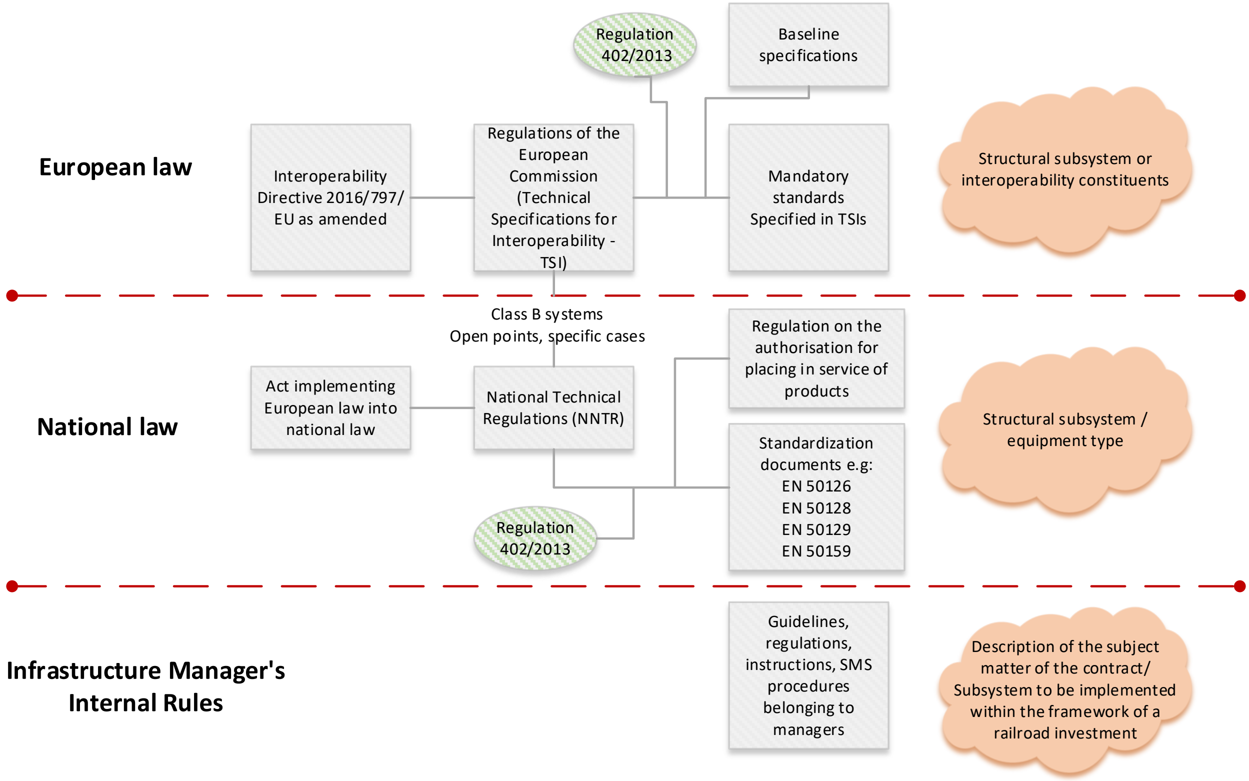


Figure 40. Legal requirements in the railway transport commissioning processes (Source: own elaboration based on the European Union Agency for Railways TSIs Guidelines)

The description of the adopted essential requirements is divided into parts applicable to the railway system as a whole and parts applicable to the individual subsystems. The complete set of all descriptions of the essential requirements is contained in Annex III to Directive 2016/797 of 11 May 2016. A directive is a legal act addressed to the member states and requires what is called a process of implementation into the domestic legal order of the country. Directives are mostly addressed to all member states. Member States implement directives by either creating or modifying existing pieces of national law as appropriate. As a result, all national laws, such as statutes or regulations, remain subject to EU regulations.

TSIs organise requirements and therefore also refer to normative documents. The Directive itself states that TSIs may refer to normative documents or parts of normative documents where this is necessary to achieve interoperability. In addition, it states that the use of these documents is compulsory as far as the use of the TSI is compulsory. Standards which are referenced in TSIs therefore become mandatory.

TSIs do not indicate harmonized standards developed in conjunction with the Interoperability Directive. Harmonized standards are European Standards developed by the European standardization organisations in support of Union harmonisation legislation, adopted on the basis of requests for standardization from the European Commission after consultation with the Member States. Harmonized standards are part of European Union (EU) law, but their application is voluntary. However, meeting the essential requirements for a specific product is paramount. Products manufactured in accordance with harmonized standards benefit from a presumption of conformity with the relevant essential requirements of directives, regulations or other EU legislation. The use of harmonized standards facilitates the fulfilment of the essential requirements, but is not mandatory. The exceptions are standards that are referenced in TSIs.

The harmonization of technical requirements of the European Union railway system is carried out in two ways. Firstly, all Member States are obliged to apply the same technical requirements contained in special legal acts of the European Union - the Technical Specifications for Interoperability. Secondly, Member States are obliged to reduce their national technical requirements.

Implementing interoperability is a gradual process planned over many years. Ensuring that rolling stock and infrastructure conform to Technical Specifications for Interoperability is, in principle, only required when they are upgraded or renewed. The period before all railway lines and vehicles are interoperable is regarded as a transition period during which not only European regulations but also, to a certain extent, national regulations have to be applied. All countries have been obliged to identify and make available the national requirements which must be complied with. National requirements are a list of standards assigned to specific systems that must be met in order for a product to be placed in service. These National Notified Technical Rules (NNTR) are defined by the National Safety Authority (NSA), which is also the authority responsible for issuing all authorisations to put on the market (APOM). In terms of national requirements, also the European Union Agency for Railways aims to harmonize the approach, which was introduced with the publication of Directive 2016/797 of 11 May 2016. According to the mentioned directive, the assessment of conformity of products with national regulations is carried out by an authorised Designated Body (DeBo), which is an independent assessment body recognized for its competence. DeBo assesses and verifies the conformity of all phases (design, production, operation and maintenance) in accordance with the applicable national regulations. On the other hand, verification of conformity of products with European requirements in order to confirm interoperability is carried out by Notified Bodies (NoBo - Notified Body), which must first be accredited and then authorised and reported on NANDO (New Approach Notified and Designated Organisations) websites. Thus, full compliance with the essential requirements - as assessed by a NoBo - ensures safe interoperability across the entire European network, i.e. system or product interfaces that are fully compatible to work with other products or systems without any restrictions.

In order to prove compliance with the TSI and ensure that the essential parameters and requirements are met, verification must be demonstrated by means of detailed documentation (design documentation, test results, verification results and any evidence of conformity), which must be verified by a Notified Body (NoBo). NoBo works in all phases of the project: from design to testing and commissioning. Through independent assessment of the conformity of subsystems and constituents with the TSI, the NoBo certifies interoperability by issuing an EC certificate of conformity (for constituents) or an EC certificate of verification (for subsystems).

4.1.3 Railway transport system safety add-on

In the Railway Interoperability Directive, which is described in the above section in the essential requirements for interoperability we can find a reference to the essential requirement "safety".

Safety in EU law is very widely described in the Railway Safety Directive[8] and related documents. Data compiled from website www.eur-lex.europa.eu on November 2, 2021 show following number of legal acts related to the Safety Directive by their type:

No	Nature of the link between the legal act and the Directive	Number of legal acts
1.	Directive is the legal base	13
2.	Implementing acts based on the Directive	8
3.	Delegated acts based on the Directive	5
4.	Documents citing this document	82
	Σ	108

As can be seen from above, the Railway Safety Directive is the basis for all railway safety legislation and is a collection of more than 100 regulations aimed at ensuring the development and improvement of the Union's railway system and improving market access for rail transport services, by:

a) harmonizing the regulatory structure in the Member States;

b) defining responsibilities between the actors in the Union rail system;

c) developing common safety targets ('CSTs') and common safety methods ('CSMs') with a view to gradually removing the need for national rules;

d) setting out the principles for issuing, renewing, amending and restricting or revoking safety certificates and authorisations;

e) requiring the establishment, for each Member State, of a national safety authority and an accident and incident investigating body;

f) defining common principles for the management, regulation and supervision of railway safety.

Taking into account the content of legal acts related to the Railway Safety Directive for the purpose of this project the following common safety methods (CSMs) will be described.

Currently in European Union legal system we can find 5 CSMs and one valid until 30th October 2025 concerning:

1. criteria for safety management systems;
2. risk evaluation and assessment methods;
3. monitoring;
4. supervision by national safety authorities;
5. assessment of achievement of common safety targets.
6.

[8] Directive (EU) 2016/798 Of The European Parliament And Of The Council Of 11 May 2016 on Railway Safety

Criteria for safety management systems.

For the first time, the criteria for assessing safety management systems for a national safety authority were defined in 2010 in two Commission Regulations 1158/2010 and 1169/2010 dedicated to the assessment of safety management systems of a railway undertaking and an infrastructure manager. According to the current 4th railway package, the purpose of Regulation (EU) No 2018/762 in force in this regard is to define the requirements to be met by infrastructure managers and railway undertakings, compliance with which is supervised by the national safety authority. The applicable requirements for functioning safety management systems can be divided into the following areas:

1. organisation concerning the activities of the whole organisation,

2. leadership of the principles on which top management should be involved in the organisation to maintain or improve safety and actions to ensure a high level of safety and definition of the principles for the whole organisation, the roles and responsibilities of individuals in the organisation, the way top management communicates with employees,

3. planning activities aimed at minimizing the organisation's exposure to risks,

4. documentation of the system, system of communication in the organisation, management of employees' competencies,

5. operational activity of the organisation including change management, crisis management, cooperation with contractors and suppliers,

6. assessment of the organisation's performance including monitoring, internal audits, management reviews,

7. improvement consisting of drawing conclusions from the occurring events and continuous learning of the organisation.

Properly implemented safety management system allows you to combine many aspects of activity to ensure the organisation's ability to conduct it in a safe and effective manner. Only properly combined above mentioned elements will allow to properly demonstrate compliance with international and national regulations, standards, sector and business requirements. It also allows for the proper application and results of risk assessment and the application of good practices in all aspects of the business. To ensure that the objectives are met, the safety management system should be integrated into the organisation's business processes. Establishing a safety management system requires an organisation to understand the risks it must control, the regulatory framework in which it operates, and to have a clear vision of the expected outcomes. Properly functioning safety management system as a coherent whole within an organisation is shown in Figure 41.

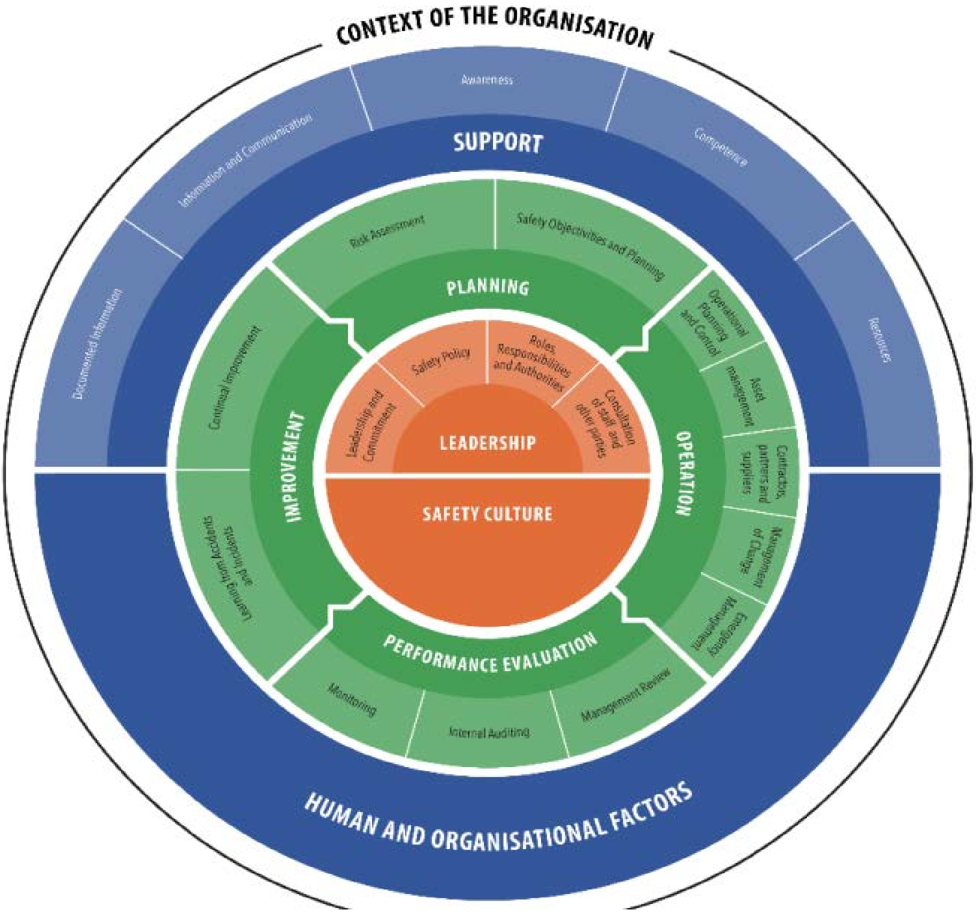


Figure 41. Comprehensive visualization of the railway Safety Management System [Source: Guidance for safety certification and supervision]

Risk evaluation and assessment methods

In rail transport, the risk management process is defined in the Commission Regulation (EU) on a common safety method for risk evaluation and assessment[9]. The purpose of this regulation is to standardize the approach to risk management and management of changes by entities operating in EU countries. Using the approach to the risk management process described in the Regulation allows harmonization of the methods used by the entities involved in the development and operation of the railway system to identify and manage risks. In addition, it unifies the methods of demonstrating compliance of the railway system with safety requirements and indicates the requirements to be met by the entities supervising the application of the risk management process.

The risk management process used consists of the following elements:

[9] Commission Implementing Regulation (EU) no 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment and repealing regulation (EC) no 352/2009.

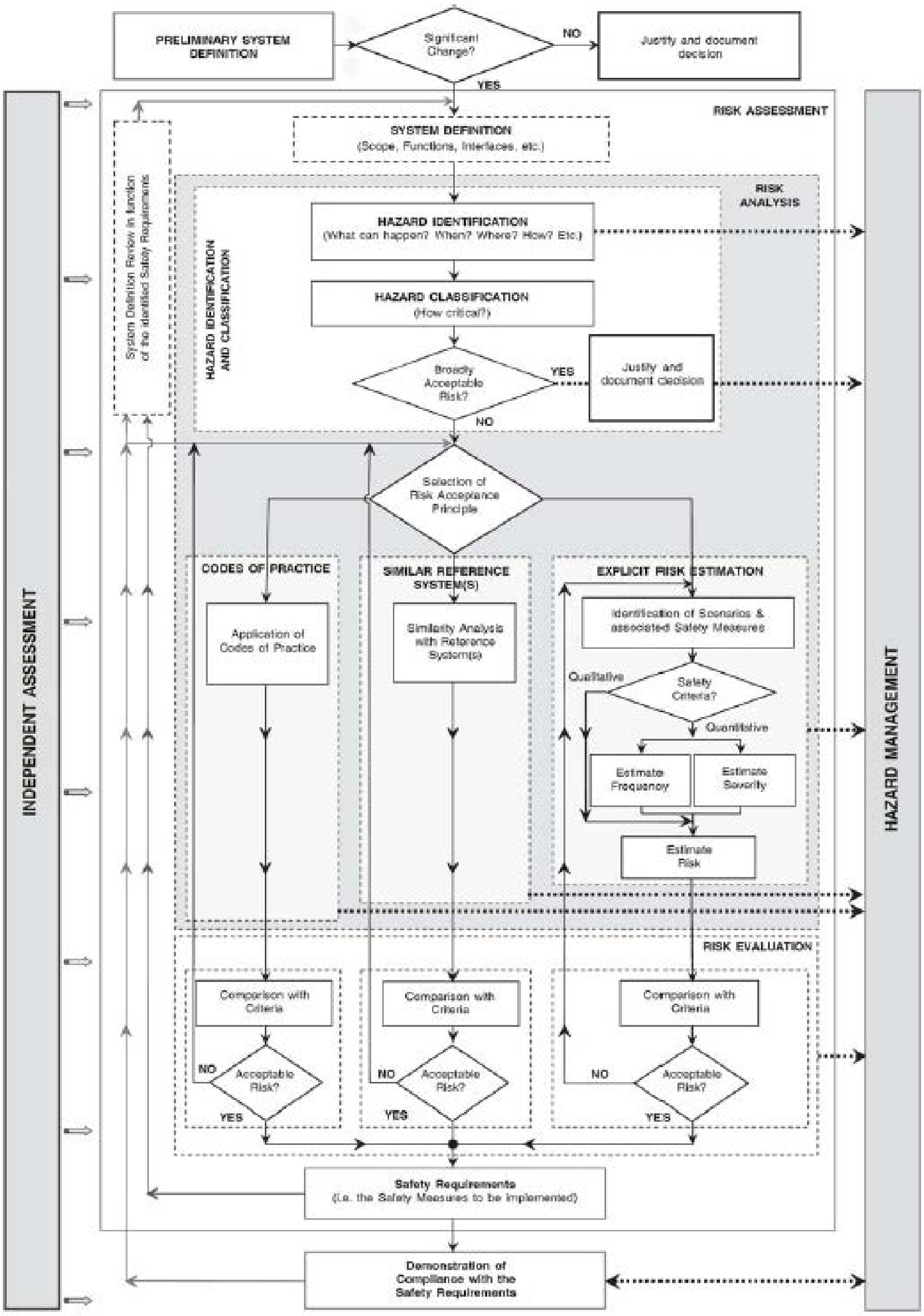


Figure 42. Elements of risk management process according to CSM-RA regulation[10]

[10] Commission Implementing Regulation (EU) no 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment and repealing regulation (EC) no 352/2009.

Monitoring

Common safety methods for monitoring for infrastructure managers and railway undertakings are defined in a dedicated Commission Regulation[11]. The establishment of a Common Safety Method (CSM) for monitoring serves to effectively manage the safety of the railway system during the organisation's operation and maintenance activities.

Implemented by infrastructure managers and railway undertakings, it is linked to the risk management process and consists of the following elements:

1. identification of strategy, priorities and monitoring plan(s);

2. collection and analysis of information;

3. development of an action plan in the event of unacceptable non-compliance with the requirements set out in the management system;

4. implementation of the action plan, if such a plan has been developed;

5. evaluation of the effectiveness of the measures provided for Monitoring means the arrangements put in place by infrastructure managers or railway undertakings to control the correct application and effectiveness of their safety or maintenance management system. Through the monitoring process the organisation can monitor the achievement of its indicator levels and identify areas for improvement.

Oversight by national safety authorities

The Common Safety Methods established by dedicated Regulation 2018/761 with regard to supervision by National Safety Authorities describe the principles to be followed by National Safety Authorities in the different European Union countries in the process of granting safety authorisations and safety certificates and their supervision, being the assessment of achieving those safety targets undertaken by the European Agency for Railways. Particular emphasis is placed on describing the supervision process, the competence of the personnel involved in the supervision process, the criteria to be followed by the national safety authority in taking its decisions and the rules for exchanging information between national safety authorities.

Assessment of achievement of common safety objectives

The common safety targets defined in the Railway Safety Directive are clearly defined in the dedicated Commission Decision 2009/460 concerning the adoption of a common safety method for assessment of achievement of safety targets[12]. Decision unambiguously indicates to all European Union countries the principles according to which they are to use statistical sources and the methodology of calculating common safety targets and relating them to national reference values for individual members in 6 risk categories: passengers, employees, level crossing users,

[11] Commission Regulation (EU) No 1078/2012 of 16 November 2012 on a common safety method for monitoring to be applied by railway undertakings, infrastructure managers after receiving a safety certificate or safety authorisation and by entities in charge of maintenance.

[12] Commission Decision of 5 June 2009 on the adoption of a common safety method for assessment of achievement of safety targets, as referred to in Article 6 of Directive 2004/49/EC of the European Parliament and of the Council.

other, unauthorised persons on railway premises and whole society. Defining uniform risk categories and indicators according to which they are determined allows for objective comparison of safety levels in individual member states. This approach enables the European Commission to raise the required level of safety in individual countries by periodically publishing a safety target value for each risk category.

Necessity of the safety add-on CSMs

Analysing the safety oversight needs of the ongoing project, we propose limiting the current 5 CSMs to the three that we consider most relevant here:

1. on criteria for safety management systems,

2. methods of risk evaluation and assessment,

3. monitoring.

The reduction of the CSMs in the area of hyperloop technology is due to the need to centralize the oversight of a part of the rail system at the central level of the European Union in the European Union Agency for Railways. Supervision of safety in this area should not be handed over to individual Member States. The European Union Agency for Railways should have two or three teams of technical experts carrying out its activities in the field of infrastructure and rolling stock used.

4.1.4 Formal standardization framework for a new transport mode

The inclusion of standardization issues in the hyperloop vacuum rail project provides an opportunity to enhance coherency and compatibility of the solutions being applied for different purposes through the use of standards and procedures. Standards help to coordinate the flow of processes and work, disseminate knowledge and support innovation. Being prepared in due time standards respond to rapidly evolving markets and their needs, and therefore shall be treated as a tool supporting different stakeholders, especially industrial companies. Standards emerge as a result of demand and the need for legal regulation of the industrial processes. Innovative transport solutions, such as the hyperloop, require establishing international framework for the development of dedicated standards. Stakeholder collaboration on a common roadmap towards standards and regulations shall lead to faster deployment of technology.

International, European and National Standardization Organisations

According to the definition, a standard is a document adopted by consensus and approved by a mandated organisational unit, setting out principles, guidelines or characteristics relating to different activities or their results and aiming to achieve an optimum degree of order in a specific area.

The standards development process at international, European and national level is overseen by following organisations:

- on international, global level by:

- ISO International Organization for Standardization – a non-governmental organisation based in Geneva, established in 1947, for which Polish Standardization Committee PKN is one of the founding members;
- IEC International Electrotechnical Commission – a non-governmental organisation also based in Geneva, established in 1906.

An international standard is a document establishing, for common and repeated use, certain technical specifications adopted and approved by the international standards organisations ISO - International Organisation for Standardization and/or IEC - International Electrotechnical Commission.

In international standardization organisations (ISO, IEC), business and industrial companies can participate in the standards development process by submitting experts to Working Groups (WGs) under Technical Committees (TCs) or Technical Subcommittees (SCs) in which national standardization bodies are active members (having so called "P-membership") and actively participate in the work of the TC or S.C. by giving opinions on working documents, vote on draft standardization documents and attend meetings.

The "O-membership" meaning observers allows access to working documents and the possibility to attend meetings of the technical body concerned but only as an observer.

- on European level, wider than EU, but linked with EU legislative processes by three European Standards Organisations (ESOs), namely by:
  - European Committee for Standardization CEN (*fr. Comité Européen de Normalisation*);
  - European Committee for Electrotechnical Standardization CENELEC (*fr. Comité Européen de Normalisation Électrotechnique*); and
  - European Telecommunications Standards Institute ETSI.

As in the case of the development of international standards, stakeholders create new European standards by participating in the different Technical Committees (TC) and Subcommittees (SC) of CEN, CENELEC and ETSI. Each national entity declares its participation in the work of each TC and SC or announces its lack of interest.

Member States of the European Union are obligated to participate in a number of TCs and SCs, as they are associated with EU legislative processes. As a result one of the requirements to be fulfilled before entering EU is to become a full member of CEN, CENELEC and ETSI. For instance Poland become a full member from the 1rst January 2004 to become a full member of the EU from the 1rst May 2004.

- on national level by National Standards Organisations (NSOs), e.g. by Polish Committee for Standardization PKN (*pl. Polski Komitet Normalizacyjny*).

At national level, the standardization process is managed by the National Standards Bodies NSOs, which adopt and publish national standards. National standardization bodies also introduce all

European standards as identical national standards and, at the same time, withdraw any national standards that do not comply with the new ones. Almost every country has its own standards institute.

In the EU, most standards are created directly as EN standards and then reflected as national standards at national level as DIN-EN in Germany, as British Standards BS-EN, as Polish Standards PN-EN, as Spanish Standard UNE-EN, etc. In case standards are identical to ones accepted by international Standards Organisations they have enhanced abbreviations in front e.g. PN-EN ISO 9001:2015-10. The year and month given after colon differs for different countries as it reflects moment when standard was adopted by specific NSO.

Harmonized standards

Harmonized standards are a separate category of European standards. These are developed by one of the European standardization organisations in response to a standardization mandate from the European Commission or possibly European Free Trade Association EFTA. They account for approximately 20% of all standards. Harmonized standards constitute base for demonstration that products or services comply with technical requirements set out in the relevant EU legislation e.g. in EU Railway Interoperability Directive. The scale of harmonisation strongly depends on industrial branch. For instance, there are nearly 200 EN railway standards harmonized with EU Railway Interoperability Directive, which makes about 80% of all EN railway specific standards. The way how standards have to be developed in order to be acceptable as harmonized standards in the future is shown in Figure 43.

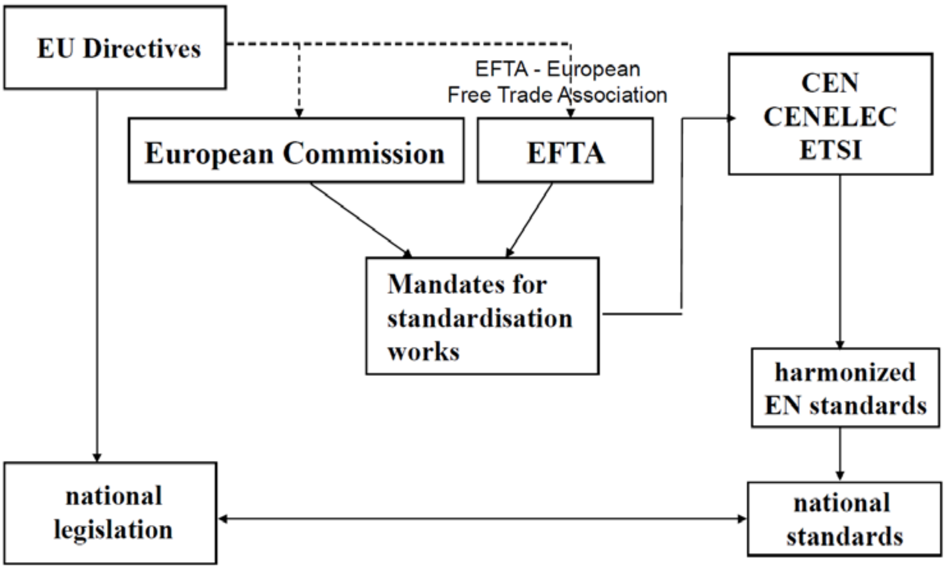


Figure 43. European harmonized standards development process (Source: CEN/CENELEC standardization guidelines)

Compliance with a European harmonized standard guarantees compliance with the applicable requirements set out in EU harmonisation legislation, including safety requirements. The use of harmonized standards is voluntary, and a manufacturer may use any other technical solution to demonstrate that his product meets the essential requirements. European standards are used as instruments to ensure, among other things, the interoperability of networks and systems, the proper functioning of the single market, a high level of consumer and environmental protection and greater innovation.

The European Standardization Organisations (ESOs) cooperate with each other at many levels. This cooperation results in the CEN-CENELEC Joint Technical Committees (CEN-CLC/JTC). The collaboration ensures that there is no duplication of work when the electrotechnical and non-electrotechnical sectors have common technical topics and that the interests of each party are taken into account. Such approach has been adopted for JTC 20 dedicated for hyperloop.

4.1.5 Goals and structure of the hyperloop CEN-CENELEC/JTC 20

A Joint Technical Committee (JTC 20) has been established in the year 2020 to provide the basic requirements for the hyperloop system. This is a joint technical committee of the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC), which was formed at the request of the start-up hyperloop companies (Hardt, HyperPoland, Transpod and Zeleros) and the national standards organisations of the Netherlands and Spain – NEN and UNE.

The most important objective of the JTC 20 technical committee is to define, establish and standardise the methodology and framework governing the hyperloop transport systems and to ensure coherency and consistency of the standards and products taking first of all safety into account. The standardization of hyperloop technology will require the definition of all its systems and subsystems, as well as the definition of general requirements for passenger and freight transport.

It is believed, that defining such standards will enable seamless travel across Europe as well as on other continents. In contrast, the lack of common requirements will result in hyperloop systems with different technical parameters (e.g. tube diameters). This will result in significantly longer travel times (the need to change between different vacuum transport systems) and higher operating costs for transport of passengers and/or freight. In terms of safety, the standards will allow the systems and subsystems of the hyperloop technology to be developed/designed taking into account the occurrence of possible risks. The common solutions will also provide the means and processes to identify, prevent and eliminate these risks during the design, production and testing phase of the hyperloop system.

The introduction of standardized interfaces between systems and subsystems will ensure their better interaction and a safer operation of hyperloop technology, for instance minimising the risks associated with failures.

The JTC 20 committee is divided into working groups whose work focuses on various components of the future hyperloop systems, including vehicles, pipe and associated infrastructure and traffic control. JTC 20 includes representatives from hyperloop developers, standardization bodies, development institutes and industrial companies. Due to the importance of coherency and compatibility, the working groups have identified areas on which work has to be started already now. Key working areas include:

- operating pressure, including the safety implications of a low pressure environment (e.g. need for evacuation, spread of fire and smoke);
- the airtightness and sealedness of the vehicles and infrastructure, including the proper functioning of doors and air locks under various conditions;
- the specification of the pipe infrastructure, including the diameter and the ability of the different vehicles to function within the same system, the resistance to weather and geological conditions;
- traffic control and management, including common communication system ensuring exchange of data between vehicles and control posts;
- emergency evacuation, including emergency procedures, frequency of emergency exits and presence of support columns);
- control command systems supervising vehicle running along infrastructure;
- influence on external environment;
- environmental conditions inside passenger vehicles, including but not limited to: temperature, ventilation, lighting, noise;
- external forces acting on passengers, including, inter alia, maximum accelerations;
- requirements for hyperloop station design and technical facilities.

4.1.6 Hyperloop transport systems interoperability and safety

The key working areas does not constitute clear picture what has to be defined. What has to be defined earlier, and what has to be dependent on already taken decisions. There is no clear roadmap to be followed to ensure in case of hyperloop appropriate hyperloop interoperability referring to railway interoperability rules presented in subclause 5.1.2 and appropriate hyperloop operational safety referring to railway safety rules presented in subclause 5.1.3.

In order to create a clear roadmap to operability and hyperloop operational safety it is necessary to start with broad agreement on operability which will be similar but not equal to railway interoperability. Following operability for hyperloop definition is proposed taking into account results of the above mentioned analyses and the EU Railway Interoperability Directive "interoperability" definition.

Operability for hyperloop definition

'Operability' for hyperloop means the ability of a hyperloop system to allow the safe and uninterrupted movement of vehicles/pods and hyper-trains which accomplish the required levels of performance for hyper-infrastructure. This ability depends on all the regulatory, technical and operational conditions which must be met in order to satisfy the essential requirements.

Key questions to be answered to fully clarify operability and then define requirements for hyperloop technical solutions

1. Do we assume different categories of hyper-lines?

It is rather the case that we can have different categories of hyper-lines.

2. How will we construct stations in relations to low pressure?

There are different possibilities influencing especially use of front or side doors in vehicles/pods and need for synchronization with platform doors.

3. Will we create trains out of vehicles/pods?

Growing speed requires enlarging headways understood as distance between vehicles running indecently one after another disregarding whether it is measured in space or in time. Growing headway decreases capacity and therefore creation of hyper-trains out of vehicles/pods should be taken into account.

4. Is safety enough?

Safety has to be understood in a wide way. We suggest taking into account safety, security and cybersecurity as well as their functional integrity.

5. How widely we should take into account degraded situations?

After an accident it is usually possible to point safety measures and procedures which would prevent occurrence of the accident or minimise its consequences. It is however impossible to prevent occurrence of all imaginable situations. Even applying at the same time ALARP principle (stating that ensuring risk has to be “As Low As Reasonably Practicable”, which is legally required in UK), GAME principle (stating that transport system “should be globally as safe or safer than the existing system accepted as a reference”, which is legally required in France) and MEM principle (accepting the same risk to an individual independently of any technical system calculating it on the basis of the “Minimum Endogenous Mortality” based on the natural death rate of human beings of specified age, which is legally binding in Germany), all together do not ensure one hundred percent protection against accidents13.

Detail answers would lead to different possible approaches to operability for hyperloop. Four possible approaches are shortly described and visualised below.

[13] The ALARP, GAME and MEM principles are described in annex A of the EN standard 50126-2:2017.

Possible hyperloop interoperability approaches:

1. Full interoperability even wider than in case of railways,

- Security and cybersecurity have to be taken into account,
- Some decisions will probably block further development of the technology.

2. Standardized infrastructure and traction vehicles but not hauling vehicles:

- Wide possibilities for constructions of vehicles in relations to different needs for different types of cargo and for regional and long distance passenger traffic.

3. Only self-propelling vehicles/pods in normal operation:

- Trains may be created due to capacity challenges.

4. Subdividing vehicles into capsules/containers & traction/guiding frames to enable wide hyperloop flexibility:

- It is possible to define solutions appropriate for different purpose keeping full interoperability between vehicles and infrastructure.
- such approach widely opens intermodality based on transport containers.

The four possible proposed operability approaches for hyperloop are shown in Figure 44 to Figure 47.

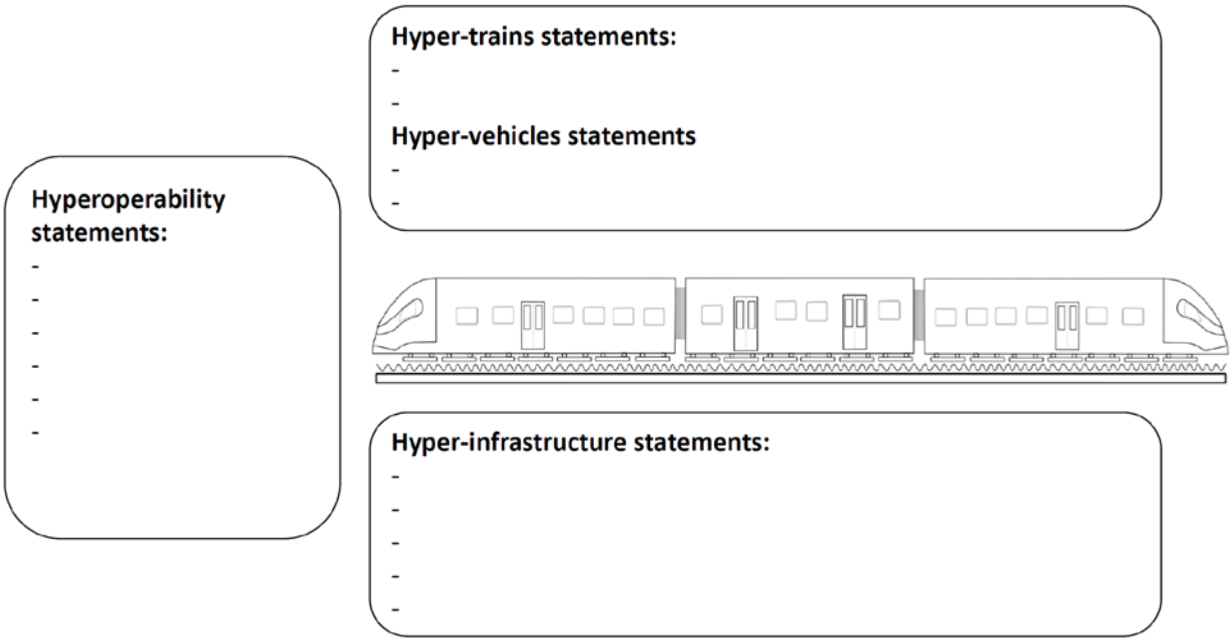


Figure 44. Visualisation of the full legal enforcement of precise requirements (Source: own elaboration)

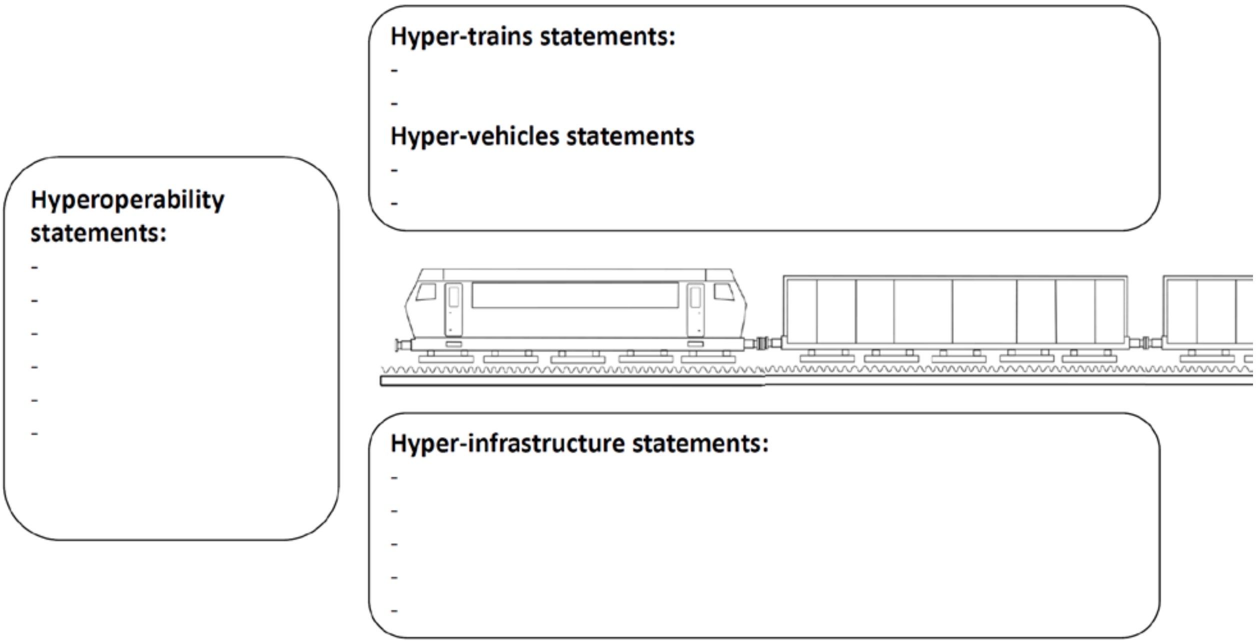


Figure 45. Visualisation of introducing not standardized hauling vehicles (Source: own elaboration)

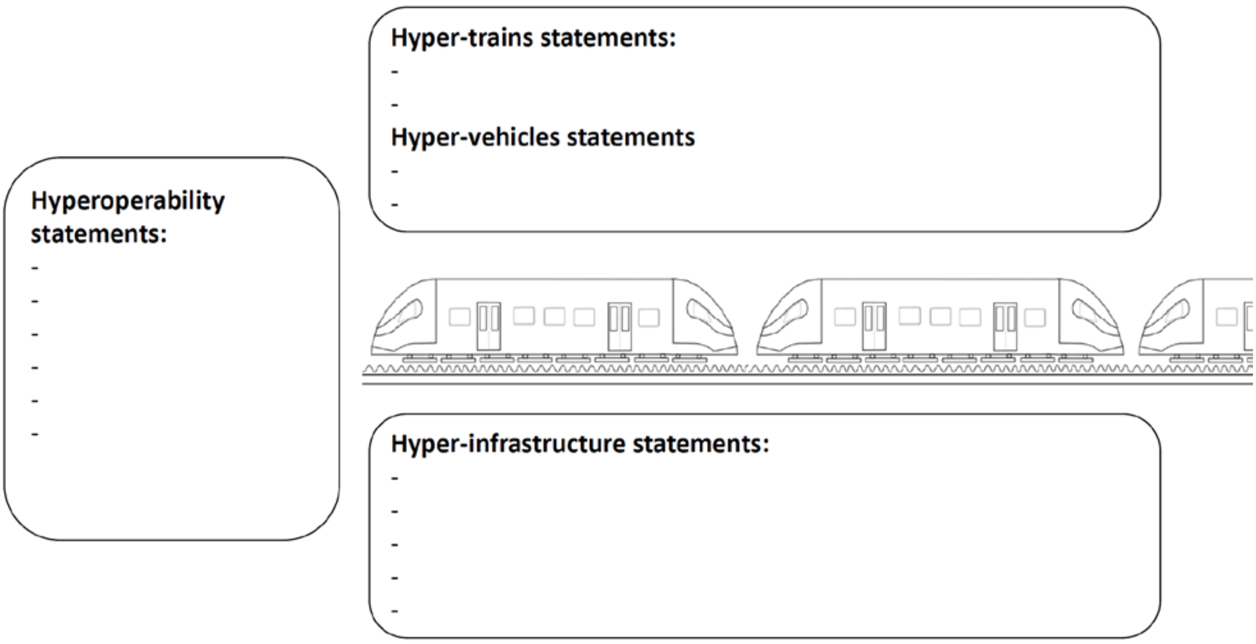


Figure 46. Visualisation of introducing compositions of self-propelling vehicles/pods (Source: own elaboration)

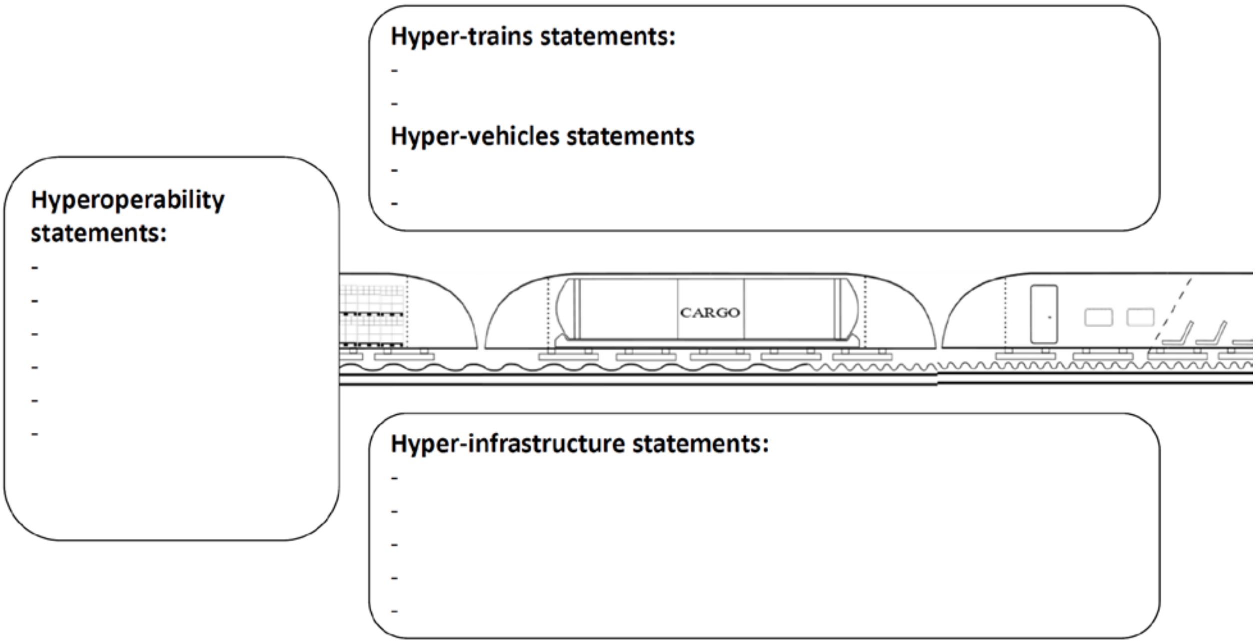


Figure 47. Visualisation of introducing hyperloop vehicles subdivision into capsules/containers & traction/guiding frames running on not standardized infrastructure (Source: own elaboration)

Accepting one of the proposed approaches would allow taking decisions regarding required standards defining rules, procedures, technologies and interfaces. Preparation of some standards would require precise defining of the chosen technical solutions, and for that research and development projects are expected to be the best tool. Presently ongoing research and development works dealing with exact technical solutions risk that they may be legally not acceptable when finally elaborated.

Necessity of the safety add-on CSMs.

It is important to see the operational safety framework already when working on technical solution on the basis of the essential requirements defined specifically for hyperloop. As existence of different kinds of companies e.g. infrastructure managers and hyperloop undertakings is not foreseen the amount of Common Safety Methods CSMs may be restricted. However following three CSMs seems to be necessary:

1. **CSM regarding acceptance of hyperloop operators and safety supervision** by National Safety Authority. Both hyperloop infrastructure and hyperloop transport services shall be taken into account, and both internal safety monitoring and external safety supervision shall be taken into account, and both safety and security shall be taken into account. It is proposed to take into account also cybersecurity and the functional integrity of the safety, security and cybersecurity.

2. **CSM regarding rules dedicated to verification of the trends in accidents, incidents and events** preceding accidents and incidents. A catalogue of types of accidents, incidents and events needs to be elaborated together with precise definitions as well as precise rules how to verify trends in individual and societal risk at least on the yearly basis.

3. **CSM regarding risk assessment and evaluation for risk acceptance** (CSM RA) is the only one which may stay as it is at the moment. However even in that case a change of the scope of its applicability as well as hyperloop dedicated guidelines are necessary to be elaborated.

4.1.7 Hyperloop assessment and acceptance basic principles

4.1.7.1 Acceptance based on essential requirements

Clear assessment and acceptance basic principles for a new transport mode will be achieved thanks to defining operability of the hyperloop on the basis of the essential requirements. The essential requirements can be defined similarly as for railway in Railway Interoperability Directive in Annex III. The main difficulty will be associated with safety. The aspects which are defined in the directive are quoted below in italic. However, we believe it has to be complemented with security and cybersecurity aspects as well as with comprehensive approach to safety, security and cybersecurity. Proposed adds to essential requirements are bold and blue. Some of them are followed by comments.

Safety in relation to railway system as a complete system is defined as follows:

1.1. Safety
1.1.1. The design, construction or assembly, maintenance and monitoring of safety-critical components, and more particularly of the components involved in train movements, must be such as to guarantee safety at the level corresponding to the aims laid down for the network, including those for specific degraded situations.
1.1.2. The parameters involved in the wheel/rail contact must meet the stability requirements needed in order to guarantee safe movement at the maximum authorised speed. The parameters of brake equipment must guarantee that it is possible to stop within a given brake distance at the maximum authorised speed.
1.1.3. The components used must withstand any normal or exceptional stresses that have been specified during their period in service. The safety repercussions of any accidental failures must be limited by appropriate means.
1.1.4. The design of fixed installations and rolling stock and the choice of the materials used must be aimed at limiting the generation, propagation and effects of fire and smoke in the event of a fire.
1.1.5. Any devices intended to be handled by users must be designed in such a way as not to impair the safe operation of the devices or the health and safety of users if used in a foreseeable manner, albeit not in accordance with the posted instructions.

Add 1. Supervising areas accessible to passengers and bystanders (e.g. escorting passengers) shall ensure adequate detection of hazardous situations and enable appropriate action to be taken.

Comment: It is important to use technical means supporting security. Video monitoring with video stream analysers able to automatically detect e.g. left luggage, aggression, pickpocketing, etc. Luggage screening and x-ray gates are also to be used.

Add 2. Supervising unauthorised areas, rooms, containers and cabinets shall guarantee adequate level of protection against fire, vandals, thieves and unauthorised persons with other bad intentions and the activation of appropriate systems and procedures.

Comment: All working places and technical equipment cabinets has to be protected against unauthorised access e.g. by videophones, electrical locks, etc. with remote control protected against cyber threats. Protection against fire also has to be ensured by remotely controlled equipment e.g. fire and smoke detection systems, automatic fire extinguishing systems. Data from systems ensuring protection against unauthorised access and fire shall be recorded.

Safety in relation to infrastructure is defined as follows:

2.1.1 Safety
Appropriate steps must be taken to prevent access to, or undesirable intrusions into, installations. Steps must be taken to limit the dangers to which persons are exposed, particularly when trains pass through stations.
Infrastructure to which the public has access must be designed and made in such a way as to limit any human safety hazards (stability, fire, access, evacuation, platforms, etc.).
Appropriate provisions must be laid down to take account of the particular safety conditions in very long tunnels and viaducts.

Add 3. Appropriate steps shall be taken to ensure safe pressure lowering and keeping pressure lowered.

Safety in relation to traction power supply is defined as follows:

2.2.1. Safety
Operation of the energy-supply systems must not impair the safety either of trains or of persons (users, operating staff, trackside dwellers and third parties).

Add 4. Protection means has to cover both traction power supply for vehicles/pods and traction power supply for infrastructure equipment with special attention given to lowering pressure and keeping pressure lowered.

Safety in relation to signalling sub-system is defined as follows:

2.3.1. Safety
The control-command and signalling installations and procedures used must enable trains to travel with a level of safety which corresponds to the objectives set for the network. The control-command and signalling systems must continue to provide for safe passage of trains permitted to run under degraded conditions.

Add 5. Safe unattended automatic vehicles/pods operation, of UTO type, supervised remotely have to be ensured taking into account all risks in normal and degraded operation as well as during rescue activities.

Safety in relation to vehicles is defined as follows:

2.4.1. Safety

The rolling-stock structures and those of the links between vehicles must be designed in such a way as to protect the passenger and driving compartments in the event of collision or derailment.
The electrical equipment must not impair the safety and functioning of the control-command and signalling installations.
The braking techniques and the stresses exerted must be compatible with the design of the tracks, engineering structures and signalling systems.
Steps must be taken to prevent access to electrically-live constituents in order not to endanger the safety of persons.
In the event of danger, devices must enable passengers to inform the driver and accompanying staff to contact them.
The safety of passengers boarding and alighting from trains must be ensured. The access doors must incorporate an opening and closing system which guarantees passenger safety.
Emergency exits must be provided and indicated.
Appropriate provisions must be laid down to take account of the particular safety conditions in very long tunnels.
An emergency lighting system having a sufficient intensity and duration is an absolute requirement on board trains.
Trains must be equipped with a public address system which provides a means of communication to the public from on-board staff.
Passengers must be given easily understandable and comprehensive information about rules applicable to them both in railway stations and in trains.

Safety in relation to maintenance is defined as follows:

No requirements in railway interoperability directive.

Add 6. Maintenance has to be based as far as possible on continuously working diagnostic equipment. The IT support for maintenance has to respect cybersecurity especially for interfacing, data transmission and data processing.

Safety in relation to operation and traffic management is defined as follows:

2.6.1. Safety
Alignment of the network operating rules and the qualifications of drivers and on-board staff and of the staff in the control centres must be such as to ensure safe operation, bearing in mind the different requirements of cross- border and domestic services.
The maintenance operations and intervals, the training and qualifications of the maintenance and control centre staff and the quality assurance system set up by the operators concerned in the control and maintenance centres must be such as to ensure a high level of safety.

Add 7. Remote supervision over unattended automatic vehicles/pods operation, of UTO type, have to be ensured taking into account all risks in normal and degraded operation as well as during rescue activities.

Comment: Unattended automatic operation needs to be supervised by an operator located trackside supported by ATS type system (Automatic Train Supervision) forming upper layer over signalling, control command and communication systems. Remote control centre has to be prepared also for ensuring communication with emergency and rescue services as well as public address system for announcements to passengers which are important in case of disturbances.

4.1.7.2 Common safety methods CSMs for hyperloop

Defined above essential requirements will be used for acceptance of new hyperloop systems composed with infrastructure and vehicles. It will be used also in case of delivery of additional vehicles and in case of construction of additional kilometres of infrastructure e.g. extension of a hyperloop line. However, many technical changes being introduced during exploitation will not be require such verification. Therefore, so called common safety methods have to used similarly to that what takes place in case of railway and was proposed at the end of subclause 5.1.6. Therefore, following three CSM methods are proposed:

1. CSM regarding acceptance of hyperloop operators and safety supervision,
2. CSM regarding rules dedicated to verification of the trends in accidents, incidents and events,
3. CSM regarding risk assessment and evaluation for risk acceptance.

It is believed, that such CSMs can be defined on the basis of the CSMs used in railway transport.

4.1.7.3 Defining FIL functional integrity level of safety, security and cybersecurity as an add on to SIL safety integrity level required by RAMS standards

It is necessary to ensure, that hyperloop transport systems are protected also against cyberattacks. Protection in that respect shall be on a level similar to the level of protection against safety risks. In relation to safety all signalling and control command technical solutions are required to follow RAMS standards14 Technical means for protection against security hazards shall also be on a level similar to the level of protection against safety risks. There is a need to ensure coherency of different protections. In that respect it is proposed to use Functional Integrity Level of safety, security and cybersecurity – the FIL concept. It has been defined in 2019 and accepted in Poland for construction of new railway lines serving new airport in Poland in 2021.

Functional integrity levels for safety, security and cybersecurity, the FIL levels, are based on eleven groups of functionalities:

- five dedicated to data transmission based technical means supporting railway traffic safety,

[14] RAMS standards – reliability, availability, maintainability and safety standards – EN 50126-1, EN 50126-2, EN 50128, EN 50129 and EN 50159 which define application of protection against random and systematic failures for railway solutions applicable on twelve different lifecycle phases as well as rules applicable to safety management in technical projects, preparation of the safety cases and determination of the Safety Integrity Levels SILs.

- five dedicated to data transmission based technical means supporting railway transport security,

- one dedicated to resistance against internal malfunctioning, extreme external conditions, cyber-crime,

which were used to prepare sets of questions containing two types of questions – knock-out questions and differentiating questions. Each knock-out question can receive value “0” or value “1”. Each differentiating question can receive value “1” or value “2”.

Five differentiating questions are defined for safety, five for security and five for cybersecurity. In case of railway transport they are following15:

Safety:

1 *Whether control command messages contain data which are used by on-board control command equipment for verification of completeness and coherency of all received messages?*
2 *Whether on-board control command equipment verifies cryptographic protection of all received messages?*
3 *Whether drivers are informed by control command about latest places for starting braking and warned before equipment interventions?*
4 *Whether automatic braking interventions are using more than one braking mode (full service braking and emergency braking)?*
5 *Whether receiving emergency signal automatically initiates braking which ensures stopping in a place appropriate for evacuation and for security and rescue staff interventions?*

Security:

1 *Whether emergency medical equipment, especially automated external defibrillators, are available in all stations in areas accessible for passengers and provides with appropriate signs and instructions?*
2 *Whether video-monitoring system used for providing security is equipped with video-stream analyser ensuring immediate generation of security warnings?*
3 *Whether luggage scanning is provided?*
4 *Whether protection against possible natural disasters is provided?*
5 *Whether tracking of dangerous goods is provided?*

Cybersecurity:

1 *Whether in case of detecting loss of communication for signalling automatic reconfiguration of communication system takes place or automatic switch on of the backup communication system takes place to ensure traffic control by technical means (and not only procedures)?*
2 *Whether safety related personnel is equipped with backup communication means?*

[15] All questions are defined and described in a dedicated monograph.

3 *Whether in case of detecting loss of communication for control command automatic reconfiguration of communication system takes place or automatic switch on of the backup communication system takes place to ensure train running supervision?*
4 *Whether in case when control command system is out of order trains can be driven on the basis of the signal aspects displayed on the track-side signals?*
5 *Whether technical systems and devices supporting security, especially video-monitoring systems are provided with backup power supply?*

Defining such questions for hyperloop systems is to be agreed e.g. within JTC 20 works if such approach is accepted as necessary.

The overall values for safety, security and cybersecurity are products of answers to questions. Thanks to such approach even a single negative answer is a knock-out for safety, security or cybersecurity of a whole transport system.

Safety, security and cybersecurity are therefore represented by a vector.

$[\, safety \,, security \,, cybersecurity \,]$ (1)

in other notation

[SF , SC , CS] (2)

where:

SF – product of all answers regarding safety,
SC – product of all answers regarding security,
CS – product of all answers regarding cybersecurity.

The Functional Integrity Level for safety, security and cybersecurity, FIL level, is defined as a sinus of an angle between vector and reference geometrical plane, for which maximum vector is perpendicular.

$$FIL_{SF,\,SC,\,CS} = \sin \measuredangle\left(\begin{matrix} 32 & 0 & 0 \\ 0 & 32 & 0 \\ 0 & 0 & 32 \end{matrix} \,, [\, SF, SC, CS \,] \right) \quad \left| \begin{matrix} SF \neq 0 \\ SC \neq 0 \\ CS \neq 0 \end{matrix} \right. \qquad (3)$$

where:

$FIL_{SF,\,SC,\,CS}$ is a safety, security and cybersecurity functional integrity level

An angle between vector and geometrical plane (represented by matrix) may only be right (=90°) or acute (< 90°). FIL is defined only for non-zero values of the SF, SC and CS. Maximum FIL value equals “1” (as a sinus of 90°) when products of the answers regarding safety, security and cybersecurity are equal to each other. Growing discrepancies between products of the answers causes dropping of the FIL keeping it > zero.

4.1.8 Conclusions from guided transport analyses

Above considerations show, that it is due time to define main legal rules for the future fifth transport mode. Without agreement on operability there will be different not compatible hyperloop systems. Consequences would be significant and having different nature – technical, operational, economical and organisational. All costly. There are different possibilities, at least four described ones how to define operability. All of them have advantages and disadvantages. Moreover, some features resulting from the way how operability would be defined will be treated already now as advantages or as disadvantages depending on the point of view. It is easy to say, that accepted approach shall be the best one, but depending on the stakeholder – early hyperloop implementers, railway industries, aviation industries, aerospace industries, low pressure industries, metal/plastic/composite materials industries, communication and information technology industries, propulsion industries as well as governments, local authorities, etc. – advantages and disadvantages differ not only depending on type of the stakeholder but in case of companies already involved in some works on individual companies as it depends on technologies they are working on at the moment and their readiness and potential.

Operability shall be therefore quickly discussed and decided. Taken decision shall be reflected in a legally binding form as it will influence many already pending works being conducted by different entities working in different countries. Existence of the joint technical committee JTC 20 creates a chance for substantive discussion taking into account technical and economic aspects, but it may show that already now agreement is hard to be reached as different stakeholders have too differentiated views. Moreover, even if agreement would be found it is not enough to have it in CEN/CENELEC documents as newcomers, which will certainly come when hyperloop starts to be more and more feasible, will not be obliged to follow. Therefore, just after finding agreement on the JTC 20 level in globalised economy at least European legally binding decisions have to follow to secure investments in companies, people, technologies and development projects.

4.2 Value chain

Hyperloop systems will share commonalities with both railways (fixed-rail and maglevs) and air transport: vehicles will achieve speeds similar to commercial aircraft while travelling over fixed guideways. Although not yet clear how due to the early development stage, these commonalities can trigger innovations in for both infrastructure and vehicles in the field of rail transport.

The Table 5 below provides a breakdown of both railway and hyperloop systems, with the aim to provide an overview on how these works and the current state of the art.

Table 5. Overview of hyperloop, maglev and railway systems [Source: own work]

	Hyperloop	Maglev	Railway
Infrastructure	Enclosed tube on pylons Tube-on-bridge Tunnel	Slab track on pylons Track-on-bridge Tunnel	Track on embankment/ground Track-on-bridge Tunnel

	Hyperloop	Maglev	Railway
Infrastructure (superstructure)	None	Slab track	Ballast/slab track on embankment
Track	Magnetic levitation and guidance system mounted on a tube	Magnetic levitation and guidance system on slab track	Rail and sleepers (when applicable) on ballast/slab track
Power supply	Trackside linear motor or vehicle-side mounted power supply (battery, fuel cell, etc.)	System-dependent	Overhead line or third rail (electrified track) Vehicle-side power supply (diesel engine, fuel cell, etc., non-electrified track)
Signalling and train control system	Computerized vehicle positioning system. Brake distance monitoring system (moving block)		Train engineer communications (GSM-R, other national systems) Classic interlocking systems (trackside lights/semaphores, balises, traffic signs, track circuits, axle counters, etc.) Modern interlocking systems (ERTMS 3)
Braking	Work in progress	Electromagnetic braking	Classic pneumatic brake Rheostatic or regenerative electric brake Magnetic brake[16]
Motor	Electric motor	Linear motor	Trackside linear motor or vehicle-mounted propulsion

4.3 Shift to Rail frame

Shift2Rail (S2R) is the first European rail initiative to seek focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. S2R promotes the competitiveness of the European rail industry and meets changing EU transport needs. R&I carried out under this Horizon 2020 initiative develops the necessary technology to complete the Single European Railway Area (SERA).

HYPERNEX finds its time in Shift2Rail, the Rail Research contribution under European Research Program Horizon 2020. Now, Europe's Rail partnership, the successor to the current Shift2Rail Joint Undertaking, is one of the 10 new European Partnerships under the Horizon Europe

[16] Selected trainsets and countries only (i.e. ICE 3).

programme. A common objective is shared for those all partnerships: to achieve a climate neutral and digital Europe.

ERJU feeds the common start point under Shift2Rail that Europe's Rail JU takes in account in the hyperloop as one of the targets under scope of the Flagship Area 7: Innovation on new approaches for guided transport modes. The objectives of FA7 are the exploration of non-traditional and emerging flexible and/or highly guided transport systems, creating innovation opportunities that favour a scientific framework under the global railway system while promoting socioeconomically efficient and long and businesses throughout Europe. Terms that will be produce under the Multi Annual Work Plan (MAAP) available in open access in https://shift2rail.org/wp-content/uploads/2021/12/20211222_mawp_v1_agreed-in-principle_clean.pdf

The aims of S2R are to double the capacity of the European rail system and increase its reliability and service quality by 50 %, all while halving life-cycle costs.

The S2R activities should prioritise the following general objectives (Shift2Rail, 2014):

- Achieve the Single European Railway Area through the removal of remaining technical obstacles holding back the rail sector in terms of interoperability and through the transition to a more integrated, efficient and safe EU railway market, guaranteeing the proper interoperability of technical solutions.
- Radically enhance the attractiveness and competitiveness of the European railway system to ensure a modal shift towards rail through a faster and less costly transition to a more attractive, user-friendly (including for persons with reduced mobility), efficient, reliable, re-designable and sustainable European rail system.
- Help the European rail industry to retain and consolidate its leadership on the global market for rail products and services by ensuring that R&I activities and results can provide a competitive global advantage to EU industries vis-à-vis foreign competition and by stimulating and accelerating the market uptake of innovative technologies.

The following Figure 48 presents the intervention logic of Shift2Rail, illustrating how the objectives are interconnected.

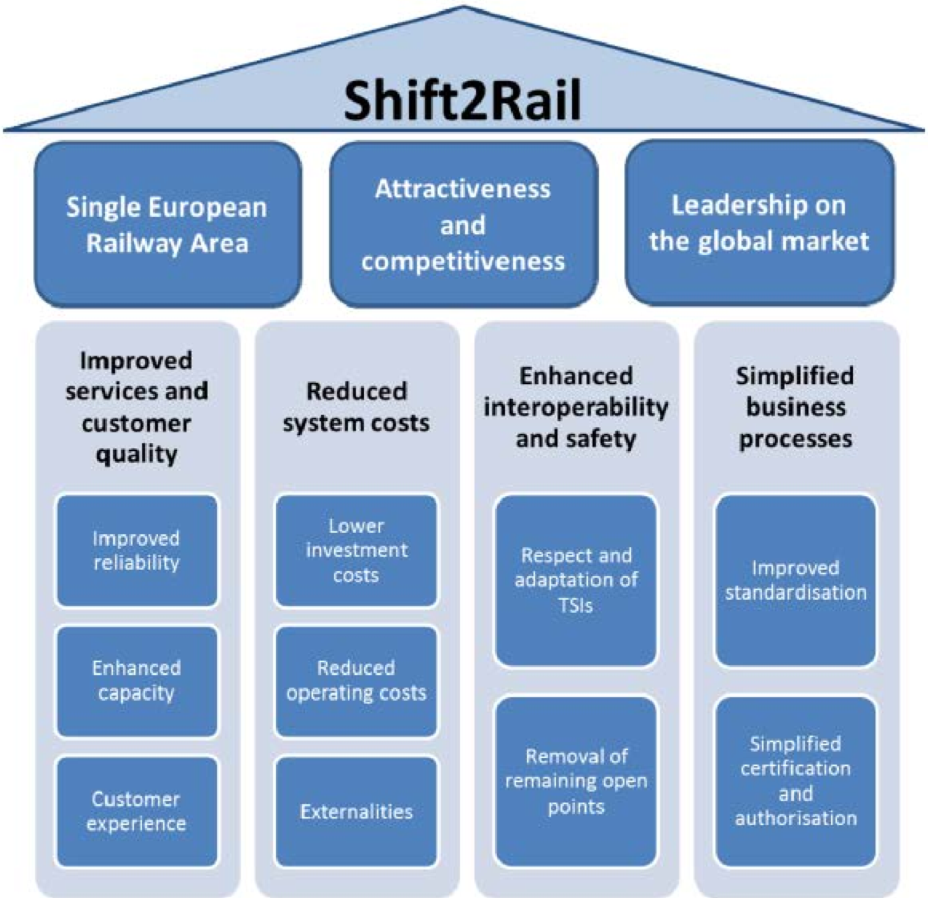


Figure 48. Intervention logic of Shift2Rail (Shift2Rail, 2014)

The Transport white paper written by the Commission in 2011 gave to rail transport relevant advantages in terms of environmental performance, land use, energy consumption and safety. A number of goals were stablished related to railway systems with others related to urban mobility with an indirect impact on rail, Table 6).

S2R have designed a Multi-Annual Action Plan (MAAP) with a wider mindset and holistic vision of the research and innovation of the activities that need to be performed and beyond the S2R Master Plan program[17] (2015) including activities to be carry on by all operational stakeholders coordinated to achieves a Single European Rail Area. The S2R Program runs from 2014 to 2020, with final implementation and phasing out envisaged by 2024.

[17] http://ec.europa.eu/transport/sites/transport/files/modes/rail/doc/2015-03-31-decisionn4-2015-adoptions2r-masterplan.pdf

Table 6. Rail-related goals in the Transport White Paper

GOALS FOR PASSENGER RAIL	Triple the length of the existing high-speed rail network by 2030 so that by 2050 the majority of medium-distance passenger transport is by rail and high-speed rail is used more than aviation for journeys up to 1000 km
	By 2050, connect all core network airports to the rail network, preferably the high-speed rail network
	By 2020, establish the framework for a European multimodal transport information, management and payment system
GOALS FOR FREIGHT	30 % of road freight over 300 km to shift to other modes such as rail or waterborne transport by 2030, and more than 50 % by 2050
	Rail freight to almost double, adding 360 billion t-km (+ 87%) compared with 2005
	Deploy the European Rail Traffic Management System on the European Core Network by 2030
	By 2050, connect all seaports to the rail freight system
	Rail freight corridors to form the backbone of the EU freight transport system
GOALS FOR URBAN MOBILITY	Halve the use of 'conventionally fuelled' cars in urban transport by 2030; phase them out in cities by 2050
	Achieve essentially CO2 -free city logistics in major urban centres by 2030
	By 2020, establish the framework for a European multimodal transport information, management and payment system

This vision includes three opportunities to the railway sector:

Opportunity 1. to become the backbone of mobility as a service and on-demand future logistics
There is an opportunity in the development of the technologies related to digitalization that configured a new radical approach to mobility, using mobile devices as interfaces. This creates an opportunity to strengths the railway as a transport of mass transit capacity, comfort and high-energy efficiency covering services that goes from the first to last kilometre (door to door mobility of people and goods).

Opportunity 2. to identify and establish new market segments for exploitation
New technologies, innovation and digitalization will open new markets and services to railway; to exploit under-used capacity and network branches in radical new ways. This opportunity is especially relevant for freight and high speed users.

Opportunity 3. to enhance the overall competitiveness of the industry, both in Europe and globally
The fast technological innovation added to the digitalisation can boost competitiveness in the railway sector. Manufacturing 4.0, new products and systems, enhanced skills development engaging new professionals, etc. will make the railway sector unique and competitive.

This program aims to develop, integrate, demonstrate and validate innovative technologies and solutions that accomplish the regulations and the safety requirements. The goal for this envision is measured with the following key performance indicators:

- 100 % increase in rail capacity, leading to increased user demand;
- 50 % increase in reliability, leading to improved quality of services;
- 50 % reduction in life-cycle costs, leading to enhanced competitiveness;
- removal of remaining technical obstacles holding back the rail sector in terms of interoperability and efficiency;
- reduction of negative externalities linked to railway transport, in particular noise, vibrations, emissions and other environmental impacts.

With a coordinate effort of all levels stakeholders, the S2R Joint Undertaking and this MAAP will develop these innovation capabilities.

Five innovation programs (IP) have been defined to achieve these objectives covering technical and operational systems and subsystems of the railway. These IP cover five-cross cutting areas covering the relevant topics for each area (Figure 49).

The five cross cutting areas (CCAs) are:

- Long term needs and socioeconomic research
- Smart material and processes
- System integration, safety and interoperability
- Energy and sustainability
- Human capital

Demonstrator of the S2R activities are a combination of single technology demonstrator, integrated technology demonstrators and system platform demonstrators (Figure 50).

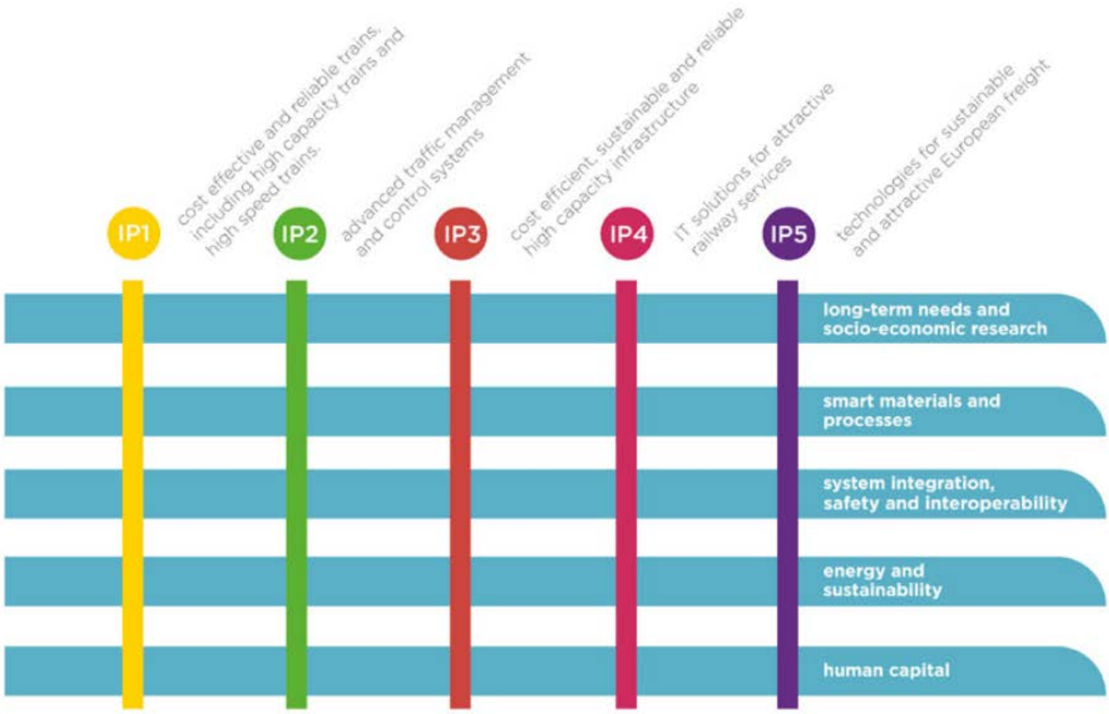


Figure 49. Structure per IP and Cross cutting areas in MAAP (Source: MAAP document)

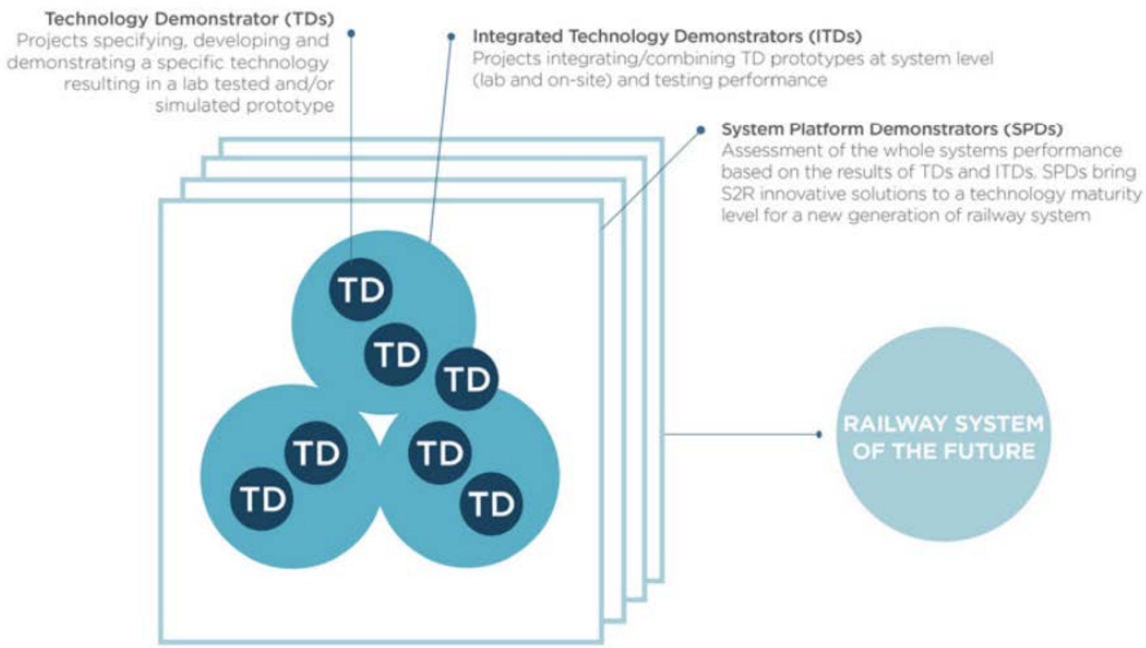


Figure 50. Structure of Shift2Rail demonstrators (Source: MAAP document)

The MAAP contains a Part A that links the S2R vision and its contribution to delivering EU societal goals; and a Part B provides the development and implementation of the R&I activities exploiting new technologies and following a Europe-wide system-of-systems approach that is novel for the sector (Figure 51). The MAAP exposes the S2R vision highlighting the characteristics of customer-driven rail transport. This vision is characterised by (extracted from MAAP):

1. It is available seven days a week and is reliable, resilient, safe and sustainable.

2. A whole-system approach across the industry fosters innovation and attracts the best talent. Entrepreneurs and innovators have the right conditions to develop new products and services.

3. Network capacity is optimised to meet all requirements for passengers and freight. Intelligent maintenance increases train and track availability and reduces disruption and delays. World-class asset management is aligned across the industry to improve performance, lower costs and reduce business risks.

4. Flexible, real-time intelligent traffic management and in-cab signalling reduce headway and decrease traction energy consumption. Control centres know the precise location, speed, braking and load of every train on the network to optimise operational performance and keep passengers

5. Carbon emissions are minimised by widespread electrification of the network and sustainable, energy-efficient solutions for the remaining non-electrified routes. Energy recovery systems in rolling stock and alternative fuels allow lower cost trains that run on and of the electrified network. Sustainable Development Principles are embedded in the design, construction and operation of infrastructure and rolling stock assets and the railway is resilient to climate change.

6. The industry is increasingly cost-effective as more efficiencies are introduced. Unplanned maintenance and damage to track and train are minimised through enhanced industry-wide condition monitoring. Generic designs for buildings and rolling stock interfaces are used instead of costly bespoke solutions to simplify expansion, upgrades and replacements.

7. Operational and customer communications are supported by equipment that can be updated with plug-and-play fitments. Rail services are integrated with other transport modes so that passengers have seamless door-to-door journeys.

8. Station information systems and personalised messaging offer passengers all the relevant information to travel easily and reliably to their destinations. Passenger friendly stations eliminate the need for queues or physical barriers. Revenue collection and security are based on electronic systems.

9. An extensive high-capability strategic freight network with increased route availability provides freight customers with flexible and timely responses to their operational and planning requests.

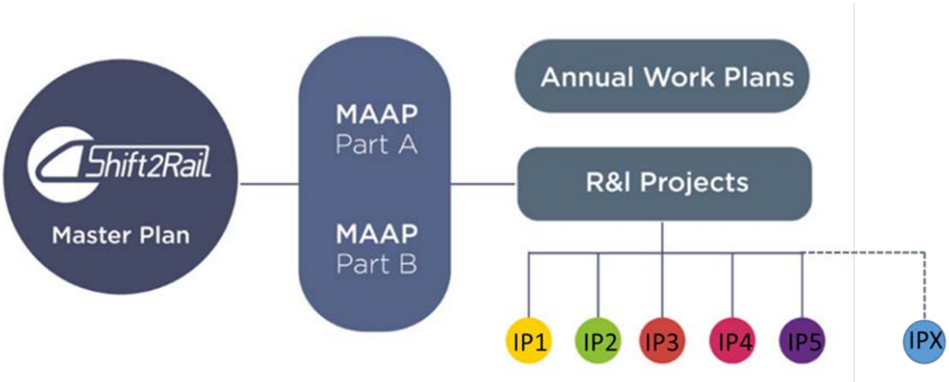


Figure 51. The Shift2Rail framework

In addition, S2R address key societal trends as digitalisation, urbanization, climate change and the increasing average age of the population. This are four megatrends that affects to the railway sector and had been selected from the eleven megatrends identified by the European Environment Agency (EEA)[18].

4.4 Capabilities

A catalogue of 12 innovation capabilities has been selected in the MAAP with focus in digitalisation and automation.

Capability 1. Automated train operation

Trains and rail operations can be autonomous, partly or fully automated. Autonomous and remote controls ensure safe operation.

- 1A Automated (passenger and freight) trains run closer together with increased flexibility.
- 1B Passenger and freight train preparation processes are automated.
- 1C Vehicles split and join on the move. New operational approaches (e.g. virtual coupling, convoying, reduced headway, communication connections between trains/units) are employed.
- 1D Self-propelled automated/autonomous single units guide themselves through the system.

Capability 2. Mobility as a service

Customer demand-driven services lead the railway to provide excellent service within the overall mobility chain. All customers and potential customers are connected to mobility services.

[18] EEA, 'Assessment of global megatrends – an update', February 2017.

- 2A Tailored guidance on the best use of available transport services is provided so that each customer receives a personalised service.
- 2B Every journey is provided intelligently and seamlessly, with rail physically integrated with other modes.
- 2C Continuous flow of information facilitates the journey, making connections between the different modes seamless.
- 2D Electronic ticketing and payment are the norm.
- 2E Superior passenger experience and comfort are key advantages of rail over other transport modes.

Capability 3. Logistics on demand

Logistics services are driven by customer demand, with freight moved reliably in wagons designed to carry various loads. The rail system is fully integrated with the multimodal logistics chain.

- 3A Planning and scheduling are synchronised in real time with customer demand.
- 3B Flexible, interchangeable, multipurpose and smart freight transport units increase handling flexibility and unit utilisation.
- 3C Shipments are moved effectively, efficiently, safely and securely through the physical internet logistics chain.
- 3D Freight trains are able to integrate within high-intensity passenger operations.
- 3E Automated yards, intermodal hubs, ports and cross-modal interchange locations connect the rail system into the multimodal logistics chain.

Capability 4. More value from data

To deliver on all the capabilities, rail manages a growing volume of data contributing to the data economy.

- 4A Secure, robust, scalable and resilient open architecture and protocols allow full interoperability 26
- 4B The internet of things (IoT) and artificial intelligence (AI) provide efficient capture, storage, management and interpretation of data.
- 4C The customer and the rail system communicate intelligently with each other.
- 4D Railway businesses exploit new data-driven revenue streams.

- 4E Big data analytics enable a range of new and improved services to be developed. State-of-the-art cybersecurity ensures reliable and secure information and communications technology services, protection of the rail system and business continuity in the event of an incident.

Capability 5. Optimum energy use

Railways maintain their position as the most environmentally friendly mode of transport by decreasing energy consumption. The introduction of new technologies and methods as supporting tools enables reduced and optimised demand-led energy use and energy efficiency.

- 5A Alternative propulsion concepts such as fuel cells are introduced. Hybrid-power trains can run over non-electrified track sections. Discontinuous electrification at stations and on branch lines dramatically reduces the capital costs of extending electrification.

- 5B Automated train operation improves energy efficiency.

- 5C Optimised on-board and line-side energy storage and charging technologies (e.g. dynamic wireless power transfer) allow the railway to redistribute energy throughout the system according to supply and demand.

- 5D A high proportion of energy is recovered through regenerative braking, and small-scale energy generation and harvesting technologies feed energy-efficient trackside systems.

- 5E A fully integrated systems approach to intelligent energy supply maximises renewable energy generation and the use of smart grids, including those outside the railway system, through links with the wider energy supply sector.

Capability 6. Service timed to the second

Situational awareness, where each train's location and speed is known at all times and in real time, supports service operation timed to the second.

- 6A Automated vehicle identification and monitoring is the basis of precise service operation.

- 6B Smart traffic management ensures that every train is in the right place and travelling at the right speed.

- 6C Automated dynamic timetables are facilitated. Automated recovery from disruption (a 'self-healing' process) quickly restores normal service.

Capability 7. Low-cost railway

New models to deliver efficient and affordable infrastructure, rolling stock and railway operation allow the rail mode to be viable in areas of low demand and to compete for new transport links.

- 7A A low-cost, affordable rail system supports the rural economy. This is supported by the application of tailored standards.
- 7B A simplified control–command system appropriate for low-intensity operation is used, allowing various degrees of autonomy.
- 7C The use of lightweight materials for rolling stock reduces maintenance costs and energy consumption.
- 7D A whole-life operating cost approach balances the use of low-cost technical assets and good-value service.
- 7E European simplified train certification processes and validation techniques reduce time taken for and the cost of product deliveries and subsequent modifications.

Capability 8. Guaranteed asset health and availability

Optimised maintenance keeps the railway continuously open, fostering minimal disruption to train services. Robust modular units and infrastructure are easily maintained and repaired through a robotic automated system, making the operation punctual, safe and quick.

- 8A The IoT enables real-time monitoring through connected sensors (ground/air/embedded).
- 8B AI supports predictive maintenance decision-making to reduce manual interventions on infrastructure and rolling stock.
- 8C Greater use of robotics, modularity and automation simplifies maintenance and reduces the number of components.
- 8D Remote maintenance of trains and infrastructure allows operations to continue uninterrupted.
- 8E Performance-based service specifications encourage a diverse supply chain.

Capability 9. Intelligent trains

Intelligent trains are aware of themselves, their passengers/loads and their surroundings, knowing where they need to be and when, and able to automatically adjust journeys to meet demand. The trains are also aware of and able to take account of the status of other transport modes.

- 9A Autonomous trains can monitor and regulate themselves.
- 9B Communication is possible between trains, between train and infrastructure, and between train and passenger/freight customers.
- 9C Trains feature advanced mechatronics, reducing dependence on wheel conicity and permitting simplified running gear design.

- 9D In-train signalling capability is used to resolve conflicts at junctions and stations.

Capability 10. Stations and smart city mobility

Rail is the backbone of urban mobility, with stations at the heart of smart cities, being places to work, live, meet and communicate, where individual transport modes, including public transport and long-distance rail transport, are physically connected.

- 10A Railways are a core part of smart city mobility management systems and city fulfilment and delivery services. Stations are key to smart city governance structures and development plans.

- 10B Railways are connected to smart city mobility platforms for a seamless end-to-end journey within and beyond the city.

- 10C New designs for infrastructure and rail vehicles provide easy access and interchange between transport modes.

- 10D Flow management systems guide customers safely and efficiently through stations and to and from adjacent transport hubs and city infrastructures, using dynamic way finding, barrier-free access and multisensory information systems.

- 10E Platform management systems help passengers position themselves for their train and facilitate efficient boarding.

- 10F Security and revenue protection at stations and interchanges are based on electronic gates using smart wireless technologies, ticket detection systems and biometrics.

Capability 11. Environmental and social sustainability

Railways are able to operate with minimal environmental impact and with a low carbon footprint. Inclusive and easy access is available for all citizens to railway facilities, products and services.

- 11A The adoption of circular economy principles enables the railway to move towards zero waste operation.

- 11B Sustainable and ethical procurement and production reduces the carbon footprint of the railway, with a whole-life approach and a focus on inputs to the system, recycling, transport of materials, renewable energy, operations and disposals.

- 11C A climate change adaptive approach mitigates the impact of climate change on the railway.

- 11D Green technologies enable the railway to operate exhaust emissions free and with low noise and vibration levels.

- 11E Information and accessible facilities put the railway within the reach of citizens as an inclusive, affordable and accessible transport system.

Capability 12. Rapid and reliable R&I delivery

An ecosystem for R&I, based on effective collaboration, the provision of greater technology demonstration capability and the rapid integration of technology into the railways, removes barriers to the adoption of new technologies and decreases time to market.

- 12A An R&I ecosystem with centres of excellence fosters a high rate of participation in knowledge networks, opening up new forms of collaboration, facilitating technology transfer from other industry sectors and keeping railway skill sets fresh.

- 12B The sector has a strong commercial focus and awareness of the maturity levels of new technologies. There is a well-coordinated and fast decision-making process, reducing time to market.

- 12C Virtual testing and efficient implementation processes speed up production and deployment of new products. There is close cooperation within the sector on standardization and testing. Component-driven development and modularised products are key elements of rapid deployment of innovation to the market. Railways have a permanent focus on disruptive technologies, using their challenges to increase their innovation capabilities and speed.

- 12D Agile development approaches, labs, hackathons and early involvement of customers are elements of customer-centric innovation. Open labs invite end users/customers to be part of the innovation process.

4.5 Demonstrators and capabilities

According with Figure 52, the demonstration of the different technologies is implemented in three types of demonstrators:

- Technology demonstrators (TDs): projects that develop, and validate a specific technology. Usually, a simulated prototype is achieved.

- Integrated technology demonstrators (ITDs): projects that combines different TDs prototypes at system level.

- System Platform Demonstrator (SPDs): These projects bring innovative solutions to a technology maturity level and assess a whole system performance based in the results of the TDs and ITDs.

To achieve the necessary capabilities (previous section) the S2R vision is based in the completion of the so-called Building Blocks (BB). A building block is an enabler of one or more capabilities that is composed by one or several TD outcomes (Figure 49).

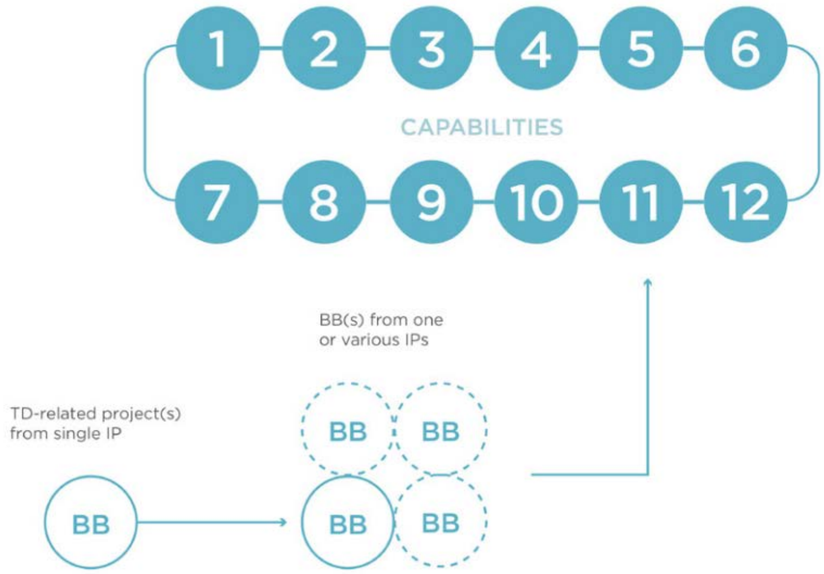


Figure 52. Building blocks (BBs) approach to capabilities

Part A of the MAAP clarifies the S2R vision and its contribution to delivering EU societal goals. It identifies the associated set of 12 new innovation capabilities that S2R will help the railway to develop and bring to market.

The part B includes the technical contents of the MAAP and was approved in November 2019.

Part B is focus in the R&I activities according with the framework defined in the Part A of the MAAP. It introduces the commitments undertaken by the members and stakeholders of the S2R JU. Also introduces a plan to bring various technology demonstrators (TDS) that includes relevant ideas and solutions for the S2R programme. A link with the innovation capabilities of Part A have been created for each TD or work area (WA).

These TDs will be combined for testing different solutions that enabled Integrated Technology Demonstrators (ITDs). The following Figure 53 presents the structure of demonstrators with in S2R. As we can see the integration of the different ITDs creates a system platform demonstrators (SPDs) that bring innovative solutions to a technology maturity level for a new generation of railway systems.

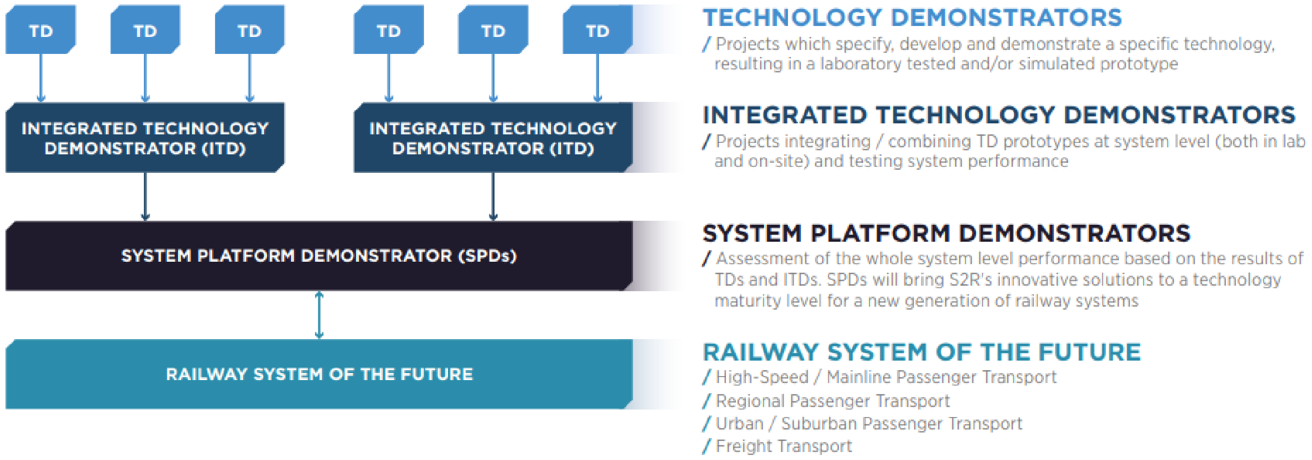


Figure 53. Structure of the different levels of demonstrators (Source: MAAP)

The proposed SPDs will cover the following segments: high-speed passenger rail, regional passenger rail, urban/suburban passenger rail and rail freight.

High-speed passenger rail

Probably is the most successful rail market in the last years. The innovation is not only focus in the comfort development but also in safety, in increasing the number of passenger although HS rail is the favourite choice for long distance passengers and efficient operation.

Regional passenger rail

Regional passenger is one of the keys of the European transport system with an increasing number of passenger for the last years. This segment is in competition with private car and bus services. The core challenge for this market segment is to offer increased capacity to ever-increasing numbers of passengers, through improved system capacity with enhanced traffic management and automation concepts, and high-capacity rolling stock. Passengers want a more reliability transport, with infallible frequency and speed with a low price.

Urban/suburban passenger rail

This market is experimenting an increase due the support of the majorities to a decarbonised politics in the cities and surroundings as an alternative to the private car. Cost-effectiveness and increased attractiveness are also important challenges, requiring higher levels of proven, affordable technology, improved accessibility, comfort and security, and innovative services based on ITS.

Rail freight

Rail freight is indispensable for the competitiveness in the European economy.

4.6 Hyperloop synergies

This section intends to provide further details regarding existing and potential synergies between hyperloop and the guided transport sector (railway). This means, on the one hand, that hyperloop can benefit from existing railway practices, technology, research, and innovation trends; and, on the other hand, the railway sector can benefit from the innovation emerging from the hyperloop development (Figure 54). For the case of the synergies sourcing from hyperloop to railway, most of them will be through R&I since there is no system in operation yet (lower TRLs compared to the railway industry).

To identify current R&I trends within the rail sector, S2R MAAP was taken as a baseline. Solutions proposed in the five Innovation Packages of the MAAP were crossed with hyperloop technologies/developments to find potential synergies.

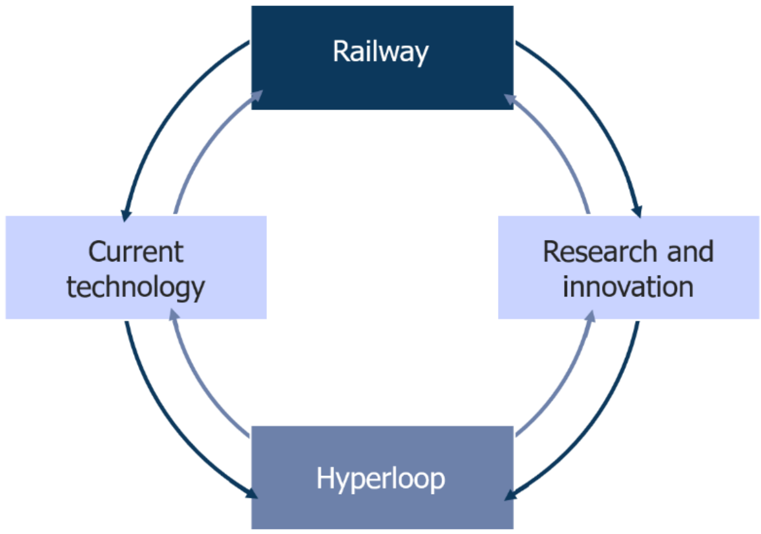


Figure 54. Hyperloop and rail synergies

An overview of the potential for synergies between S2R projects (aggregated in 5 different Innovation Packages) and the hyperloop system is displayed in Figure 55.

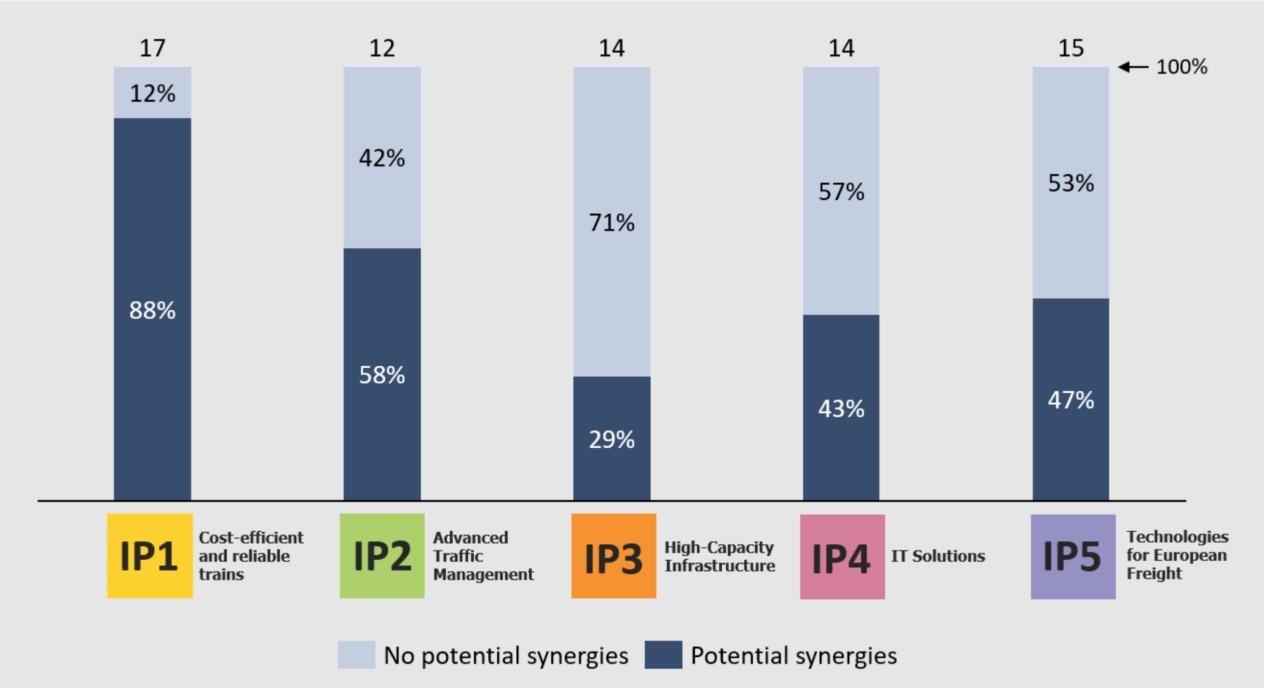


Figure 55. S2R projects showing potential synergies with the hyperloop development

Table 7. Hyperloop relation with MAAP

IP#	TD#	Innovations affecting hyperloop
IP1	Traction system (TD 1.1)	This TD could help hyperloop by implementing some of the new systems that could relate to magnetic levitation traction.
	Train control and monitoring system (TCMS)	This TD could help hyperloop by implementing or be the basis for its traffic management system.
	The new generation of car body shells (TD 1.3)	This TD could help the new technology by adapting some of the conclusions about the use of these light materials on hyperloop vehicle.
	Innovative doors (TD 1.6)	This TD could help by adopting some of the solutions presented in it.
	Heating, Ventilation, Air conditioning and Cooling (HVAC) systems (TD1.8)	Every transport has their own HVAC system, so hyperloop could gather some conclusions from this TD to implement on its system.
IP2	Development of a new Communication System (TD 2.1)	This TD could help hyperloop by adapting this new communication system.
	Automatic Train Operation (ATO) (TD 2.2).	There will be a need for an ATO for hyperloop so this TD could help by implementing or taken as a basis for the one in the new technology.
	Moving Block (TD 2.3)	This TD would be probably implemented on the new systems that hyperloop could embrace or take as a basis.
	Safe Train Positioning (TD	This positioning system is going to be necessary on the

IP#	TD#	Innovations affecting hyperloop
	2.4)	implementation of previous TDs
	Train Integrity (TD 2.5)	This TD would be an integration of other, this could help hyperloop by having as an example of integration for the new developments.
	Virtual Coupling (TD 2.8)	This could help hyperloop by enhancing its initial capacity and granting travel gaps to be maximize in terms of passenger capacity.
	Optimized Traffic Management System (TD 2.9)	This TD applies for every transport to interconnect with the railway as well as every guided transport.
	Smart radio-connected all-in-all wayside objects (TD 2.10).	This TD could help hyperloop to develop their wayside objects.
	Cyber Security (TD 2.11)	This TD applies to every system that aims to achieve a high safety level.
IP3	Proactive Bridge and Tunnel Assessment, Repair and Upgrade (TD 3.5)	As a new guided technology, this TD could help to develop the new infrastructure assets.
	Dynamic Railway Information Management System (DRIMS) (TD 3.6)	This TD could help hyperloop to apply the similitudes to its own purposes
	Railway Integrated Measuring and Monitoring System (RIMMS) (TD 3.7)	This TD could help any hyperloop to develop their own data acquisition system
	Intelligent Asset Management Strategies (IAMS) (TD 3.8)	As every system, the new hyperloop system must develop their own maintenance system and could use this TD as a basis for its development
	Smart Power Supply (TD 3.9)	The smart grid is to be implemented on every power supply system of new development. This TD could be set as a basis for a node power supply system.
	Smart Metering for Railway Distributed Energy Resource Management System (TD 3.10)	This is related to the previous TD to set the new power supply system.
	Future Stations (TD 3.11)	As a guided transport with traveller nodes interfaces, hyperloop could use this TD as a bases for those interface nodes.
IP4	Interoperability Framework (TD4.1)	This TD applies to every mode integrated on a multimodal network.
	Travel Shopping (TD4.2)	This TD applies to every mode integrated on a multimodal network
	Booking & Ticketing (TD4.3)	This TD applies to every mode integrated on a multimodal network.

IP#	TD#	Innovations affecting hyperloop
	Trip-tracker (TD4.4)	This TD applies to every mode integrated on a multimodal network.
	Travel Companion (TD4.5	This TD applies to every mode integrated on a multimodal network.
	Business Analytics (TD4.6)	This TD applies to every mode integrated on a multimodal network or every transport in which many persons have to be integrated on it.
IP5	Fleet Digitalisation and Automation (TD 5.1)	This TD is in line with hyperloop vision of automated freight transport in inside networks.
	Digital Transport management (TD 5.2)	This TD is in line with hyperloop vision of automated freight transport in inside networks.
IPX	This whole IP is to be taken on account for the development of new technologies such as the hyperloop.	

4.6.1 Innovation Package 1

The first innovation package aims at increasing the physical capacity of vehicles and railway lines, reducing travel disruptions for passengers by increasing reliability and availability of vehicles by using more reliable components or systems. It also aims at reducing the life cycle costs of fleets (by reducing maintenance, energy consumption, etc) and other subsystems of the railways interacting with vehicle fleets. These combined goals ambition to promote a modal shift by developing more attractive and comfortable vehicles, improving punctuality and providing cheaper services.

This package is organised around different technology demonstrators:

- **Traction system (TD 1.1)** will develop new traction components and subsystems using mainly silicon carbide (SiC) technologies, leading to new architectures.

- **Train control and monitoring system (TCMS) (TD 1.2).** New generation TCMS are currently being developed. These employ new drive-by-data concepts for train control, along with wireless information transmission. Consequently, new control functions will be possible. Furthermore, it involves interaction between vehicles. These new developments will help overcome the current bottlenecks caused by physically coupled trains.

- **The new generation of car body shells (TD 1.3)** using composite or other lightweight materials will be a step change in the sector, leading to significantly lighter vehicles that carry more passengers within the same axle load constraints, use less energy and have a reduced impact on rail infrastructure.

- **Running gear (TD 1.4)** will develop innovative combinations of new architectural concepts, new actuators in new lighter materials leading to new functionalities, and significantly improved performance levels with the possibility of vibration energy recovery. A mechatronic bogie able to steer through points and crossings will help unlock possibilities for a new design philosophy in collaboration with IP3.

- **New braking systems (TD 1.5)** with higher brake rates and lower noise emissions will provide major capacity gains in terms of mass and volume in bogies. Combined with traction innovations, the next generation of passenger rolling stock will be able to offer improvements in acceleration and deceleration rates, in turn increasing line capacity).

- **Innovative doors (TD 1.6)** aim to move away from current access solutions based on honeycomb and aluminium or steel sheets; their drawbacks relate to energy consumption, and noise and thermal transmission. New lightweight composite structures could be made to react faster at existing safety and reliability levels, reducing platform dwell times and increasing overall line capacity. Customer-friendly information systems and improved access for people with reduced mobility using sensitive edges and light curtains are part of this new development.

- **Train modularity in use (TD 1.7)** will develop new modular concepts for train interiors that allow operators to adapt vehicle layouts to the actual usage conditions. This will improve passenger flows and optimise both the capacity of the vehicle and station dwell times.

- **Heating, Ventilation, Air conditioning and Cooling (HVAC) systems (TD1.8)** These HVAC units will focus on activities for the pre-standardization of mechanical, electrical and control interfaces of HVAC units as well as on fundamental work on alternative refrigerants (such as air or CO2).

A more global view on functional interactions existing between TDs is shown in Figure 56.

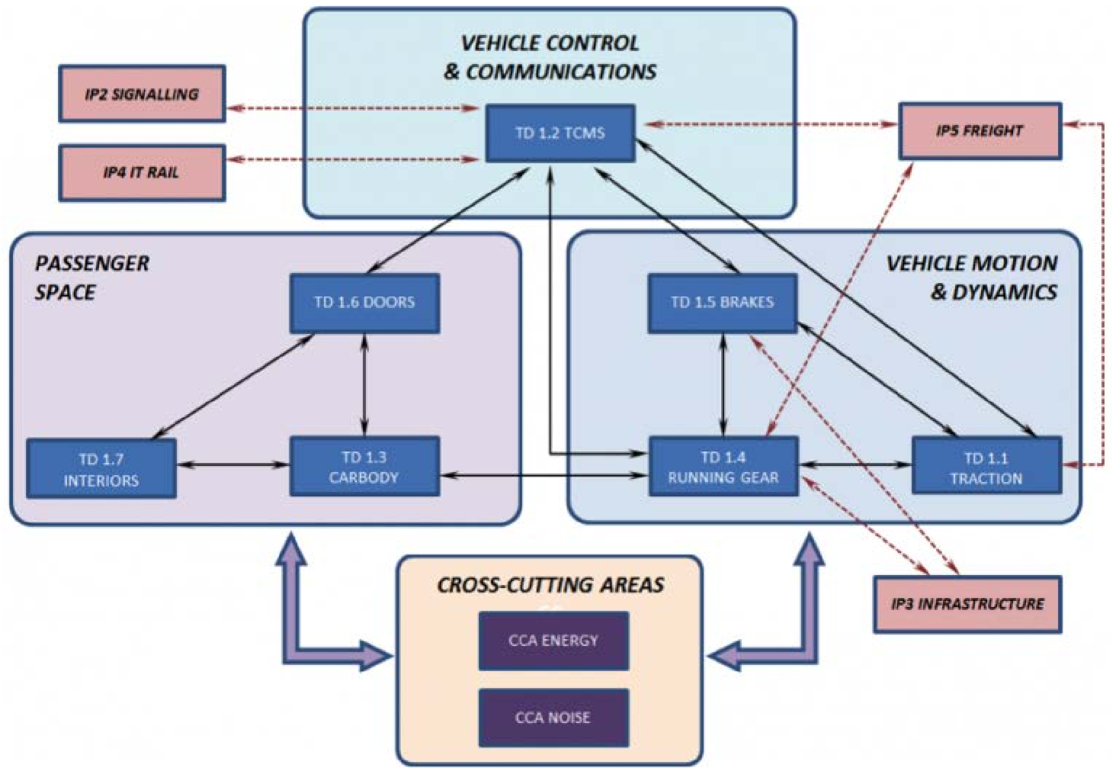


Figure 56. Global view on functional interactions existing between TDs

Table 8. Projects of Innovation Package 1

Project	TRL	Date	TD1.1	TD1.2	TD1.3	TD1.4	TD1.5	TD1.6	TD1.7	TD1.8
Roll2Rail	TRL1 to TRL4	2015-2018	Lighthouse Project							
PINTA	TRL2 to TRL4	2016-2018	x				x			
PINTA 2	TRL5 to TRL6	2018-2021	x				x			
PINTA 3	TRL7	2020-2023	x							x
RECET4Rail		2020-2023	x							
Conecta	TRL3 to TRL4	2016-2018		x			x			
Conecta 2	TRL5	2018-2021		x						
Conecta 3		2020-2023		x						
Safe4Rail		2016-2018		x			x			
Safe4Rail 2		2018-2021		x						
Safe4Rail 3		2020-2023		x						
Run2Rail		2018-2019				x	x			
PIVOT	TRL4 to TRL5	2017-2019			x	x	x	x	x	
PIVOT 2	TRL6 to TRL7	2019-2022			x	x	x	x	x	x
Mat4Rail		2017-2019			x			x	x	
CARBODIN		2017-2019			x			x	x	
NextGear		2019-2021				x				
GEARBODIES		2020-2022			x	x				

The projects where a potential synergy with the hyperloop development was found (highlighted in green in Table 8) are the following:

PINTA 1: The project developed a SiC Power Converter that allows to save energy. Other advantages are an improved switching frequency, noise reduction, a smaller cooling system and an overall weight reduction. It has a potential synergy with hyperloop in terms of optimizing battery storage performance and enabling higher speeds than IGBTs in power systems. A traction motor (360 km/h @ 2.4 MW) was also developed with potential for proposals featuring a compressor as a propulsion system or as wheel power systems. Similar projects (PINTA2, PINTA3) plan to develop technology from TRL 2 to TRL 7.

Recet4Rail: This project conducts studies of 3D printing technologies for new heat transfer systems. These improvements can be helpful in transferring heat in a low-pressure environment, which is currently one of hyperloop's great challenges. Wireless power transfer is also being developed, with SiC semiconductors energy storage system as a potential solution to charge the hyperloop vehicle.

CONNECTA (1, 2 & 3): provides new architectures and technologies, tools, norms, and standards for the future generation of TCMS, as well as new electronic brake allows for automatic train operation with less systems components, and finally new virtual validation and certification systems for all the communication networks and functions of the new generation TCMS. Its scalability, interoperability, its use of common standards and its ease of use will allow hyperloop to propose similar systems for automatic operation and optimal use of each journey. ERTMS 3 main feature is the "moving block" technology. By using this, railway lines can increase their capacity by reducing intervals between trains to their braking distance (in the order of several minutes). At the same time, all trackside signals can theoretically be removed. Since hyperloop pods will travel autonomously without the need for any signals, cross-development of the technology can be envisioned.

Safe4Rail (1, 2 & 3): The aim of this project is to define new train standards and pave the way for deterministic, secure, and interoperable connections while increasing TCMS efficiency and safety. It is based in three technological pillars: 1) Development of the Drive-by-Data (DbD) devices in the train network using Time-Sensitive Network technology, (2) Development of high TRL wireless devices and antennas that are suitable for Wireless TCMS (WLTB and WLCN domains) 3) Integration of a Heating, Ventilation and Air Conditioning functionality on the train Network. Since hyperloop is based on a system without or with minimal human operation, its operations will resemble those of railways due to its guided nature. Complex computing systems will be needed to ensure safe and reliable operation and the short headways between pods that could benefit from synergies with this project.

Run2Rail: Three main areas are developed in this project: (1) Smart sensors and smart running gear components with self-diagnosing capability. (2) Use of novel materials and manufacturing methods in combination with intelligent / active suspensions to enable non-conventional running gear concepts, assessment of existing off-the-shelf technology for active control coming from other sectors. (3) Identification of efficient fabrication processes for the running gear (3D metal printing, automated tape layering of composite materials). Aircraft engines do have self-monitoring sensors that are able to send real-time updates on their condition to the manufacturer. Shall hyperloop adopt this solution; it could maybe be easily adapted to railways. However, depending on the solution, the vehicle's taxonomy can differ from railway vehicles (compressor vs maglev-based vehicle). In any case, sensors for the following parts could be cross developed:

Electric engine, power electronics, control system, communication system, component temperature sensors and door system integrity (passenger doors and cargo hatches).

PIVOT (1&2): In these projects eddy current brakes, new friction pairs, electromechanical brake solutions with high Safety Integrity Levels (SIL) are studied. Furthermore, the projects also tackle virtual certification. Also, lightweight materials have been explored for structural application and a sustainability assessment of other concepts like repairability and recyclability. Consequently, modular interiors can be developed to make vehicle reconfiguration easier. It has been seen that currently available structural composites do not meet the Fire, Smoke & Toxicity requirements of the railway sector. **Mat4Rail** project develops new fire-retardant resins, new structural joints (adhesive and bolted) and studies their possible repairability. Also, the **CARBODIN** project explore different production techniques, automation concepts, introduction of co-cured and co-bonded composite parts, and multi-material integrated joints and inserts to lower the overall costs. Finally, the **GEARBODIES** project is working on an advanced platform to inspection the carbody shell, thereby extending overhaul periods and improving maintenance processes. Finally, **PIVOT 2** is the first European rail initiative to seek focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail products. All these technologies developed for composite materials would allow hyperloop to be more efficient, in the specific case that hyperloop fire, toxicity and smoke requirements will likely be far higher than those of railways due to its enclosed environment. The passengers and crew must be able to safely survive and escape in case of an emergency. The enclosed environment makes the escape of toxic gases, heat, and smoke more difficult than the open-air conditions of railways, even in railway tunnels. Cross-development shall be fostered in this case.

NextGear: Measure the long-term savings on new running gear changes is a challenging task. NextGear's goal is to ease this task by developing a universal cost model to estimate the economic impact, while also studying the construction of new cost-efficient railway wheelsets. The economic models will help hyperloop to make safe decisions about which technology can be better in economic terms. Also, precise models will allow knowing the life cycles and the cost of some systems. This also has an important impact in hyperloop, because in other modes of transport such as airplanes, Trains, and maglev, wheels, and suspensions systems, have a high cost of maintenance.

4.6.2 Innovation Package 2

The second innovation package focuses on innovative technologies, systems, and applications in the fields of telecommunications, train separation, supervision, engineering, automation, and security. This package strives to improve ERTMS' market position as the main solution for railway signalling and control system. The aim is to speed up the time to market, improve interoperability, offer improved functionalities, and standardise interfaces to ensure the public transport network's reliability.

This package is organised around different technology demonstrators:

- Communications System **(TD 2.1):** aiming at overcoming the deficiencies of ETCS and Communications-Based Train Control (CBTC).

- Automatic Train Operation **(ATO) (TD 2.2):** aiming at developing and validating a standard ATO up to GoA3/4 over ETCS.
- Moving Block **(TD 2.3):** with the objective of improving capacity by decoupling the signalling from the physical infrastructure.
- Safe Train Positioning **(TD 2.4):** aims at developing a failsafe, multi sensor train positioning system, applying technologies such as the GNSS to the current ERTMS. It will potentially boost the quality of train localisation and information integrity.
- Train integrity **(TD 2.5):** aims at specifying and prototyping innovative on-board train integrity check solution, capable of autonomous train-tail localisation, wireless communication between the tail and the from cabin.
- New laboratory test framework **(TD 2.6):** represents a set of simulation tools and testing procedures for carrying out open test architecture with clear operational rules and simple certification of test results.
- Set of standardized engineering and operational procedures **(TD 2.7):** aims at contributing to the creation of an open standard interface and functional ETCS description model.
- Virtual Coupling **(TD 2.8):** aims to enable virtual coupled trains to operate much closer to another and modifying the train consist on the move, while ensuring the same safety levels as existing systems.
- Traffic Management System (TD 2.9): aims to improve traffic management operations with automated processes for data integration and exchange with other rail business services.
- Smart radio-connected all-in-all wayside objects **(TD 2.10):** aims at developing autonomous, complete, intelligent equipment able to connect not only with control centres, but also with on-board units.
- Cyber security **(TD 2.11):** aims to achieve the optimal level of protection against any significant threat to signalling and telecom system in the most economical way.

The projects where a potential synergy with the hyperloop development was found (highlighted in green in Table 9) are the following:

Table 9. Projects of Innovation Package 2

Project	TRL	Data	TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
X2RAIL 1		2016-2021	x	x	x			x				x	x
X2RAIL2		2017-2021				x	x		x		x		
X2RAIL3			x		x			x		x			x
X2RAIL4				x			x				x	x	x
X2RAIL5			x		x	x		x	x				x
Mistral			x										
ASTRail			x	x	x	x			x				
EMULRADIO4RAIL			x										

Project	TRL	Data	TD2.1	TD2.2	TD2.3	TD2.4	TD2.5	TD2.6	TD2.7	TD2.8	TD2.9	TD2.10	TD2.11
AB4RAIL			x										
MOVINGRAIL					x					x			
GATE4RAIL						x		x					
ETALON							x						
VITE								x					

- **X2RAIL (1, 2, 3, 4 and 5):** covering the increased use of automatic train operation up to GoA4 (highest level of automation) coupled with the decentralized and less cost intensive signalling system, such as the moving block, or even virtual coupling and consist on-the-go incorporation and leaving related to high speed. Hyperloop could benefit from incorporating the signalling system to the moving block concept provided by some of the hyperloop promoters, specially at ultra-high speeds.
- **ASTRail:** To increase the efficiency and safety in the railway sector by enhancing the signalling and automation of the railway system thanks to innovative solutions that exploit cutting edge technologies already in use in sectors different from rail, such as the aeronautic. As an example, transfer expertise of GNSS from aviation to railway systems to improve the localization of trains. Hyperloop could exploit the knowledge obtained from this project by using the GNSS technology to localize the vehicles with high accuracy and integrity, especially because of the speeds that match those of commercial aircraft. However, train localisation in an enclosed environment via satellite navigation shall be addressed beforehand.
- **EMULRADIO4RAIL**: provides an innovative platform for tests and validation of various radio access technologies (Wi-Fi, GSM-R, LTE, 5G and satellites) offering a graphical based interface for the users, and to investigate the various communication environment scenarios in railways covering degraded modes, outages, network overload scenarios or perturbations with particular focus on interferences. Hyperloop will benefit from 5G and similar communication systems. Given its ultra-high operating speeds and low latency requirements for precise communications and pod positioning, this package could provide with further knowledge on this regard.
- **MOVINGRAIL**: Operational procedures for moving block and virtual coupling signalling, validation and testing of moving block technologies, also assessing impacts on different railway market segments in terms of costs, performance and operator needs. Hyperloop is already exploiting these technologies (moving block and virtual coupling) needed for the high-density nature of its operation, allowing for high capacities and frequencies. Thus, creating operational procedures and testing methods for the signalling of these technologies will help reducing time to market for hyperloop.
- **GATE4RAIL**: Laboratory test capable of simulating railway scenarios for GNSS-based ERTMS. It will define both GNSS and ETCS lab architectures as well as the interfaces connecting remotely the testing labs. Hyperloop will require from high precision localisation, and GNSS-based technologies can provide these requirements for a high frequency and ultra-high speed transportation.

4.6.3 Innovation Package 3

The third innovation package will enable resilient, cost efficient and high-capacity European network by delivering research, development, and innovation in the rail infrastructure. The approach to consider the system, linking infrastructure and station design with maintenance actions, asset management and energy management.

This package is organised around different technology demonstrators:

- Enhanced Switch & Crossing System **(TD 3.1):** aims to improve the operational performance of existing Switch & Crossing designs through the delivery of new subsystems with enhanced reliability, availability, maintainability, and safety.
- Next Generation Switch and crossing system **(TD 3.2):** to provide radical novel system solutions that deliver new methods for direction trains to change tracks.
- Optimised Track System **(TD 3.3):** challenge track construction by exploring how new products or procedures can increase the reliability, sustainability, capacity, and life-cycle costs savings.
- Next generation track system **(TD 3.4):** improve the track system, targeting a time range of 40 years beyond the present state of the art.
- Proactive bridge and tunnel assessment, repair, and upgrade **(TD 3.5):** improve inspection methods and repair techniques to reduce costs, improve quality and extend life of service.
- Dynamic railway information management system **(TD 3.6):** aims to define an innovative system for the management, processing, and analysis of railway data.
- Railway integrated measuring and monitoring system **(TD 3.7):** to provide innovative tools and techniques for capturing information on the status of assets, in a non-intrusive and fully integrated manner.
- Intelligent asset management strategies **(TD 3.8):** whole-system approach of asset management employing collected and processed data provided by TD3.6 and TD3.7.
- Smart power supply **(TD 3.9):** develop a railway power grid in an overall interconnected and communicating system.
- Smart metering for railway distributed energy resources management system **(TD 3.10):** achieve a fine mapping of energy flows within the entire railway system.
- Future stations **(TD 3.11):** improving the customer experience at stations.

Table 10. Projects of Innovation Package 3

Project	TRL	Date	TD3.1	TD3.2	TD3.3	TD3.4	TD3.5	TD3.6	TD3.7	TD3.8	TD3.9	TD3.10	TD3.11
In2Rail			Lighthouse Project										
In2Track	TRL2 to TRL4	2016-2019	X		X		X						
In2Track2	TRL5 to TRL6	2018-2021	X	X	X	X	X						
Scode		2016-2019		X									
In2Zone		2020-2023				X							
Assets4Rail	TRL5 to TRL6	2018-2021					X		X				
In2Smart		2016-2019						X	X	X			
In2Smart2	TRL6 to TRL7	2019-2022						X	X	X			
In2Dreams		2017-2019						X				X	
DayDreams		2020-2023						X					
Momit		2017-2019							X				
Stream		2020-2023								X			
In2Stempo		2017-2022									X	X	X
Fundres		2019-2021									X		
FairStations		2017-2019											X

The projects where a potential synergy with the hyperloop development was found (highlighted in green in Table 10) are the following:

- **In2Rail**: enhancing the existing capacity fulfilling user demand of the European railway system, increasing the reliability and delivering better and consistent quality of service of the European rail system reducing the life cycle cost increasing the competitiveness of the rail system and industry. Hyperloop, as a ground means of transportation, will need to deep dive into the topics of the In2Rail project: capacity (with unprecedent demand growth in transportation), reliability (required for a high frequency and ultra-highspeed system like hyperloop), and life cycle cost.
- **In2Track**: enhancing and optimising the switch and crossing track system to ensure the optimal line usage and capacity, as well as investigating novel ways of extending the life of bridges and tunnels. Hyperloop is an infrastructure-intensive transport system, where assets like tunnels,

bridges and tubes will be essential for operation. In2Track can provide with extensive knowledge and approach in these topics that hyperloop could benefit from.

- **In2Smart (1 and 2):** improving monitoring systems and automatic detection and prediction of the railway asset decay. It focuses on the development of maintenance strategies to generate a common framework to pave the road for future decision support tools and systems, as well as intelligent asset management strategies. The hyperloop, being a complex and infrastructure intensive system, needs to define proper maintenance approaches and strategies that can ensure safety while maintaining life cycle costs within reasonable limits. In2Smart package can generate specific knowledge regarding asset monitoring and management that could boost the hyperloop development in this field.

4.6.4 Innovation Package 4

The fourth innovation package covers those IT solutions that could make railway services more attractive, responding to customer needs to better support multimodal transport.

This package is organised around different technology demonstrators:

- Interoperability framework **(TD 4.1):** facilitate multimodal travel in a highly diverse environment with many transport modes.
- Travel shopping **(TD 4.2):** aims to provide a comprehensive shopping application enabler combining all modes of transport, all operators, and all geographies.
- Booking and ticketing **(TD 4.3):** multiple but parallel interactions with several booking, payment, and ticketing engines.
- Trip-tracker **(TD 4.4):** will give passengers in-trip assistance when navigating transport nodes, while providing personalised information and up to date status reports on subsequent legs of the journey.
- Travel companion **(TD 4.5):** stores and shares personal preferences to allow the traveller having full control of the journey.
- Business analytics **(TD 4.6):** services related to travellers and sensors will generate a set of high value data, being the role of this project to manage these data with technologies like big data, improving the capabilities to analyse distributed and heterogeneous linked data.

Table 11. Projects of Innovation Package 4

Project	TRL	Data	TD4.1	TD4.2	TD4.3	TD4.4	TD4.5	TD4.6	TD4.7
IT2Rail			Lighthouse Project						
GOF4R		2016-2018	X					X	
ST4RT		2016-2018	X					X	
Connective		2017-2022	X					X	
Sprint		2018-2020	X						X
Ride2Rail		2019-2022	X	X	X	X	X		
Co-Active		2016-2019		X	X				X
Maasive		2018-2021		X	X	X	X		
Extensive		2020-2023		X	X	X	X	X	X
Attracktive		2016-2019				X	X		
My-TRAC		2017-2020				X	X		
COHESIVE		2017-2022							X
Shift2Maas		2018-2021							X
IP4Maas		2020-2023							X

The projects where a potential synergy with the hyperloop development was found (are highlighted in green in Table 11) are the following:

- **IT2Rail**: As a lighthouse project, it is designed as the first step towards long-term S2R IP4, with a main objective of enabling the development of solutions providing a seamless travel experience by giving access to a complete multimodal travel offer, connecting first and last mile of long-distance journey. It combines air, rail, coach, and other services, integrating current and future services for planning, ticketing, and booking transactions. For the hyperloop development, and especially for its deployment, a seamless travel experience becomes paramount for the success of the new travel mode, hence platforms like IT2Rail will be of much interest when hyperloop integrates into the multimodal framework.

- **GOF4R**: Define sustainable governance for the Interoperability Framework that will create the right conditions to introduce seamless mobility services and overcome obstacles impeding the development of market innovations by integrating them into the "semantic web for transportation". Hyperloop shall be included as a link for the "web of transportation" to ensure its integration in to the broader transportation ecosystem and seamless multi-modal travel.

- **Connective**: will develop a set of tools fostering digital transformation of rail and transport ecosystem, enabling multimodal travel experience and new levels of interoperability and seamless access to all transport data and services in a multimodal environment, while offering business intelligence to extract insights of the ecosystem, valuable for both users and service providers. The "Connective" project's findings can help hyperloop to be included into the European multimodal travel experience.

- **Ride2Rail**: focuses on the development of an innovative framework for intelligent mobility and the integration of multiple data sets and existing transport platforms for promoting ride sharing among the general public, making railway a complementary transport mode that extends public transport networks. It increases of high-capacity transport services in low-demand areas. Hyperloop routes shall be integrated in intelligent mobility systems to foster its use and to facilitate its integration into the current transportation network.

- **Attracktive**: aims to provide new concepts, tools, and systems to improve the attractiveness of rail transport by developing a real door-to-door travel solution including all modes of transport. As with the previous projects, hyperloop, as a new mode of transportation, could be integrated into the broader network to provide medium-range connections. Furthermore, the door-to-door mobility solutions of "Attracktive" could be used to develop similar frameworks for hyperloop systems.

- **My-TRAC:** To develop a user centric platform providing operator web-based interface and a traveller companion application, guiding the used through the complete trip in real time. Hyperloop could integrate itself into this platform to provide travel details in real time and ease the transfer between both transport modes.

4.6.5 Innovation Package 5

The five TDs are organised around the three following work streams, optimisation of operational processes for infrastructure, operations and assets: automation of rail freight system and new markets.

This package is organised around different technology demonstrators:

- Fleet Digitalization and Automation **(TD 5.1)** aims to improve strategic areas of rail freight transport by developing key technologies to enable a digital and automated rail freight system. core topics like Condition-based Maintenance (CBM), Automatic Coupling, Freight Automatic Train Operation (ATO) and Connected Driver Advisory Systems (C-DAS).

- Digital Transport management **(TD 5.2)** The aim of this TD is to develop freight solutions that are highly reliable and flexible, and that enable the optimization of overall transport time, in particular by increasing the average speed for rail freight operations and by reducing handling and set up times at marshalling yards and in terminals taking into account the new automation technology, but also by ensuring that rail freight is able to better operate in conjunction with passenger traffic in order to maximize the utilization of the existing network.

- Smart Freight Wagon Concepts **(TD 5.3):** The main objective is to produce technical demonstrations of the next generation of freight bogies and freight wagons, in order to prove their competitiveness and show that the rail freight market demands of the year 2020+ can be addressed, so that a change in modal split becomes feasible.

- New Freight Propulsion Concepts **(TD 5.4):** The focus of this TD is on improving the operational efficiency by automating various activities such as train start-up, train preparation, start of mission, storage, parking and shunting. This is possible by adding flexibility for operation in non-electrified and in electrified lines, hybridization of locomotives by offering auxiliary electric traction for shunting operations and low speed operations, feature remote control for distributed power, etc. This way, trains of maximum train length up to 1,500 m and consequently improving the cost efficiency of rail transport.

- Business analytics and implementation strategies **(TD 5.5):** This TD ensures that IP5 develops technologies are in line with the market needs and have sound plans for its entrance into the market. This is provided by migration plans for implementing new technology solutions on a large scale, identifying market segments, and developing specifications and Key Performance Indicators for freight.

Table 12. Projects of Innovation Package 5

Project	TRL	Date	TD5.1	TD5.2	TD5.3	TD5.4	TD5.5
SmartRail		2015-2019	Lighthouse Project				
FR8Rail		2016-2019	X		X		X
FR8Rail 2		2018-2021	X		X	X	
FR8Rail 3		2019-2022	X	X	X	X	
FR8Rail 4		2020-2023	X		X	X	
ARCC	TRL5	2016-2021	X	X			
SMART		2016-2019	X	X			
SMART 2	TRL6-7	2019-2022	X				
InnoWag	TRL5	2016-2019	X		X		X
Locate		2019-2021	X				
FR8HUB		2017-2021		X	X	X	X
Optiyard		2017-2019		X			
FFL4E		2016-2019				X	
DynaFreight		2016-2018				X	
M2O		2018-2020				X	

The projects where a potential synergy with the hyperloop development was found (are highlighted in green in Table 12) are the following:

- **SmartRail:** The goal of the project is to reduce replacement costs, delay and provide environmentally friendly maintenance solutions for ageing infrastructure networks, thus monitoring of the Rail infrastructure at real-time. Thus, procedures of Structural Health Monitoring. A suite of environmentally friendly, low-cost, minimal disruption measures will be produced as the result of the project. The concept of Structural Health monitoring can be used in hyperloop infrastructures for maintenance cost optimisation.

- **SMART:** the goal is to achieve train automation at low speeds by being capable of recognizing objects at short and long distances from the rolling stock. Thus, studying the action and control over different situation, i.e. real-time marshalling yard management system. In this project, it develops a prototype hardware and software algorithms for obstacle detection for short and long distance. Two-night vision technologies: thermal camera (intensifier with multi-stereo vision) and laser scanner are used to achieve obstacle detection of up to 1000 m and to provide short range (< 200 m) wagon recognition for shunting operations with a +/- 5 cm distance estimation tolerance. TAF/TSI standard data formats are implemented as standard. In **SMART 2** also develop two new innovative systems, the advanced trackside (TS) and airborne OD&TID for later integrate the three systems and to be able to take it to TRL7.

Obstacle detection and intrusion detection systems will be a key part of hyperloop infrastructure, given the high speeds involved, the enclosed nature and the low-pressure environment that prevents in-person surveillance of the hyperloop tube. Hyperloop will have to monitor possible obstacles (foreign object debris, unexpected/malicious intrusions of the tube environment) by means of image recognition software. The software shall be able to detect and react much faster than a human being's capabilities to possible obstacles or intruders in to prevent or minimize collision damage. An evolution of rail systems towards hyperloop is less likely than the opposite due to the speeds involved.

- **InnoWag**: This project aims to innovate in intelligent freight wagon and predictive maintenance through 3 packs: (WS1) Cargo condition monitoring: autonomous self-powered sensor system for cargo tracing and condition monitoring, (WS2) New wagon design, (WS3) Predictive models and tools in rolling stock maintenance programs. At a first glance, hyperloop pods will be more stable than railway vehicles due to the levitation systems and their strict tolerances; however, cargo condition monitoring systems will allow knowing vibrations and movements experienced by the payload to monitor possible damage or to foresee damage based on data acquired by onboard sensors, and to be implemented in preventive maintenance.
- **Locate:** Develop a tool to access the condition of freight locomotive bogies to implement a condition-based maintenance program. If the technology, defects movements/vibrations to monitor, and failure modes are similar, then a complete synergy can be achieved. A detailed analysis on what both systems share (vibrations, etc.) must be performed before synergies can be detected.
- **Optiyard:** Tools in real-time to optimize processes and manage yards more efficiently are develops. It also integrates activities towards automation. This technology can optimize the resource schedules and the shunting movements of the locomotives which are the main gains that can be reached in the yard operations. Yard management is complex. Hyperloop yards will have to ensure that the pods depart within the very strict timeslots the system allows. Ideally, the system will employ automatic scheduling extended to shunting manoeuvres to place the required pods on the right track.

Furthermore, measures to tackle unforeseen events such as breakdowns, pod changes, cancellations, etc. must be put in place to guarantee system integrity during incidents.

Therefore, progress made in rail for yard management can be used for hyperloop and vice versa.

- **FFL4E:** The aim of this work package is to successfully integrate, commission and certificate powerful Li-Ion batteries in mainline railways application, with a focus on full electric last mile propulsion use cases, therefore batteries having high energy and power density have been developed. All projects focused on developing Li-Ion batteries have synergy with hyperloop, in this project the battery storage has reached a capacity of 300 kWh and 400 kWh, Power: 300 kW, with a DC/DC converter (with overvoltage), a thermal conditioning unit, a BMS, a Thermal MS and their Mission manager.

5 Non-guided transport. Current and future trends

5.1 Introduction of the current and future way of transportation with the exception of the guided transport

5.1.1 Definition of way of transportation

Transportation is defined as the movement of humans, animals, and goods from one location to another. Transport enables trade between people, which is essential for the development of civilizations. “Modes” or “ways” of transportation refer to the different methods of transportation, of which several examples will be introduced below.

5.1.2 Definition of guided transport

The current and future trends of guided transport have already been introduced in the previous chapter. This chapter will introduce the current and future trends of non-guided transport.

Guided transport modes that are not covered in this chapter include railway, subway, and tramway.

5.1.3 Introduction of the current and future transport

Modes of transport include air (helicopter, airplane, drone), land (including rail via railway, subway and tramway, and road via walking, bicycle, car, bus, truck), water (motorized boat, ferry, sailing boat), cable, pipeline, and space. Alternatively, the transportation field can be divided into infrastructure, vehicles, and operations.

Transport infrastructure consists of the fixed installations, including roads, railways, airways, waterways, canals, and pipelines, as well as terminals such as airports, railway stations, bus stations, warehouses, trucking terminals, refuelling depots (including fuelling docks and fuel stations), and seaports. Terminals may be used both for interchange of passengers and cargo and for maintenance.

Means of transport are any of the different kinds of transport facilities used to carry people or cargo. Vehicles may include wagons, automobiles, bicycles, buses, trains, trucks, helicopters, watercraft, spacecraft, and aircraft.

5.1.4 Introduction to the ways of transportation discussed in this report

In order to organize this study relative to modal shifts and cross-fertilization, a segmentation of the current non-guided transportation systems is first set.

The first split of transportation is considering the different modes, which include:

- Ground transportation
- Aerial transportation
- Aquatic transportation

- Pipelines
- Space

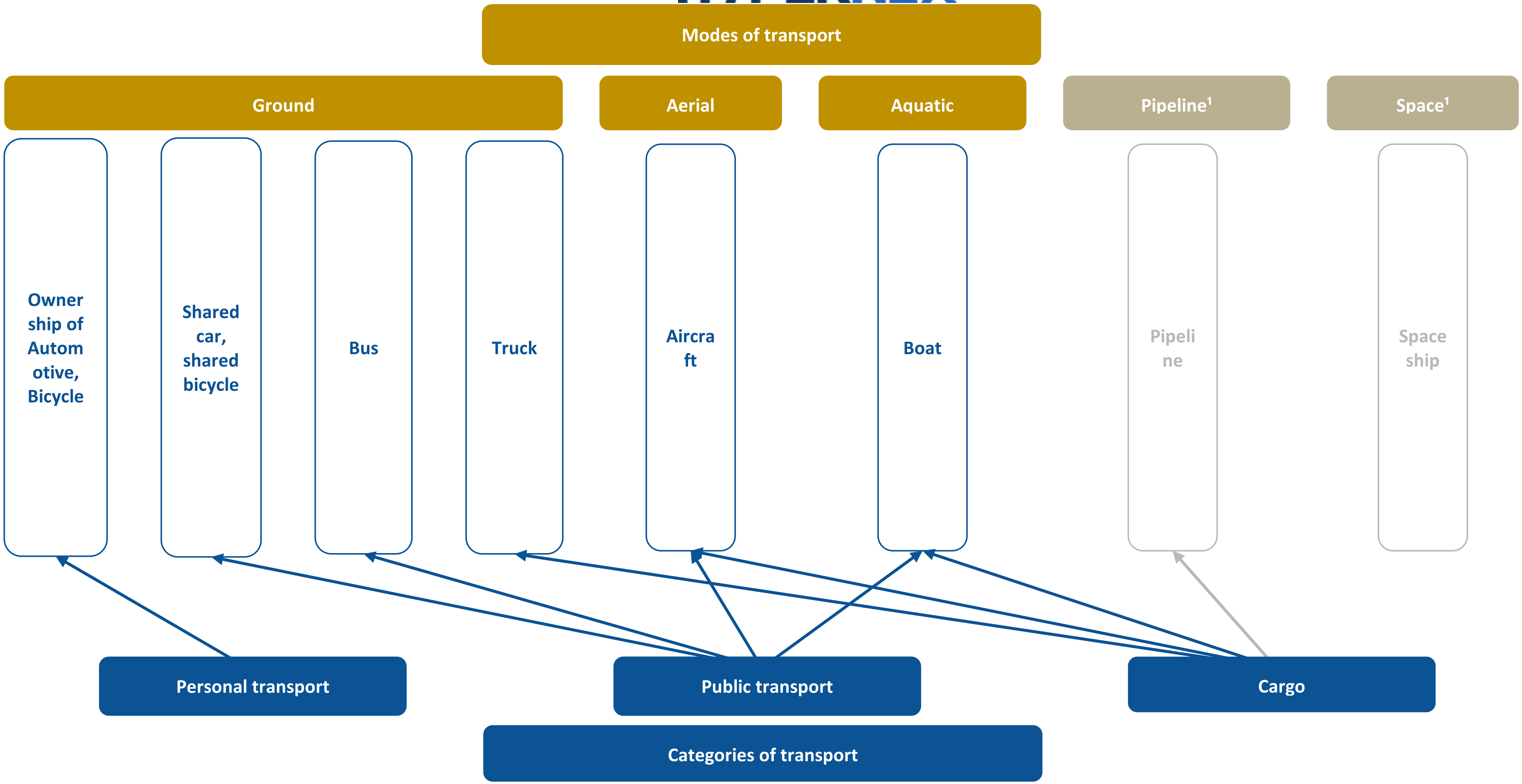
The second split of transportation is considering the different categories, which include:

- Personal transportation
- Public transportation
- Cargo transportation

Both of these segmentation methods are followed in the Annex 1: “Proposal 1 of Segmentation: Hierarchy of Transportation” and the Annex 2: “Proposal 2 of Segmentation: Classification of transports by kind and category”.

As a reminder, this section intentionally ignores guided transport, consisting of trains, subways and trams. Additionally, this study intentionally ignores walking, given that it is fully human-centric with no need for vehicles. Space transportation and pipeline transportation will only be considered in the cross-fertilization section, not in the modal shift section, given that these modes are extremely niche (in the case of space transportation, the use case is not earthbound; in the case of pipelines, the use case is a small set of specific materials).

In conclusion, the segmentation of transportation that will be considered in this study is the one introduced in Figure 57 “Field of study of transportation”.



[1] Mode not considered in the modal shift study but in the cross-fertilization study.

Figure 57. Field of study of transportation

5.2 Modal shift

This section considers the modal shift that will occur between existing transportation modes and hyperloop, upon the introduction of hyperloop systems as a new mode of transport. A "modal shift" refers to the demand for one mode of transport being captured by another mode of transport, due to comparative advantages offered by the preferred mode. In this case, the introduction of hyperloop as a mode of transport is expected to cause a certain modal shift from other transport modes to hyperloop.

The introduction of hyperloop may also cause a modal shift between other modes, depending on which are better integrated with the hyperloop systems and thereby made comparatively more attractive to customers. However, this report will focus on shifts between alternative modes and hyperloop, rather than shifts between multiple alternative modes.

5.2.1 Hyperloop vs ownership of automotive, bicycle

A common passenger transport mode today is personal automobile or bicycle - that is, using a car or bicycle that is owned for oneself or for one's family. These will be commonly referred to as "personal vehicles". Personal vehicles tend to be popular due to the high flexibility that they offer – passengers can choose whichever route they desire - as well as the low perceived operating costs, given that there is no ticket or fee directly associated with each ride. (Studies on behavioural science have demonstrated that operating costs for gasoline or maintenance can be more easily rationalized / ignored than the price of a ticket for public transportation, given that they are not associated with one specific journey - leading us to generally undervalue these costs when considering whether or not to use our personal vehicle for a trip).

Upon the introduction of hyperloop, it is expected that a portion of users of personal automobiles will shift their demand to hyperloop systems. Hyperloop and personal auto are both well-adapted for medium and long-distance journeys, but hyperloop offers several comparative advantages - most notably speed and the ability to work or be productive while travelling - which are not offered by personal auto. Therefore, a portion of personal vehicle journeys are expected to shift to hyperloop.

Journeys via personal bicycle are not expected to be significantly impacted by the introduction of hyperloop, and may even increase if bicycles are well-integrated into hyperloop stations. Currently, bicycles are rarely used for medium or long-distance journeys, and in cases where they are, the user is generally basing their decision on factors which are not offered by hyperloop (such as the pursuit of fitness / exercise). Therefore, few bicycle journeys will shift to hyperloop. However, if hyperloop becomes a preferred mode of travel for medium to long-distance travel, then personal bicycle use may increase for the "first and last mile" of the journey, i.e. to transport passengers to and from stations, for journeys which otherwise would currently be handled from start-to-finish by personal automobiles. In this way, hyperloop introduction may cause a modal shift towards personal bicycles.

5.2.2 Hyperloop vs shared car, shared bicycle

Shared cars and bicycles, referred to generally as “shared vehicles”, are those which are owned by centralized companies and provided to passengers on an as-needed basis, generally for a rental fee or subscription. These vehicles usually have fixed locations where they can be picked up and dropped off, but users have the flexibility to travel wherever they want in the interim.

The modal shift between shared vehicles and hyperloop is expected to be approximately the same as that between personal vehicles and hyperloop. That is, it is expected that some passengers will shift their demand for shared cars to hyperloop, while shared bicycles will be relatively unaffected and may even benefit from the introduction of hyperloop systems.

5.2.3 Hyperloop vs bus

A bus is a large vehicle, typically with space for approximately 50 passengers, which travels generally by road on a fixed route. For a fee, passengers can ride buses along this fixed route, but must have another method for getting to and from the origin and destination stations. Buses are most frequently used for short-distance trips within cities, but are also used at times for intercity trips.

It is expected that the introduction of hyperloop systems will cause a significant modal shift from bus to hyperloop for intercity journeys, given that hyperloop systems and buses offer similar use cases for these routes but the hyperloop will have significant speed and comfort advantages. For intracity routes, it is not expected that a significant modal shift from bus to hyperloop will occur, as the speed benefits of hyperloop are less apparent for shorter routes and therefore the accompanying hyperloop infrastructure cost is expected to outweigh the benefits, meaning that significant intracity hyperloop infrastructure will likely not be built.

5.2.4 Hyperloop vs truck

In this context, a truck refers to a “tractor-trailer” or “semi-truck” which is used to transport cargo for short, medium, and sometimes long distances - not to be confused with a “pickup truck”, which is a mode of passenger transport encompassed in the previous category for ownership of automotive, bicycle.

It is expected that the introduction of hyperloop systems for cargo will result in a modal shift from truck to hyperloop for medium and long-distance journeys, given the comparative speed advantage of hyperloop, for any time-sensitive cargo such as eCommerce, medical supplies, or perishable goods. For non-time-sensitive cargo this modal shift is expected to be less pronounced, due to the lower cost per kilometre likely to be associated with trucking. That being said, the flexibility of trucks (given their ability to go anywhere that there is a road) is superior to that of hyperloop systems, and therefore it is expected that trucks will be used for the first- and last-mile of any cargo journey, taking items from their origin to the hyperloop station, and again from the hyperloop station to their final destination.

5.2.5 Hyperloop vs aircraft

Aircrafts refer to powered airborne vehicles which can carry passengers (from roughly 1,800 per aircraft) or cargo (up to approximately 200 m^3). They are generally used for long-distance trips, given the speed advantage they provide over long distances; however, for short distances this speed advantage is outweighed by the additional travel time required to get to and from each airport, making it generally preferable to take other transport modes.

It is expected that the introduction of hyperloop systems will cause a significant modal shift from aircraft to hyperloop, for both passenger and cargo transportation, for medium and long-distance travel. This is due to the fact that hyperloop will offer both a speed and cost advantage compared to aircraft. For overseas travel, aircraft will remain the best option given the low likelihood that hyperloop systems will be constructed across oceans.

5.2.6 Hyperloop vs boat

Boats refer to vessels which travel over water, propelled by either oars, motors, or sails. They can be used for passenger travel or cargo travel, and range in size from "personal watercraft" which can carry as little as one person, to cargo ships or commercial vessels which can carry thousands of passengers or thousands of tonnes of cargo.

It is not expected that a significant modal shift will occur between boats and hyperloop upon the introduction of hyperloop systems, given the relatively different use cases and possible routes served by the two transport modes. However, there is an opportunity to integrate hyperloop systems into ports, making for a smooth transition between boat and hyperloop travel and thereby making each system more attractive than otherwise.

5.2.7 Tools to enhance intermodality with non-guided modes of transportation

Certain methods can be used to enhance intermodality between hyperloop systems and shared or personal vehicles, which would make it more likely that these alternative modes would benefit from rather than be harmed by the introduction of hyperloop. Specifically, introducing mobility stations that are well-integrated with numerous modes of transport will make the transfer between one mode and another more efficient, and thereby make each mode integrated in that mobility station more attractive. This would mean constructing bike sharing, car sharing, and public transportation stations all in the same location as a hyperloop station, while also potentially offering electric vehicle recharging stations, nearby gasoline / refuelling stations, parking lots for personal automobiles and bicycles, and any other modes which might be integrated. To make this transfer station as smooth as possible, it would also be ideal to have accurate signage to guide people between their desired modes, as well as one card or pass which provides access to multiple modes.

5.3 Hyperloop cross-fertilization

5.3.1 Definition of the hyperloop cross-fertilization in transport

5.3.1.1 Concept of cross-fertilization

The term did originate from biology where cross-fertilisation is “the fertilization of an organism by the fusion of an egg from one individual with a sperm or male gamete from a different individual” (Collins dictionary). In botany, it is the “fertilization of the flower of one plant by a gamete from the flower of a closely related plant (opposed to self-fertilization)” (Collins dictionary).

Cross-fertilization, by recombining genetic material from two parents, is used to maintain a greater range of variability for natural selection to act upon. This increases a species' capacity to adapt to environmental change and its chances of survival. This concept of “exchanges for survival” can be applied to a broader spectrum, hence this third definition from Collins dictionary: “Interaction or interchange, as between two or more cultures, fields of activity or knowledge, or the like, that is mutually beneficial and productive a cross-fertilization of scientific and technical disciplines.”

As such, cross fertilization is a valuable concept from a transport standpoint, with more and more competitive environments and the increasing demand of transport due to population growth. Cross-fertilization applied to transportation and its stakeholders is all about importing and mixing ideas from different places, markets or people to produce better products and services. Importing a technology from another industry, or hiring people from a different company are examples of this.

5.3.1.2 Categories of transport cross fertilization

In this section, the considered transports are the ones introduced in the Figure 57 “Field of study of transportation”.

The concept of cross fertilization can be considered through different prisms:

- Prism: Categories

• Economical/Environmental/Business cross fertilization
• Cross fertilization of knowledge

- Prism: level of study

• Enterprise level
• National level
• International level

For the definition of transport cross fertilization, we will introduce the 2 previous categories and each category may be studied under the enterprise, national and international level provided that it is pertinent.

5.3.2 Economical / environmental / business cross fertilization

Transport is of strategic importance for each country. Transport trends largely reflect the economic development of the state. There is a close connection between the transport sector and other sectors of the economy. On the one hand, to be successfully developed, they need an effective and well-developed transport sector. On the other hand, the transport sector is highly dependent on the development of other economic sectors. One of the main tasks of the transport sector is the provision of efficient and reliable transport services to help improve the economic and social stability. (Source: EU Funded ILO Technical Cooperation Project).

5.3.2.1 Economic aspects of cross-fertilization

5.3.2.1.1 City growth

Developing a new mode of transportation in a region comes with benefits for various sectors. For starters, the possibility of innovation, productivity and growth are created. As R&D is conducted for the infrastructure project in a region, the knowledge gained through production can be distributed and applied to other areas in the field. Therefore, an innovation hub is established from the new technology of a hyperloop system at a city and/or national level. Building a new form of transportation in a city can heavily impact the desire for the location of firms and housing areas. Investing in this type of development also enhances the attraction of a region for new business. Increased ease and accessibility of transportation within the supply chain for a business and for employees to transport to and from work amplifies the potential for increased productivity.

5.3.2.1.2 Decongestion

Congestion of city centres is an ongoing problem. Growth of population and increase in traffic leads to the rise of air and noise pollution. Firms choose their location based on what is most optimal for the company. For instance, a firm may choose to locate close to their manufacturers and distribution centres in order to optimize productivity. This leads to the exponential growth of urbanization in cities. However, citizens want to live close to their work while maintaining a reasonable cost of living. A hyperloop system offers a solution to this equation that is often quite difficult to resolve. For example, between Calgary and Edmonton, the fastest available travel option currently takes over three hours (Driving takes an estimated 3 hours 15 minutes; taking the bus is over 4 hours; and flying takes roughly 3 hours 30 minutes, when considering the time in the air, getting to and from each airport, and waiting in the airport before departure) rather than taking the hyperloop would be slightly above one hour (including access and egress time) (Source: Alberta feasibility study, TransPod, Inc.). This implies that the construction of a hyperloop system would unlock the potential for new development sites for both business and housing areas far from the city centre. This would mean a more affordable cost of living, a better standard of living, and urban decentralization, which would revolutionize home to work travel.

5.3.2.1.3 Fill in areas currently unserved by sufficient public transportation

The hyperloop designers have already begun feasibility studies in regions all over the world. The regions are chosen based on a number of factors, but one of the largest factors includes discovering locations that lack a sufficient transportation system. For example, a feasibility study was performed for the Edmonton-Calgary corridor in Alberta. The accessible modes of transportation between the Edmonton-Calgary corridor include personal transport (personal vehicle) and public transport (bus or aircraft). The study concluded that all possible modes of transportation in the corridor were inefficient in terms of time savings and environmental impact. Trips driving or flying (including boarding wait times) between the two cities take approximately 3-4 hours to complete one way. Although driving is the favoured mode of transportation due to the significantly cheaper price per trip, both methods create negative impacts for the region. Negative environmental impacts stem from the greenhouse gas emissions released from burning fuel for flights and driving vehicles. A hyperloop system will reduce the need for unsustainable methods of transport in the region. Likely, citizens will choose the hyperloop system because it fills the gaps other transportation methods are unable to fill. It is an ultra-high-speed mode of transportation that is easily accessible and affordable with a positive environmental impact.

5.3.2.1.4 Employment

During the construction of each hyperloop infrastructure, thousands of direct jobs in the fields of engineering and construction will be created. Indirect jobs (along the supply chain) and induced jobs (among industries that serve the construction and engineering workers) will also be created. Jobs will also be created for research and development during the testing phase.

It is a necessity that numerous disciplines be integrated, in order to make the hyperloop system function. For instance, a hyperloop team should be composed of: materials engineers, telecommunications engineers, nuclear physicists, structural engineers, mechanical engineers, electrical engineers, transportation planners, and numerous other non-engineering focused roles. Additionally, the hyperloop industry must rely on methods from aerospace engineering, rail, aviation, automotive, construction techniques, and several other disciplines. For this particular project, integration with construction entities, architects, and other industries is required.

The feasibility study for Alberta predicts that building a hyperloop line would be a major contributor to Alberta’s economy in the coming years. In Alberta alone, over 15,000 jobs per year are expected to be created by the construction project, along with a GDP boost of almost $20 billion and a total economic output of roughly $40 billion. Feasibility studies for other regions such as [commenter invited to add some of their feasibility studies inputs] have found similar results.

5.3.2.2 Environment

5.3.2.2.1 Climate

Reduced greenhouse gas emissions

Reducing the greenhouse gas emissions in transportation is a crucial problem to solve before 2050. In 2017, 27 % of total EU-28 greenhouse gas emissions came from the transport sector (22 % if international aviation and maritime emissions are excluded) (Source: EEA). By substituting for pollution-heavy transportation modes, the hyperloop system can drastically reduce Europe's emissions.

The hyperloop's fully-electric system is designed to be linked to the regional grid, via substations positioned external to the tube infrastructure. The vehicles have no direct emissions - rather than using fossil fuels on-board, the vehicles pick up the tube infrastructure's electrical power via a third rail. The grid-tube power is regionally-generated and delivered by grid, taking advantage of high-efficiency power plants (or solar/wind), rather than individual, inefficient internal-combustion engines as in cars and airplanes. The grid power can also be supplemented with photovoltaics (solar panels) which can be installed along the length of the infrastructure to provide power to the system, in the event that the local power grid is not powered by sufficiently sustainable energy sources.

This presents significant emissions benefits compared to existing transportation modes. For instance, the feasibility study for Alberta, Canada between the 300-kilometre Calgary-Edmonton corridor is currently served by cars and planes. The analysis concluded that implementing a hyperloop line would result in roughly 16 million tonnes of CO_2 emissions from transportation being avoided in the first 30 years of operations, by reducing the number of cars and planes required in operations. This environmental benefit - already strong - would be even stronger in most regions; Alberta's energy grid is almost fully powered by coal and natural gas, meaning that any power requirements above and beyond our ability to produce electricity via solar panels on the infrastructure is coming from extremely unsustainable sources. In a country like France, where the energy mix is almost 100% supplied by nuclear and sustainable sources, the environmental benefits of the hyperloop system would be even stronger.

Minimal land impact

The modern design of the hyperloop system decreases the environmental impact in an unexpected way. The infrastructure is to be built on elevated pillars. This means that the land required for the infrastructure is minimal, especially in comparison to transportation systems such as highways and railways. That is, the hyperloop line only needs the land underneath each pillar - about 800 square meters per kilometre. In contrast, a typical railroad or highway requires a corridor of 40,000 square meters per kilometre (40 meters wide, for the full length of the corridor), completely dissecting regions. Unlike railroads or highways, the hyperloop system does not disturb animal migration patterns or local activities such as farming, because it is designed with enough clearance so that animals, tractors and local roads can pass underneath the infrastructure.

5.3.3 Cross fertilization of knowledge

Cross fertilization of knowledge is not only about exchanging purely technical or R&D knowledge but also about sharing experience.

The goal is to reinforce international cross-border and cross-sector collaboration in research and innovation by means of exchanges of research and innovation personnel in order to be able to face global challenges better. Key activities shall be to support exchanges of R&I.

What follows are the knowledge fields that the hyperloop system can take advantage of.

5.3.3.1 Specific technology

The hyperloop system is a new way of transportation exploiting already existing technologies including technologies used by the current transports. In the hyperloop system's development process, one of the key challenges is to identify the current technologies that can be adapted and/or enhanced to be implemented on the hyperloop system.

What follows is the reference architecture of the hyperloop system. These aspects are issued from the JTC 20 works - WI (Work Item) "Aspects, Reference architecture". The JTC 20 is the Joint Technical Committee establishing the European standardization framework of the hyperloop system. At the time of writing, the standards of the WI Aspects, Reference architecture are being drafted, hence, the following reference architecture is not authoritative. Nevertheless, the following reference architecture allows a high level overview of the hyperloop's aspects which can be adapted from existing technologies.

Hyperloop system - Reference architecture

— Infrastructure: Structure and Environment

- Route Structure and Enclosure
- Low-Pressure Environment Control
- Stations and Station-Related Infrastructure
- Infrastructure Maintenance

— Vehicle: Structure and Environment

- Vehicle Structure
- Vehicle Internal Environment
- Vehicle Maintenance and Storage

— Dynamic Control and Operation of the System

- Longitudinal Forcing of Vehicle
- Transverse Forcing of Vehicle
- Energy Management
- Command, Control, Communication, Signalling
- Emergency Management

The specific knowledge and skills of the current modes of transportation which can be adapted to the hyperloop system are listed below in Table 13.

Table 13. Cross table between the hyperloop system's aspects and the current transport

Hyperloop systems & subsystems	Current transports with technologies / knowledge useful to the hyperloop system				
	Railway	**Airplane**	**Spaceship/ space station**	**Subway**	**Road**
Infrastructure: Structure and Environment					
Route Structure and Enclosure	Tunnel, geographical line			Tunnel, tube	Tunnel
Low-Pressure Environment Control		Aircraft fuselage	Spaceship enclosure		
Stations and Station Related Infrastructure	Station	Station	Space station	Station	
Infrastructure Maintenance	Tunnel & Track maintenance			Track maintenance	Tunnel maintenance
Vehicle: Structure and Environment					
Vehicle Structure	Aerodynamism, frame	Aerodynamism, frame, pressure resistance	Aerodynamism, pressure resistance		Manufacturing process
Vehicle Internal Environment	passenger environment	passenger environment		passenger environment	
Vehicle Maintenance and Storage	Vehicle Maintenance and Storage	Vehicle Maintenance	Vehicle Maintenance	Vehicle Maintenance and Storage	
Dynamic Control and Operation of the System					
Longitudinal Forcing of Vehicle			Motion in vacuum environment		
Transverse Forcing of Vehicle			Motion in a vacuum environment		
Energy Management	Power transmission, power storage	Power storage	Power storage, vacuum power transmission	Power transmission, power storage	
Command, Control, Communication, Signalling - CCCS	CCCS	CCCS	Vacuum CCCS	CCCS	
Emergency Management - EM	EM	EM		EM	

NOTE In this table, the tube transport was not mentioned but can still be considered as an initial input for the *Route Structure and Enclosure* and *Infrastructure Maintenance*'s aspects

5.3.3.2 Safety frame

In order to develop a safe hyperloop system, the system's conception must be highly constrained by standards. These standards must provide general guidance in evaluating the safety aspects of a design.

Knowing that the hyperloop system is a new way of transportation under development, its safety frame still needs to be established. For this purpose, it is consistent to initiate the process by following existing guidelines and methods to be used to achieve different levels of safety.

These levels of safety define the rigour to be applied in the conception of the critical systems. In the avionics domain, this safety level named Development Assurance Levels varies from A to E where A is the highest. In the Railway domain this level named Software Safety Integrity Levels (SSIL) varies from 1 to 4 where 4 is the highest. High levels mean high impact of a failure on safety.

The hyperloop system's safety requirements can be adapted from standards of many application domains including the civil aviation, the automotive, the space, the nuclear plants, the railway, the automation and the industrial control. What follows are the standards used by each application domain to establish the safety requirements at the system level process and system level product.

Civil aviation (ARP 4754, ARP 4761) (Source: CG2E)

The ED79A/ARP4754A addresses the total life cycle for Systems that implement aircraft level functions. It excludes specific coverage of detailed Systems, software and hardware design processes beyond those of significance in establishing the safety of the implemented system. More detailed coverage of the software aspects of design are dealt with in EUROCAE/RTCA document ED-12B/DO-178B. Coverage of complex hardware aspects of design are dealt with in ED80/DO254. Methodologies for safety assessment processes are outlined in SAE document ARP4761.

Automotive (ISO 26262) (Source: CG2E)

The ISO 26262 standard introduces a 4-level ASIL scale for categorizing systems, hardware and software components based on a ranking of criticality of the consequences of their potential failure.

Space (ECSS-Q-ST-30C, ECSS-Q-ST-40C) (Source: CG2E)

The ECSS safety (Q-ST-40C) and dependability (QST-30C) standards introduce a 4-level scale for categorizing systems, functions and hardware and software components implementing them, based on a ranking of severity of consequences of their potential failures. At system level, the allocated criticality category impact is twofold: Generic product safety requirements with direct impact on the design; Process safety requirements with direct impact on the activities to perform.

Nuclear plants (IEC 60880, IEC 61513) (Source: CG2E)

In nuclear domain the term "safety" is used for prevention of accidents, when other domains use instead the term "security". This latest term is in the nuclear domain, used for malevolent actions that are not in the scope of this paper. Note also, that for the domain, we have to make a distinction between the "nuclear facility" as a system and the "I&C systems", that can be based on "conventional" technologies (relays, hardwired logic) or programmed technologies (computer based).

Railway (CENELEC EN 50126, EN 50129) (Source: CG2E)

For railway domain, the reference standards in Europe are the CENELEC reference system: (in particular EN 50126 and EN 50129 at system level, and the IEC 61508. The latter (a generic standard applicable after appropriate instantiation to any type of electrical/electronic/programmable electronic safety-related system) is furthermore a founding standard from which many aspects of the CENELEC series are derived as railway applications of IEC 61508 prescriptions.

Automation, industrial control (IEC 61508, IEC 61511, IEC 62061) (Source: CG2E)

By automation, we understand the industries that are not already described in the previous chapters of this paper. This includes the continuous process industries such as nuclear facilities (beside energy production), non-nuclear energy, metals, cement, oil and gas and chemicals, the manufacturing industries with the exception of automotive and the batch production industries such as pharmaceuticals and food and beverage. These industries are relevant of IEC 61511 for the continuous and batch processes and of IEC 62061 for manufacturing industries. Both standards are derivates of IEC 61508 and, as they are not self-supporting, refer to IEC 61508.

5.3.3.3 Project & production management

The hyperloop system has much to learn from the existing ways of transportation in terms of project management and production management.

About project management, breaking work into smaller tasks is a common productivity technique used to make the work more manageable and approachable. The WBS (Work Breakdown Structure) is one of the most important project management documents. This is a tool followed by the aircraft, ship, space and surface vehicle systems to mention just a few. Their WBS are available in the Annex 3: Work Breakdown structure examples.

According to these examples, a general WBS applicable to all the transports, including the hyperloop system, would include the following aspects.

- Integration, Assembly, Test and checkout
- Systems Engineering
- Program Management
- System Test and Evaluation
- Training
- Data

- Peculiar Support Equipment
- Common Support Equipment
- Operational/Site Activation
- Industrial facilities
- Initial Spares and repair parts

Production management's responsibilities are summarized by the "Six M's": men, machines, methods, market, materials, and money (Source: Production management, Britannica).

"Men" refers to the human element in operating systems. Since the vast majority of manufacturing personnel work in the physical production of goods, "people management" is one of the production manager's most important responsibilities.

The hyperloop system can, among others, learn from the automotive domains with its mass production methods to achieve a successful ramp-up for its vehicle (the m of "methods" from Six M's), but also by turning to automation and robotisation (the m of "machine" from Six M's) and by ensuring a logistic flow management by identifying and tracking individual components from their journey along the assembly line (the m of "material" from Six M's).

5.3.4 How to integrate in the current & future mesh of the transport infrastructure

During the hyperloop system's development process, the hyperloop system's integration needs to be anticipated in order to build a design actually thought to fit with the current & future mesh of the transport infrastructure.

There are two main axis of integration to highlight. The one relative to the physical implementation and the one relative to the virtual implementation.

The first one is highly dependent on the location of the future hyperloop' lines and stations. It is agreed that – according to the typology, the environment and the activity of an area – it will be preferred one of the implementation's solutions of the hyperloop system (on-pylons / on-ground / underground / in-tunnel). Also, the stations' implementation will be adapted according to the needs and layout of the area. Other physical integration topics would be the access points, service points, infrastructure maintenance and energy access.

Knowing that, the physical integration of the hyperloop system will not be detailed in this paper. Nevertheless, this topic is detailed in the feasibility studies conducted by the hyperloop stakeholders on specific geographical sections. (See the Alberta feasibility study).

The second axis of integration to consider is the one related to the virtual implementation. How to integrate the hyperloop system in the current & future virtual mesh of the transport infrastructure?

The TMS are consistent tools to deal with the future hyperloop implementation. They are used to manage the air, road, ship and railway traffic. The "TMS (Traffic or Transportation Management Systems) provide permanent control across the network, automatically sets routes for [vehicle] and logs [train] movements as well as detects and solves potential conflicts." (according to Thales Group). It is "a logistics platform that uses technology to help businesses plan, execute, and optimize the physical movement of goods [and passengers], both incoming and outgoing, and making sure the shipment is compliant, proper documentation is available". (according to Oracle)

To ensure the transportation management, the TMS provide visibility into day-to-day transportation operations, trade compliance information and documentation, and ensures the timely delivery of freight, goods and passengers. To do so, they "collect traffic-related data from heterogeneous sources such as vehicles, traffic lights, and in-road and roadside sensors" for the road domain, GPS data for the ship domain to name but a few (Source "Traffic management systems: A classification, review, challenges, and future perspectives"). Also, the interaction, connectivity communication between the different transport actors is the key to TMS.

The TMS have multiple interests as reducing traffic congestion, enhancing the coordination of civil protection and emergency actions but also streamlining the shipping process to make it easier for businesses to manage and optimize their transportation operations, whether they are by land, air, or sea.

6 Standardization and regulation

6.1 Introduction

Hyperloop standards setting and regulatory framework is an essential enabler of the seamless travel in a global hyperloop network. As numerous studies show standards have been influencing society and businesses across various markets and have been creating common grounds and language for producers/ manufacturers and consumer for many decades. For hyperloop specifically the absence of standards and regulatory framework may hinder further development and potential deployment of the hyperloop. In addition safety by design in every single part of the system can only be achieved through standards. The expectation is, based on the success stories of standards development and applicability, the standards adopted by hyperloop or specifically developed for hyperloop systems will be an important market tool for industrialization and commercialization of hyperloop as a new transport mode. The generic benefits of the standards for innovation have already been depicted in the WP3.

Standardized hyperloop requirements, systems and parameters that ensure interoperability and safety, while at the same time support a regulatory framework are key for the development of the hyperloop and its global operating network.

6.2 Standards development benefits

The benefits of standards and development are multifold and create value at many levels[19] and parts of the society. The generic benefits as listed for different parts of the society, the impact on the business and also for the participants directly involved in the standards development are listed in the Table 14.

The main objective is the standard setting in support of the hyperloop industrialization and development of the EU regulatory framework. Usually key developers/organizations get together to jointly create a standard if they see a potential in developing standards that will give access to a much larger marketplace rather than a scattered landscape of different technology being used. Hyperloop European Standards (ENs) will be needed not only for complying with the technical requirements of an EU hyperloop related legislation, but also in commercialization and industrialization of the sector. In addition the standards provide a good basis for the policy makers at the national and European level to understand the technology and its requirements.

The absence of a regulatory framework may hinder further development and potential deployment. There is an agreement between the hyperloop promoters that they would face the “valley of death” of the development cycle (loss of motivation, decrease of investment) with a long time-to-market if the regulatory environment is not defined in parallel with the hyperloop systems development.

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[19] BLIND, Knut. et al. *The Economic Benefits of Standardization – an update of the study carried out by DIN in 2000.* DIN German Institute for Standardization. 2011.

Table 14. Generic standards benefits. (Source: A World Built on Standards – A Textbook for Higher Education)

SOCIETY	BUSINESS	PARTICIPANTS
• Reduced technical barriers to trade • Trust in products and services • Increased quality and safety • Dissemination of best practices • Economic growth	• Market penetration • Global availability • Increased sales • Knowledge and sharing best practice • Increased productivity • Frame innovation and reduce development cost • Improved quality/cost balance	• Influence on standards – being the standard setter • Up front knowledge on coming standards • Deeper understanding of standards • The networking effect – creating and main-taining contacts

Closer coordination between EU / government driven regulation and industry driven standardization will allow for maximizing synergies in supporting innovation (*K.Blind et.al 2017*). This will enable shorter time to market and return of investments for hyperloop developers.

The development of hyperloop standards is ongoing at the Joint **CEN/CENELEC Technical Committee 'Hyperloop Systems'**. Initially at the European level with a strong link to international standards. European Standard is powerful and beneficial through its regulated status at European Union. There cannot be national competing standards with ENs. Once hyperloop standards are in place they will allow various stakeholders such as manufacturers, suppliers, service providers, (local) governments to certify and assess the hyperloop systems and related products against one single standard in all of Europe. The European standardization organizations such as CEN / CENELEC together with their members such as NEN, DIN, UNE, UNI, AFNOR, etc. enable through their agreements with the ISO/IEC international standards development as well.

Following the specifics and environment of the hyperloop technology development the benefits of standards development are multifold as well. These benefits are summarized in the Table 15 [source IEC, Ref: https://storage-iecwebsite-prd-iec-ch.s3.eu-west-1.amazonaws.com/2019-09/content/media/files/iec_case_studies.pdf].

Table 15. Hyperloop standards benefits

Standardization Benefits:	
Value proposition	**Hyperloop Public Acceptance** Standards enable industry wide known and well accepted requirements, safe by design products, interoperability, common language for testing/prototyping and demonstration, reduced risk, level playing field. This all leads to trust, confidence / competence build-up and good reputation with partners and public.
Business impact	**Market Leadership** Gain competitiveness through standards shaping and easier early adoption of the latest standards: - Open markets, ability to do business and build partnerships; - Reduce costs; - French companies that are members of standards committees achieve annual growth of 4% compared with average growth of 3.3% for all companies together ((Ref: AFNOR Report) https://marketing.afnor.org/en/Etude/ImpactEconomiqueNormalisation)
Detailed overview of benefits	- influence the standard setting; - facilitate the **development of the regulatory framework;** - support testing/ prototyping and development at the test facilities; such as infrastructure; subsystem test, magnetic levitation subsystem test - facilitate the **safety** and **compliance**; - shorten time to market;
Relationship building	**Enhance trust and visibility** - Build up trust for **public acceptance** necessary for hyperloop market **scaling up**; - Visibility in relationship building with the technical partners, government(s),
Competitive environment	**Market intelligence** - gather **market intelligence** – anticipate market developments and needs; - leverage from the knowledge of participants, partners, competitors in a neutral environment.

6.3 Open standardization

Current hyperloop standards are being developed as open standards with broad participation from various sectors.

One of the alternative paths in the hyperloop technology standardization could have been the development of proprietary standards outside of the open and formal standards development such as the CEN-CENELEC/JTC 20.

Traditionally the choice to follow such path is driven by two main reasons: protect of own technology and lack of trust / incentive in sharing knowledge with their competition in an open standard setting. Typically, such organizations aim for full control of the standard in a very limited closed community of partners. Judging from various cases in different sectors in the past this may provide competitive advantage for such a company, the so called first-mover advantage. However, there are major issues with such a strategy:

1. **Lock-in**: in a closed environment with proprietary standards the lock-in is likely to happen. Lock-ins can result in monopolies that are not encouraging to competition[20]. In EU and many other countries, the markets are subject to antitrust and competition laws that prevent monopolies and provide an equal playing field for similar businesses that operate in a specific industry while preventing them from gaining too much power over their competition. The expectation is that the same laws will apply to the hyperloop sector as well. In addition, the governments are expected to be potential customers for the hyperloop sector. Usually in their procurement process governments make sure to avoid proprietary solutions and refer as much as possible to standards developed in an open consensus-based system.

2. **No adoption, limited support-base**: in developing proprietary standards many stakeholders that would have been part of the standard setting are excluded. There is very little incentive from these stakeholders to cooperate with the owner of this proprietary standard. The community is in that case very limited. Instead such stakeholders will rather join an open community such as CEN-CENELEC/JTC 20 where they can provide input and be part of the standard setting. This creates automatically a large support base for the implementation of these standards in practice as opposed to the closed proprietary standards / solutions.

3. **Fault-sensitive**: developing proprietary solutions in a closed community is prone to fault and mistakes.

Therefore, developing standards jointly with other stakeholders in an open ecosystem will address the above risks and should be pursued continuously in the future by engaging with even more stakeholders. Several activities that are already ongoing help in the development of standards that are open to all stakeholders:

1. Standardization under a JTC 20 is open to all relevant stakeholders;

2. Standards organization such as CEN/CENELEC to pursue all stakeholders and in particular hyperloop developers in participation in standardization by showing the benefits and risks of non-participation;

3. Standards organization such as CEN/CENELEC act as impartial ambassador in educating stakeholders, governments and policy makers in the importance of hyperloop standards;

4. Standardization roadmap will determine which existing standards can be used, which need modifying and which ones need to be defined;

5. Writing and maintain well defined unambiguous base hyperloop standards;

In addition, a set of activities will be necessary to pursue the openness also in the future and encourage the application of the standards in scaling the hyperloop market. A list of possible actions is listed below:

1. Enforce adoption and utilization of standards in the entire hyperloop development chain;

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[20] De Vries, H., & Oshri, I. (2008). Standards Battles in Open Source Software. London: Palgrave Macmillan UK.

2. Engage and coordinate with the EU and national / local governments for regulation and broad industry driven standardization to allow for maximizing synergies in supporting innovation:

a. engaging in standardization process;
b. national hyperloop programs and cross-country cooperation;
c. procurement policy supportive of innovation such as innovation partnership Directive 2014/24/EU [21].

3. Establish an awareness program within the standardization community as well as at the company level for:

a. technology and standards promotion in joint outreach activities e.g. press releases, workshops, etc.;
b. demonstrate technology especially on interoperability, performance and safety based on standards.

4. Write and maintain conformance tests to verify hyperloop system and sub-system compliance with the standards;

5. Establish a formal certification program based on the standardized conformance tests.

6.4 Harmonized and voluntary standards

The European standardization system is an important tool to achieve and maintain the single market in Europe. A single market for hyperloop systems is fully aligned with needs of the hyperloop industry. Most of the existing European standards are voluntary technical standards developed by the industry. Only about 20% of these standards are developed as harmonized standards (HENs) upon a request from the European Commission. These standards can then be used as a tool to demonstrate conformity with the relevant EU legislation. European Commission issues standardization request, according to so called New Approach[22] when there is a legislation or policy necessity to do so. The process is depicted in Figure 58.

[21] https://ec.europa.eu/transparency/regdoc/rep/3/2018/EN/C-2018-3051-F1-EN-MAIN-PART-1.PDF
[22] New Approach CEN/CENELEC

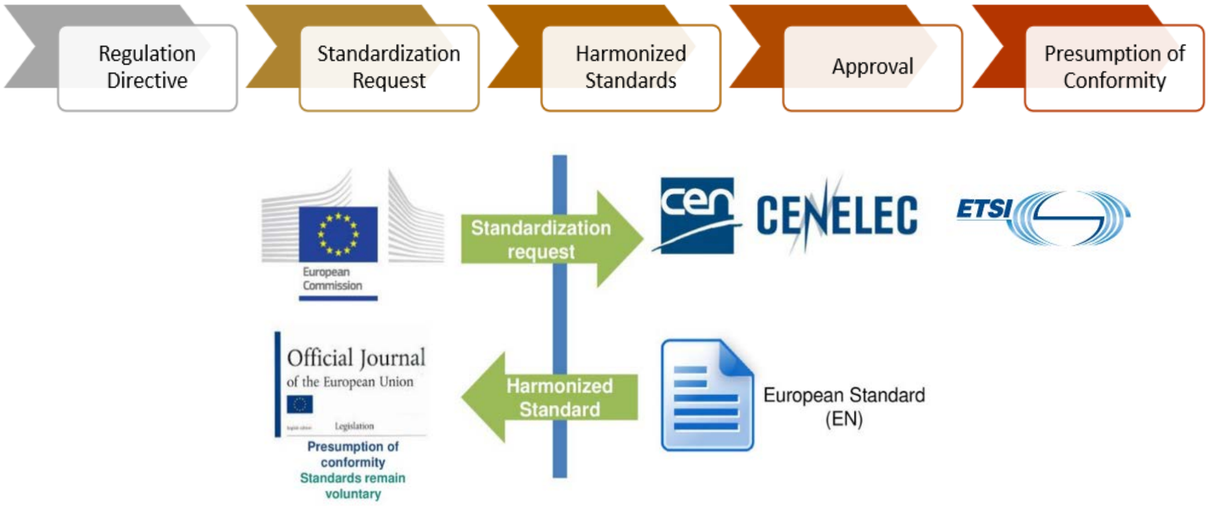

Figure 58. The New Approach[22] process

The standardization requests are discussed by a special Committee on Standards (CoS) as defined in Regulation (EU) 1025/2012. CoS members are national authorities, industry representatives, ANNEX III organizations, ESOs and industry associations (e.g. Orgalime). The entire European Standardization System (ESS) is depicted in Figure 58.

The decision makers in initiating the work necessary for the regulatory framework are thus similar to the standards setting. However, the decision making happens at yet another level. Usually, it is the DG Grow that decides on the standardization request (see Figure 58, Figure 59). This is done in consultation with other involved DGs, CoS and member states.

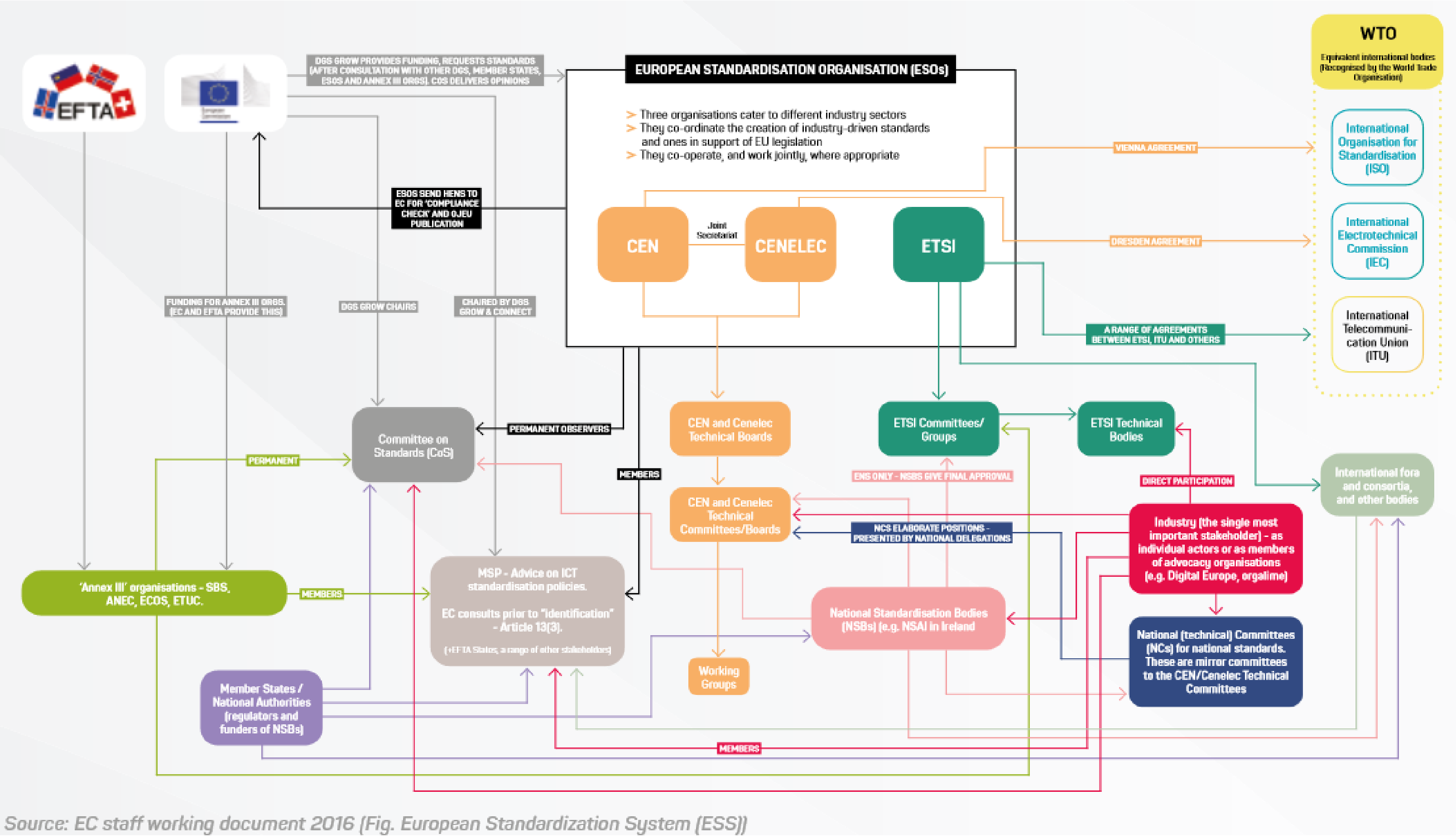

Figure 59. European Standardization System (ESS) [23]

[23] Source ETSI

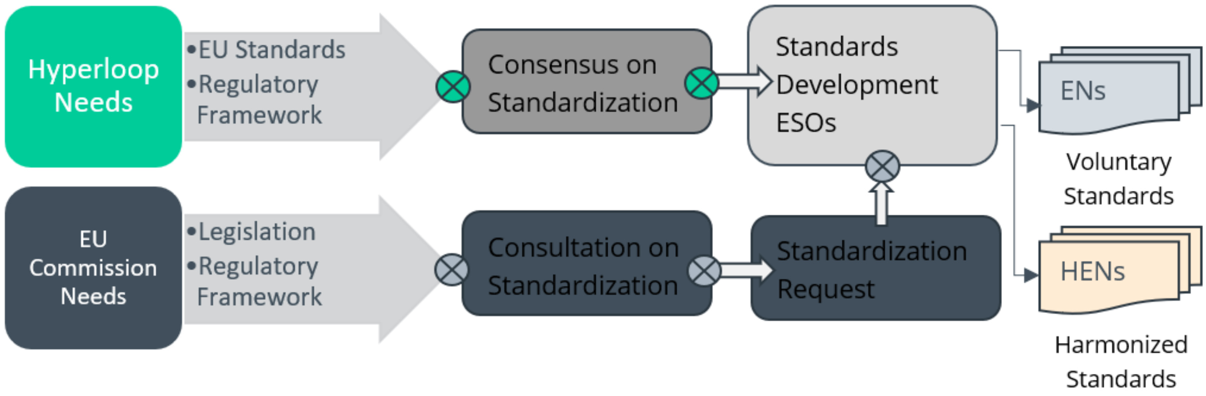

Figure 60. Stakeholders in standardization and framework development

6.5 European Conformity Assessment Bodies and Notified Bodies

The 'Blue Guide' on the implementation of EU product rules 2016 and Decision No 768/2007/EC describe the procedures related to making products available on the European market. As part of making the products available on the market, the manufacturer is responsible for the conformity assessment related to those products. The conformity assessment may be conducted either by self-declaration of the manufacturer or by self-declaration supported by assessment performed by in-house accredited conformity assessment bodies or notified bodies.

This chapter aims to discuss the utilization of conformity assessment bodies and notified bodies as part of the conformity assessment process both for making products available on the market and for specific installations (taking into service), organized as follows:

- Description of the conformity assessment bodies and notified bodies for the general market.
- Description of the approach taken within the railway domain.
- Description of the approach taken within aviation.
- Provision of general recommendations for hyperloop.

European Assessment Bodies and Notified Bodies for the general market

Whether or not conformity assessment bodies and notified bodies are required by legislation can be sector specific. Decision No 768/2008/EC on a common framework for the marketing of products describes the possibility of conformity assessment to be conducted by the manufacturer with a self-declaration alternatively by utilizing accredited in-house conformity assessment body or notified body.

The 'Blue Guide' defines the conformity assessment as:

— Conformity assessment is the process carried out by the manufacturer of demonstrating whether specified requirements relating to a product have been fulfilled.

— A product is subjected to conformity assessment both during the design and production phase.

The conformity assessment for products as described in Decision No 768/2008/EC covers both the design and production phase. The different alternatives of performing conformity assessment are further described by modules that either cover the design and production phase separately or modules that cover both phases. According to the 'Blue Guide', the conformity assessment procedures given by the modules are equivalent from a legal point of view but not technical in terms of methods. Their application in the sectoral legislation aims at providing high level of confidence as regards the conformity of products to the relevant essential requirements.

The conformity assessment procedures can vary between different sectors. The conformity assessment process for products to be put on the market is depicted in **Figure 61** below. As shown in the figure, the following actors are involved in the conformity assessment:

- Legislator (who sets out the legislative requirements)
- Manufacturer (launches design, production process and is responsible for conformity assessment being performed)
- (If required) accredited in-house conformity assessment body or notified body

In addition to performing conformity assessment of products being put on the market, there are sectors, as for example the railway domain, where conformity assessment is also performed for specific installations and system being taken into service; for further details, see section 7132.2.2.

As suggested above, the conformity assessment may be supported by accredited in-house conformity assessment body or notified body. This leads to the question, what is the definition of conformity assessment body and notified body? The "Blue Guide" defines the conformity assessment body as "body that performs one or several elements of conformity assessment, including one or several of the following activities: calibration, testing, certification and inspection." Furthermore, an accredited in-house conformity assessment body must not have any activities other than conformity assessment and must be independent from any commercial, design and production entities. In addition, it must be accredited in accordance with regulation (EC) No 765/2008. The 'Blue Guide' defines notified bodies as "conformity assessment bodies which have been officially designated by their national authority to carry out the procedures for conformity assessment within the meaning of applicable Union harmonisation legislation when a third party is required. They are called ‘notified bodies’ under EU legislation."

Decision No 768/2008/EC defines eight modules (named with letters A to H) which lay down the responsibilities of the manufacturer and the degree of involvement of the in-house accredited or notified body. There are further variants within the modules which enable the necessary level of protection to be ensured for products presenting higher level of risk while avoiding the imposition of a heavier module.

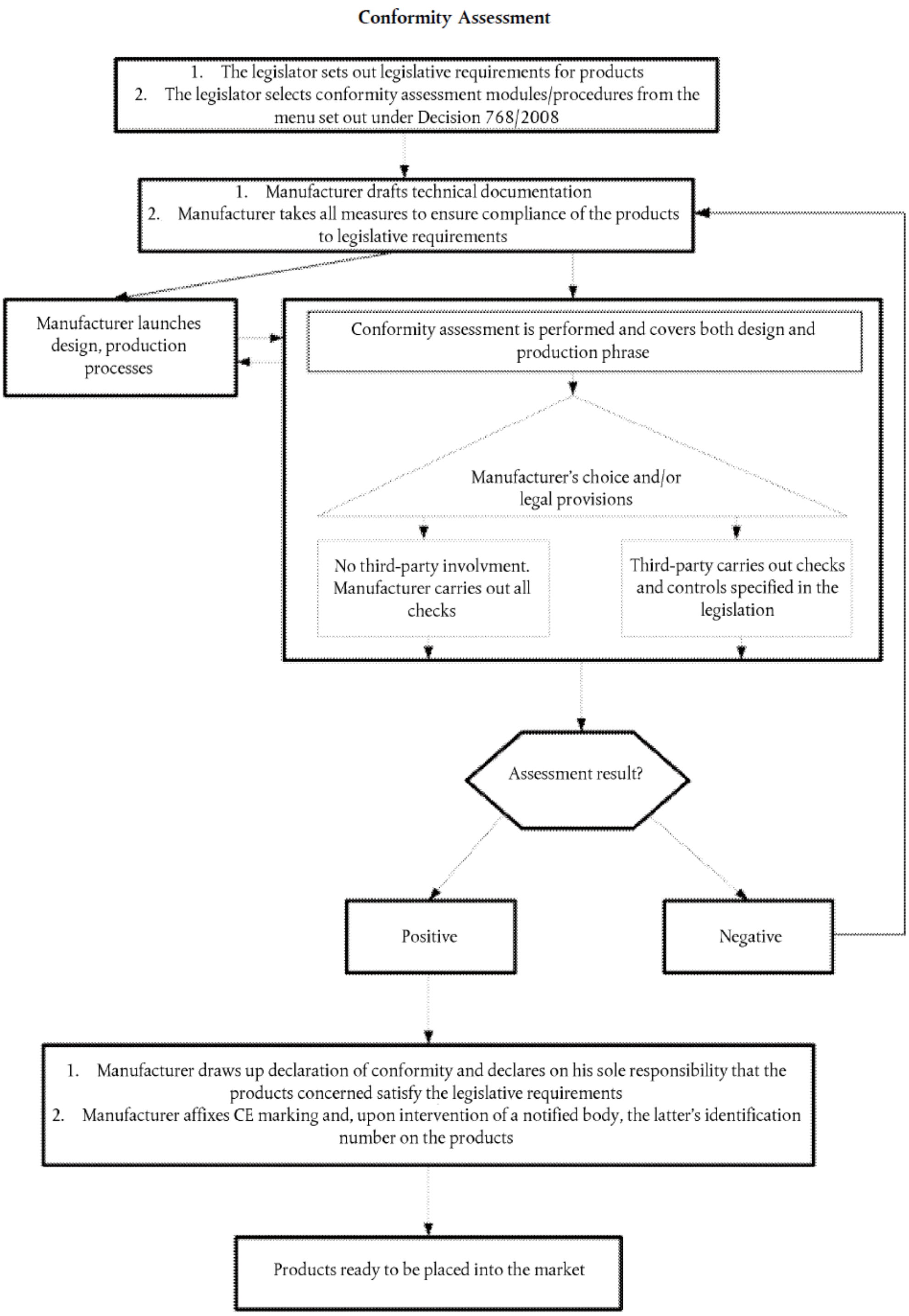

Figure 61. Conformity assessment within different sectors. Source: 'Blue Guide'

Practice in railway domain related to Assessment Bodies and Notified Bodies

Within the railway domain conformity assessment is required to be performed by notified bodies both for products that are put on the market – interoperability constituents (intended to be incorporated into a subsystem) and subsystems – and for subsystems that are placed into service.

The interoperability directive (EU) 2016/797 brakes the system constituting the Union rail system down into subsystems within structural areas and functional areas:

- Structural areas:
    - Subsystem infrastructure
    - Subsystem energy
    - Subsystem trackside control-command and signalling
    - Subsystem onboard control-command and signalling
    - Subsystem rolling stock
- Functional areas:
    - Subsystem operation and traffic management
    - Subsystem maintenance
    - Subsystem telematic applications for passenger and freight services

The structural subsystems must be subject to conformity assessment before the subsystem may be authorised to be placed into service. The conformity assessment to be performed of the subsystems involve a Notified Body that performs checks at each of the following stages: overall design, production and final testing. The process of performing the conformity assessments is described by modules that are defined in Commission Decision 2010/713/EU. The conformity assessment activities to be performed are dependent on the choice of the module(s) applied, however, in any case the technical specifications, that conformity is to be demonstrated against, are the same independently from the choice of module(s).

The conformity assessment and certification performed by Notified Bodies are both performed for interoperability constituent (to be placed on the market and incorporated into subsystems) and for subsystems (to be placed on the market and/or taken into service). The conformity assessment activities are in both cases governed by the process description of the chosen module(s).

There are ten different modules defined for interoperability constituents and five different modules defined for subsystem. Some of the differences related to the conformity assessment activities performed depending on the choice of module(s) are:

- The degree of involvement of the Notified Body. There is one module defined for interoperability constituent where there is no involvement of a Notified Body and where manufacturer provides a self-declaration that the interoperability constituents satisfy the requirements that apply to them.

- Whether the Notified Body performs tests and/or is responsible for having the tests carried out alternatively that the Notified Bodie assesses the quality management system which among other ensure that adequate testing is performed.

- Whether the Notified Body assesses each specific instance (or random samples) or whether the Notified Body assess the quality management system that assures that serial production is according to approved type.

The description provided above are only the general outline of the differences of the conformity assessment activities performed depending on the choice of module(s). Further, regarding the choice of module(s) that are possible to apply for a given interoperability constituent or subsystem may be defined by the relevant technical specifications for interoperability.

A major part of the conformity assessment performed by a Notified Body for an interoperability constituent or subsystem is the evaluation of compliance with the essential requirements defined in the interoperability directive (EU) 2016/797, safety being one of the essential requirements. For some of the subsystems and interoperability components, compliance with essential requirement safety shall be addressed by among other compliance with the Commission Implementing Regulation (EU) No 402/2013 (on the common safety method for risk evaluation). Compliance with Commission Implementing Regulation (EU) No 402/2013 is assessed by accredited or recognised (according to Annex II of (EU) No 402/2013) Common Safety Method (CSM) Assessment Body. The CSM Assessment Body can be the Notified Body itself or a different body. For the latter case, the Notified Body must take the assessment report from the CSM Assessment body into consideration when issuing the certification documents for the subsystem. In such a situation, the Notified Body must check that CSM Assessment body meets the same competency, independency, and impartiality requirements as they apply to a Notified Body. The procedure on how to perform this check is described in the recommendation for use RFU-STR-706 issue 1 released by NB-Rail.

In addition to evaluating compliance with essential requirement a major part of the conformity assessment performed by a Notified Body is to evaluate compliance with technical specifications given by the technical specifications for interoperability and/or there within referenced technical specifications.

Practice in aviation domain related to Assessment Bodies and Notified Bodies

Regulation (EU) 2018/1139 (including its amendment (EU) 2021/1087) of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, shortly denoted Basic Regulation, presents requirements needed to achieve the principal objective of establishing and maintaining a high uniform level of civil aviation safety in the Union. One of the mechanisms of achieving the objective is by performing certification and by the issue of certificates. The Basic Regulation (EU) 2018/1139 defines certification and certificate in the following manner:

'certification' means any form of recognition in accordance with this Regulation, based on an appropriate assessment, that a legal or natural person, product, part, non-installed equipment, equipment to control unmanned aircraft remotely, aerodrome, safety-related aerodrome equipment, ATM/ANS system, ATM/ANS constituent or flight simulation training device complies with the applicable requirements of this Regulation and of the delegated and implementing acts adopted on the basis thereof, through the issuance of a certificate attesting such compliance;

‘certificate’ means any certificate, approval, licence, authorisation, attestation or other document issued as the result of a certification attesting compliance with the applicable requirements.

The Basic Regulation (EU) 2018/1139 includes requirements for different areas: airworthiness and environmental protection, aircrew, air operations, aerodromes, ATM/ANS (air traffic management/air navigation), air traffic controllers, unmanned aircraft and aircraft used by a third country operator into, within or out of the Union. The requirements from the Basic Regulation related to these areas are further detailed in delegated and implemented acts. Certification and the issuance of a certificate attesting compliance may be performed related to these areas.

As part of the certification within aviation, several bodies may be involved: European Union Safety Agency (EASA), National Competent Authority, European Aviation Inspectors and Qualified Entity. A brief (non-exhaustive) description is provided in the following regarding the before mentioned bodies' involvement in certification.

EASA has responsibilities related to issuing certification specification and other detailed specifications, in addition to providing acceptable means of compliance and guidance material for the application of the Basic Regulation (EU) 2018/1139 and of the delegated and implemented acts. EASA shall further assess the applications made to EASA and where applicable issue or renew certificates. Within the area of airworthiness (several other areas are covered by the Basic Regulation (EU) 2018/1139), EASA shall among other (non-exhaustive list):

- be responsible for the tasks related to certification, oversight and enforcement with respect to type certificates, restricted type certificates, certificates of changes etc. for aircraft, engine or a propeller,

- be responsible for tasks related to certification, oversight and enforcement with respect to certificates for the design of parts, for non-installed equipment and equipment to control unmanned aircraft remotely.

The National Competent Authority is one or more entities designated by a Member State and having the necessary powers and allocated responsibilities for performing the tasks related to certification, oversight and enforcement. As an example of the National Competent Authority’s involvement regarding certification, within the area of aerodrome the National Competent Authority shall among other be responsible for tasks with respect to the issue of certificates for an aerodrome and further to the issue of certificate for an aerodrome operator.

In addition to EASA and the National Competent Authority, which could be considered the main bodies responsible for certification and the issue of certificates, there are other bodies, European Aviation Inspectors and Qualified Entity which are further described in the following.

According to the Basic Regulation (EU) 2018/1139, EASA in cooperation with the National Competent Authorities, shall establish a mechanism for the voluntary pooling and sharing of European Aviation Inspectors and other personnel with relevant expertise for certification and oversight tasks. In addition, the required qualification and experience profiles shall be defined for the relevant tasks. The European Aviation Inspectors may aid in the oversight and certification activities performed by EASA and the National Competent Authorities.

A Qualified Entity is an accredited legal or natural person which may be charged with certain certification or oversight tasks under the Basic Regulation (EU) 2018/1139 by and under the control and the responsibility of EASA or a National Competent Authority. The Qualified Entity shall be accredited, in accordance with delegated acts or implemented acts adopted on the basis of the Basic Regulation, either individually by EASA or by a National Competent Authority, or jointly by two or more National Competent Authorities or by EASA and one or more National Competent Authorities. The Qualified Entity must further be compliant with essential requirements that are defined in the Basic Regulation.

As can be seen from the descriptions provided within this section, Notified Body is not covered by the Basic Regulation (EU) 2018/1139. Instead, the certification activities and the issue of certificates are performed by EASA and National Competent Authorities with the potential support of European Aviation Inspectors and Qualified Entities.

Proposition for hyperloop

Several essential requirements (safety, reliability, availability, health, environmental protection, technical compatibility, accessibility etc.) may be considered important and a prerequisite for a successful introduction of hyperloop. Safety is considered being one of the major important requirements. Due to this, it is proposed in this project that the achievement of adequate safety level is assessed by an independent third party, e.g., an Assessment Body. This suggestion is provided partially since the involvement of independent third parties is a well proven practice followed in several other domains (railway, aviation etc.). The other reason for making this suggestion, is based on this project's view that the additional scrutiny performed by an Assessment Body at least cannot lower the level of achieved safety level, most likely it may contribute to the increased level of achieved safety but at least it will contribute to improving the safety documentation. It is further recommended by this project that the tasks to be undertaken by such an Assessment Body are defined in a standard and regulation. The tasks to be undertaken should be defined in such a degree to prevent variation of the depth and rigor of the different Assessment Bodes' scrutiny. If the tasks to be undertaken are not defined detailed enough, there may be the danger that some Assessment Bodies may choose to focus on only a few important tasks as part of their scrutiny to lower their costs and to be economically competitive. Accreditation of the Assessment Bodies may further be a feasible approach to ensure the required quality of the work performed an Assessment Body. However, this project considers that care shall be taken to prevent too strict independency requirements. One prerequisite of being a qualified Assessment Body may be having the right technical knowledge and competency. Too strict independency requirements might hamper the possibilities of acquiring the required technical knowledge and competency.

If it is decided that common European technical specifications and interoperability requirements shall be established for hyperloop, the utilization of Notified Bodies for certifications of constituents, subsystems and system may be a feasible approach. It is recommended by this project, that at least some other body than the manufacturers (of constituents, subsystem,

system), infrastructure owner and operator make the verification that the relevant technical specifications and interoperability requirements are complied with. This other party that performs the verification and certification, could be a Notified Body (as already mentioned), a European Agency (similar to European Union Agency for Railways (ERA) and European Union Safety Agency (EASA)) or a National Authority designated by the Member State. Further a combination of the involvement of the before mentioned entities could be a possibility.

7 Standardization in the HYPERNEX framework

7.1 Introduction

As stated throughout the entire project, hyperloop is a disruptive innovative technology, and standardization will play one of the most important roles for its development.

Nevertheless, some concerns about the approach of standardization for new innovative technologies exist, mainly in two aspects: in one hand, is it possible to deal with technical requirements without impairing innovation, on the other, when to start the standardization process when the maturity of the technology is under development.

The aim of this clause is to provide answers to these questions and to provide a general overview of the standardization necessities for the hyperloop technologies.

7.2 Standardization & innovation

Technical standards establish a reference level in quality and safety aspects. From a traditional point of view, standards provide information on various aspects as materials, methods and procedures, auxiliary elements, tests, etc., that simplify design, optimize resources, and guarantee compatibility with existing systems. The use of standards reduces costs and risks, generating confidence in users, facilitating market acceptance and accelerating commercialization.

Additionally to this view, standards have become a useful tool to identify and value innovative aspects and to increase and optimize collaboration to generate value and promote innovation both in existing markets and in innovative technologies. In short, it makes it possible to enhance competitiveness and sustainability in the medium and long term. Standardization also adds value to research, development, and innovation projects when including the development of new standards. Both aspects, diffusion and reaching the market, are key to the economic impact of innovation. This is how past public funding programs such as Horizon 2020 have understood it and the satisfactory results have made standardization a lever to boost the impact of projects within Horizon Europe and Europe’s Rail Joint Undertaking.

7.3 Standardization & patents

Patents and standards serve common goals as they both stimulate or support innovation and the diffusion of a new technology.

Standards should avoid mentioning specific technologies that lead to the use of specific products. This can be achieved focusing product standards in general and performance requirements rather than defining technical specific characteristics and solutions.

Nevertheless, sometimes it is desirable to include the best available technology, and this means to include in the technical standard references protected by one or more patents. This is particularly true in certain areas where interoperable and complex technologies lead standard developers to take into consideration new and upcoming technologies, which are usually protected by patents.

In order to preserve the universal approach of standards, while also respecting the rights of the patent holders, CEN and CENELEC have developed an intellectual property rights (IPR) policy under the provision of the CEN-CENELEC Guide 8 "Standardization and intellectual property rights (IPR)".

In brief, the CEN and CENELEC Patent Policy encourages the early disclosure and identification of patents that may relate to standards under development. In doing so, the aim is to encourage greater efficiency in standards development while avoiding possible and potential patent-related problems.

It is important to make clear that the final common objective of both, the patent system and the process of standardization, is to promote innovation and diffusion of technology.

7.4 Benefits of standardization

Technical standards are developed through the participation of a wide range of stakeholders in standardization activities in national standardization committees and, through these, as national delegations, and experts, at European level.

These stakeholders are representatives of business and industry (including SMEs), from the manufacturers or service providers to the different tier's level; industry associations; consumer organizations; public authorities and regulators; trade unions; universities and research centres; certification, testing and inspection bodies; environmental and social organizations; etc. Participation in standardization activities enables them to:

- Acquire detailed knowledge of the standards and in this way, anticipate needs and trends.
- Influence the content of the standards and ensure that their specific needs are taken into account.
- Establish contact with other professionals, experts and regulators, both at national, European or international level.
- Help standards guarantee the safety, performance, efficiency and interoperability demanded by products and services.

The standards provide:

- Advantages for the industry. Standardization provides a solid foundation for meeting customer demands, developing innovative technologies, and improving existing practices.
- Safety and reliability. Compliance with regulations helps ensure safety, reliability, and care for the environment. As a result, users perceive standardized products and services as more reliable, this in turn increases their confidence and contributes to increased sales and the assimilation of new technologies.
- Interoperability. Standards must be designed and verified so that compliant equipment and components ensure interoperability. Complex products and systems are often based on multiple standards, so ensuring coordination and consistency in regulatory developments across different agencies is of foremost importance.

- Support for public policies and legislation. The legislator frequently refers to the rules to ensure compliance with the law, protect the interests of users and markets, and support public policies. Standards play a leading role in the European Union's Single Market policy.

In relation to the market, the standards:

- Facilitate access to the market.
- Promote the European single market, and internationally help to eliminate technical barriers.
- Favour economies of scale.
- Promote innovation.
- Increase awareness of new initiatives and technical advances.

In the specific case of hyperloop, in addition to all the above-mentioned benefits, we must include that Europe has the opportunity to assert its political and institutional weight to guarantee the development of the hyperloop industry, especially within the framework of the European Union. Currently, there are numerous European standardization initiatives promoted by the European Commission through standardization requests to the European standardization bodies, CEN, CENELEC and ETSI, the purpose of which is to support the deployment of European safety policies.

This is why the development of the hyperloop industry strongly needs the development of a regulatory framework in coordination with a standardization roadmap. The coordination of these works will be win-win case in the near future.

On the one hand, in the short and medium terms, standards in an innovative environment as hyperloop is will help the regulator to be aware of the state of the art and serve as preliminary basis for establishing the basic rules for the hyperloop system.

On the other hand, in the medium and long terms, the regulator can use standards as a means of complying with the legislation in the appropriate manner, usually via the new approach legislative framework.

7.5 Standardization roadmap

The expectation is that there will be a need to develop standards in support the different aspects of the technology of this new mode of transportation of passengers and cargo. Currently the JTC 20 has initiated work on the foundation standards for hyperloop following the systems engineering principles. These are as mentioned earlier voluntary EN standards. In the future, there will most likely be a need for harmonized standards as well. However, there are quite some standards from different areas that may be applicable as defined or by developing an amendment specifically for hyperloop systems. A standards inventory is necessary in order to take and evaluate these standards. This inventory will be used as input to the standardization roadmap for hyperloop systems. Currently JTC 20 is working on evaluation of these standards. This report[24] is however not yet published at the time of writing this deliverable.

[24] JT020002

7.5.1 Hyperloop standardization initiatives

For having in place a correct standardization catalogue of standards, three main analysis need to be performed:

- In a first step, to analyse the existing standards and reference documents that can be applied to hyperloop.

  As explained throughout the HYPERNEX project, hyperloop is a new disruptive means of transport, nevertheless, some of the technologies are evolutions of existing ones. In addition, there are a number of similarities with other transport modes as railway, aeronautic and aerospace.

  Because of that, an exhaustive analysis of what exist must be done in order to take profit of what already has been elaborated, optimize resources and efforts, and not to duplicate reference technical documents.

- In a second step, an analysis of the standardization necessities for hyperloop.

  Once the reference material has been stablished, it will be necessary to define the new standards that need to be developed and also the existing standards that will need to be adapted to the specific needs of the hyperloop system.

  This work will allow to fix the standardization necessities and the programme of work.

- Finally, a third step of priorization.

  Depending on the state of the art, the evolution of the technologies, the relevance of the safety issues, the evolution of the regulations on hyperloop, etc. the priorization of the programme of work will define the final standardization roadmap, where necessities and priorization will define the timing for the standardization developments.

All the above mentioned is part of the work that is being done in the European Standardization Committee on hyperloop: CEN-CENELEC/JTC 20[25] 'Hyperloop systems'.

In particular, in its working group WG 1 'Hyperloop operation and services' the work item JT020002 prCEN-CLC/TR XXX 'Standards inventory and roadmap' is under development.

The Scope of this work item is the following:

"This document lists the relevant standards from various fields and provides a standardization roadmap for hyperloop systems. The roadmap will provide guidance on the applicable standards from various fields, those that need amending and the new-to be developed standards".

[25] https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:2739090&cs=182927FD714A2A1F4116CCDD5C71BFF46

7.5.2 Applicable standards

Several sectors specific standards as well as generic have been identified as relevant for hyperloop.

The division is done based on the sector and generic standards:

- generic
- rail
- aviation
- space
- construction

Potential applicable standards are included in Annex 4.

There are also other efforts in determining the relevant standards. A study published by the NETCOUNCIL[26] shows a set of standards as well. These standards were primarily identified through analyses conducted or commissioned by TÜV SÜD, HyperloopTT, the European Commission, Transport Canada, VH, and Delft Hyperloop and some additional have been included.

Additional standards were included based on input provided by various entities through public comments.

As depicted in [Ref: Nett Council] the applicability of existing standards included the following: Risk Assessment and Safety Targets, Basis of Structural and Mechanical Design Assumptions and Analysis, Materials, Vehicle/Capsule, Fire Protection and Evacuation, Electromagnetic Compatibility and Exposure, Information Security, and Certification.

7.5.2.1 Safety standards

Within the S2R/EC group of hyperloop promoters there have been a number of safety standards identified, which have the potential to be applied to hyperloop. These standards are listed in the Table 16 below.

Table 16. Potential existing safety standards

Risk Assessment / Management / general Safety principles
ISO 31000:2009, Risk management. Principles and guidelines
IEC/ISO 31010:2009, Risk management. Risk assessment techniques
ISO/IEC Guide 51:2014, Safety aspects. Guidelines for their inclusion in standards
IEC 61511 (all parts), Functional safety. Safety instrumented systems for the process industry sector
IEC 61508 (all parts), Functional safety of electrical/electronic/programmable electronic safety related systems
EN 50518, Monitoring and alarm receiving centre

[26] https://www.transportation.gov/sites/dot.gov/files/2021-01/NETT%20Council%20Hyperloop%20Standards%20Desk%20Review_14Jan2021_final.pdf

Cybersecurity
ISO IEC 27001, Information technology. Security techniques. Information security management systems. Requirements
ISO IEC 27005, Information technology. Security techniques. Information security risk management
IEC/TS 62443, Industrial communication networks. Network and system security
EM compatibility & exposure (propulsion, levitation, ICT)
EN 50413, Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)
IEC 61000 (all parts), Electromagnetic compatibility (EMC)
Structural safety / criteria
EN 1990, Eurocode 0: Basis of structural design
EN 1991 (all parts), Eurocode 1: Actions on structures
EN 1992 (all parts), Eurocode 2: Design of concrete structures
EN 1993 (all parts), Eurocode 3: Design of steel structures
EN 1994 (all parts), Eurocode 4: Design of composite steel and concrete structures
EN 1997 (all parts), Eurocode 7: Geotechnical design
EN 1998 (all parts), Eurocode 8: Design of structures for earthquake resistance
EN 1999 (all parts), Eurocode 9: Design of aluminium structures
CEN/TC 250/WG 4, report on FRPs (Fibre Reinforced Polymer or Plastic)
EN 12XXX Series, Aspects from rolling stock; maybe taken in account for comfort, materials, type of tests, compatibilities under mechanical contact with infra
EN 16XXX Series, Acceptance criteria of vehicles, devices working under acoustic propagation, auxiliary services (water, etc), PMR use area, work protection during construction or maintenance
EN 17XXX Series, Maintenance routines of rolling stock (best practices from rail could be useful for hyperloop)
Vehicle safety / acceptance criteria
EN 12XXX Series, Aspects from rolling stock; maybe taken in account for comfort, materials, type of tests, compatibilities under mechanical contact with infra
EN 16XXX, Acceptance criteria of vehicles, devices working under acoustic propagation, auxiliary services (water, etc.), PMR use area, work protection during construction or maintenance
EN 17XXX, Maintenance routines of rolling stock (best practices from rail could be useful for hyperloop)

Sectorial safety rules		
Rail	**Aviation**	**Space**
CENELEC Report R009-004:2001, Railway applications. Systematic allocation of safety integrity requirements	RTCA/DO-178C, Software Considerations in Airborne Systems and Equipment Certification	NASA Standards NASA Technical Standards (e.g. NASA-STD-6016A, NASA-STD5017)
IEC 62278 / EN 50126 (all parts), Railway Applications. The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)	RTCA/DO-160, Environmental Conditions and Test Procedures for Airborne Equipment	ECSS-M-ST-/ EN 16601 section nº M-10, Project planning & implementation M-40, Configuration & information mgmt

(open to cross-acceptance of other standards fulfilling a given SIL requirements)		M-60, Cost & schedule mgmt M-70. Integrated logistic support M-80, Risk mgmt
EN 50128, Railway applications. Communication, signalling and processing systems. Software for railway control and protection systems	RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware	ECSS-Q-ST / EN 16602 sections n: Q-10, Product assurance mgmt Q-20, Quality assurance Q-30, Dependability Q-40, Safety Q-60, EEE components Q-70, Materials, mechanical parts & processes Q-80, Software product assurance
EN 50129, Railway applications. Communication, signalling and processing systems. Safety related electronic systems for signalling	FAR Standards Part 25, Airworthiness standards: Transport category airplanes Subpart C. Structure Subpart D. Design and Construction	ECSS-E-ST / EN 16603 sections nº E-10, Systems engineering E-20, Electrical & optical engineering E-30, Mechanical engineering E-40, Software engineering E-50, Communications E-60, Control engineering E-70, Ground systems & operations
EN 50155, Railway applications. Rolling stock. Electronic equipment	EASA European Aviation Safety Agency - CS-25 Certification Specifications for Large Aeroplanes Subpart C - Structure Subpart D, Design and Construction	ECSS-U-ST / EN 16604 sections nº U-10, Space debris U-20, Planetary protection U-30, Space situation awareness
EN 50159, Railway applications. Communication, signalling and processing systems. Safety-related communication in transmission systems		
EN 45545-2+A1, Railway applications. Fire protection on railway vehicles. Part 2: Requirements for fire behaviour of materials and components		
EN 50124-2, Railway applications. Insulation coordination. Part 2: Overvoltage and related protection		
EN 50657, Railways Applications. Rolling stock applications. Software on Board Rolling Stock		

Guide for the application of the Commission Regulation on the adoption of a common safety method on risk evaluation and assessment as referred to in Article 6(3)(a) of the Railway Safety Directive ERA/GUI/01-2008/SAF		
VEHICLE – Emergency rules from Rail		
EN 15XXX Series, Drawing, mechanical coupling (emergency), vehicle welding, warning devices on board, braking performance, loading gauge, vehicle designation with functions, aspects of vehicle in rail environment, construction vehicle family,		
EN 13XXX Series, Track aspect. Only to understand request from materials in use or when vehicle circulates over rails during emergency		
Others		
Fix installations (Network Operations Centre, Depot, Track, Guideway) Health and safety rules		
IEC 60076 (Power transformers)		
EN-IEC 629XX, Batteries, UPS and other CLC/TR 50488 worker in electrified area (convergence in electrical area and in infrastructure)		
CEN/TS 16XXX, Conditions for acoustic signals-perception (convergence for users, emergency, maintenance)		
ISO 11201:2010, Acoustics. Noise emitted by machinery and equipment (complemented with EN-ISO 3XXXX on noise)		
EN 502XX Series, Rolling stock components and performances, e.g. radio control in shunting(relevant for deposits), cables		
EN 503XX Series, Cables and electrical devices including drawing and current capitation, electrical coordination vehicle-infra		
EN 504XX Series, Energy measurement		
EN 506XX Series, Standards of assumptions under Interoperability domain		
EN 60XXX Series, Power electrical components on board (as relevant for hyperloop), in field elements too		
Vehicle-specific additional elements:		
ISO 2631-4:2001, Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems		

Certification, inspection and laboratory: conformity assessment
ISO/IEC 17020:2012 (types of bodies performing inspection)
ISO/IEC 17025:2017 (competence of testing and calibrating laboratories)
ISO/IEC 17065:2012 (requirements for bodies certifying product, processes and services)

7.5.2.2 Sustainability standards

For the transport system of the future such as hyperloop sustainability standards are of great importance.

There are a number of existing standards that are providing for organizations worldwide practical tools on environmental management.

One very good example is the ISO 14000 family of standards for environmental management systems, which details practical tools for organizations to manage the impact of their activities on the environment.

The ISO 14064 series gives specifications for the quantification, monitoring and validation/verification of greenhouse gas emissions for inventories and offset projects. For Life Cycle Assessment (LCA), various standards will be considered such as ISO 14040 and ISO 14044, but also 14067, which specifies the principles, requirements and guidelines for quantifying and reporting the carbon footprint of products. Alternatively to ISO 14064-1 the GHG Protocol Corporate Accounting and Reporting Standard can be used. A Guide to reporting against the Green House Gas Protocol for construction companies [Ref: Guidance: ENCORD Construction CO2 Measurement Protocol is a relevant one for hyperloop.

The European hyperloop companies will discuss to coordinate their sustainability strategies by agreeing on common principles, i.e. use of Science-based targets (SBT), definition of Scope 3 emissions; use of common standards for Sustainability Reporting and Disclosure (such as GRI, SASB, TCFD, SDG); voluntary disclosure of greenhouse gas emissions when applicable, etc.

7.5.3 Standardization necessities for hyperloop

Currently, a set of standards is being developed. In Table 17 the list of works of CEN-CENELEC/JTC 20 is shown.

Table 17. List of standards under development

Project reference	Status
prCEN/CLC/TR XXX (WI=JT020002) Standards inventory and roadmap	Under Drafting
prEN XXX (WI=JT020001) Hyperloop transport services	Under Drafting
prEN XXX (WI=JT020004)	Preliminary

Project reference	Status
Hyperloop systems. General requirements	
prEN XXX (WI=JT020003) Hyperloop systems aspects. Reference architecture	Under Drafting
prEN XXX (WI=JT020005) Hyperloop vocabulary and definitions	Preliminary

The first set of standards for hyperloop until 2023 will focus on a generic set of standards. The more the hyperloop technology matures the more standardization and regulatory framework activities are foreseen. Beyond 2023 the expectation is that the standardization work will grow almost exponentially seen that the standards will be drafted at quite detailed level – granularity of subsystems and parts of subsystems. The regulatory framework activities will result in the development of the harmonized standards as well.

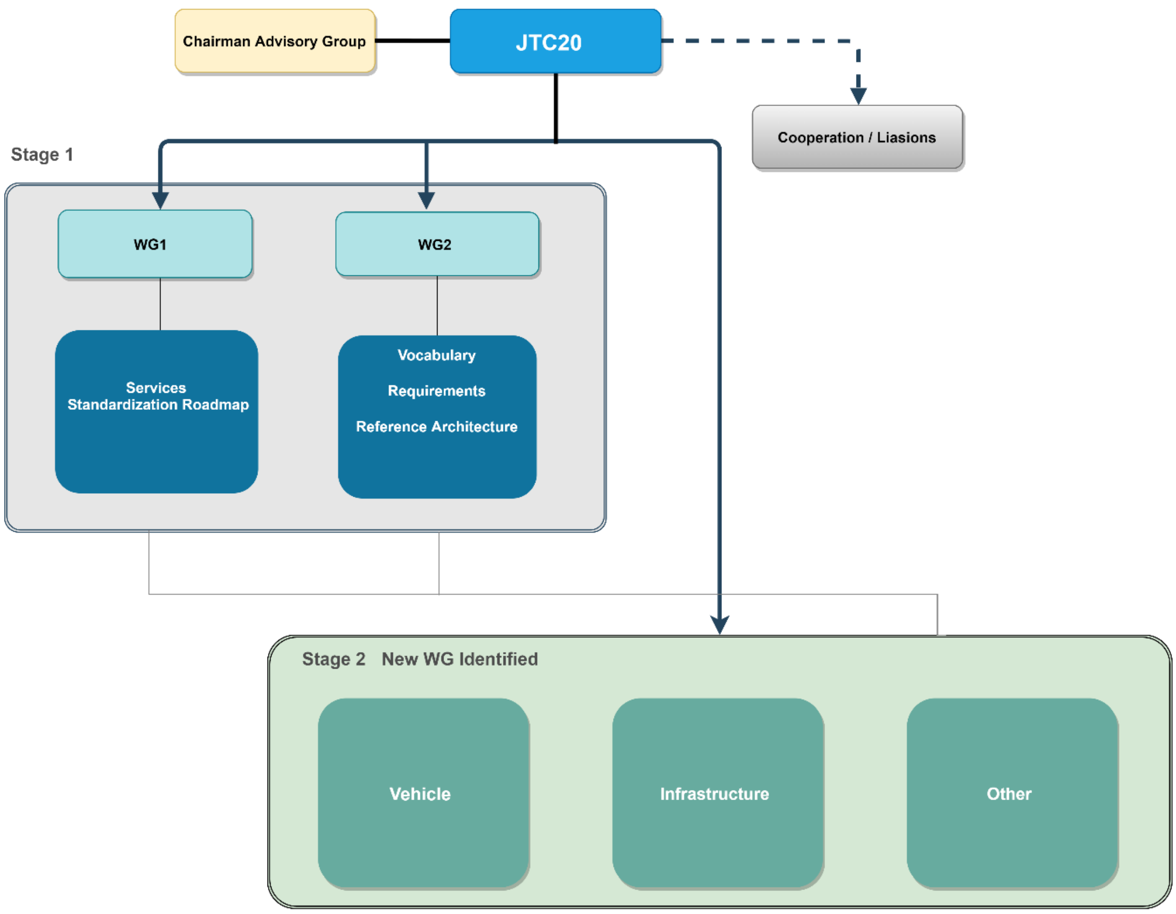

Figure 62. CEN-CENELEC/JTC 20 Structure

8 Conclusions

During the last decades the necessities, demands and performances requested to the transport systems have been broadened.
From the political point of view, the necessity of including transport in the global vision of sustainability has become a must. The European Union Green Deal and the United Nations Agenda 2030 are the best examples of the future policy goals. Both of them have a specific target in the sustainable development of transport and mobility, taking into account its three constituent parts: social, environment and economic.
From the users' point of view, considering users both passengers and goods, there are two major requests. On one hand, time is gold – the shortest the journeys duration, delays, transit lapses, etc. are, the better. On the other, new necessities as the transition from cities to peripheric or rural areas, delocalization, digitalization or e-commerce are becoming more and more important, boosting the concept of mobility as a service.
Hyperloop can provide solutions in this challenging scenario and has to do it through its integration with all the existing transport systems. Through the HYPERNEX development it has been concluded that the safety of the hyperloop and its intermodality with the existing transport systems are clear objectives.
The close relation with railway, aeronautic and space transport is clear, but also there are important relations between specific technologies developed by hyperloop and road and marine transport.
As main conclusions of this deliverable D4.1, the following are highlighted:

- Transport is evolving to answer the green, sustainability and digitalization goals. For the HYPERNEX purposes, railway and aeronautic are under an adaptation process developing new technologies for these objectives.

- Hyperloop concept integrates and provides a solution to these necessities.

- The holistic approach to the transport of the future needs to include hyperloop within the existing transport systems network. Safety of the hyperloop and intermodality with other transport modes are key challenges.

- Synergies with railway and aviation exist and can facilitate the development of hyperloop. Existing good practices, standards and regulations can be directly applied or adapted to fit necessities for establishing the regulatory framework and accelerate the certification and approval processes.

- Cross-fertilization amongst hyperloop and existing transport systems – both guided and non-guided – is a win-win opportunity to foster new technologies in fields such as communications, new materials, green propulsion systems, autonomous driving, energy storage, control&signalling&command, etc.

HYPERNEX project has demonstrated that the bases for the hyperloop development are firmly established. As stated in deliverable D2.1, the development of the core technologies is in progress.

A first safety case and concept of operations, main foundations for a safe hyperloop system, has been prepared in deliverable D3.1. Finally, in deliverable D4.1 the integration, synergies and cross-fertilization between the hyperloop and other means of transport has been demonstrated to be a success opportunity.

The success of hyperloop will be part of the success of the transport of the future. Nevertheless, further research and innovation programs dedicated to hyperloop need to be launched to deepen in the safety of the system and subsystems, demonstrate technologies and validate and verify proof of concepts.

9 References

- Chrobak, R., Prieto, R. M., Prieto, A. B., Gaido, L., & Rotella, A. (2006). Una aproximación a las motivaciones y actitudes del profesorado de enseñanza media de la provincia de Neuquén sobre temas de Educación Ambiental. Revista Electrónica de Enseñanza de las Ciencias, 5(1), pp. 31-50.
- Dukkipati, R. V. (2000). Vehicle dynamics. CRC Press.
- Forina, M., Armanino, C., & Raggio, V. (2002). Clustering with dendrograms on interpretation variables. Analytica Chimica Acta, 454, pp. 13-19.
- Gondar Nores, J. E. (2001). Análisis de Conglomerados. Retrieved Junio 30, 2007, from sitio web de estadistico.com: http://www.estadistico.com/arts.html?20001023-1
- Grupo InfoStat, FCA. (2004). InfoStat, versión 2004. Manual del Usuario. Argentina: Universidad Nacional de Córdoba, Editorial Brujas.
- Levinson, D. (2013). A Taxonomy of Modes – Transportist by David Levinson. Retrieved from https://transportist.org/2013/12/30/a-taxonomy-of-modes/
- Meneses, B., & de Sesma, A. (2000). El análisis de conglomerados en los estudios de mercado. Ciencia Administrativa.
- National Academies of Sciences, Engineering, and Medicine. (2017). Findability and Relevance of Transportation Information: Volume I A Guide for State Transportation Agencies, and Volume II Background Research. Washington, DC: The National Academies Press. doi:https://doi.org/10.17226/24804
- Quintín, M., Cabero, M. T., & Paz (de), Y. R. (2008). Tratamiento Estadístico de Datos con SPSS. Madrid: Thomson Editores.
- Segaran, T. (2007). Programming Collective Intelligence. O'Reilly.
- The Urbanist. (2019). How We Move: From Camels to Cable Cars. Retrieved from https://www.spur.org/publications/urbanist-article/2019-03-01/how-we-move-camels-cable-cars
- Vicente Villardón, J. L. (n.d.). Introducción al análisis de cluster. Retrieved from http://benjamindespensa.tripod.com/spss/AC.pdf
- SHIFT2RAIL STRATEGIC MASTER PLAN. September 2014, https://shift2rail.org/wp-content/uploads/2021/06/Shift2Rail-Master-Plan_approved-by-S2R-GB.pdf (retrieved Jan 2022).
- V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, (2021). Climate Change 2021: The Physical Science Basis, IPCC, Summary for Policymakers. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

- Professor P. Turnbull, (2009). Evaluation Report on the “International Cross-Fertilization Workshop on Social Dialogue in Road Transport in Bulgaria and Romania”, EU Funded ILO Technical Cooperation Project, p.20
- Z. Lamothe, R. Janzen, (2021). TransPod in Alberta, Summary of study on the implementation of a TransPod Line from Calgary to Edmonton, TransPod Inc.
- (2017). Greenhouse gas emissions from transport in Europe, European Environment Agency - EEA
- Joseph Machrouh, Jean-Paul Blanquart, Philippe Baufreton, Jean-Louis Boulanger, Hervé Delseny, Jean Gassino, Gérard Ladier, Emmanuel Ledinot, Michel Leeman, Jean-Marc Astruc, Philippe Quéré, Bertrand Ricque, Gilles Deleuze, (2012). Cross domain comparison of System Assurance, CG2E - Club des Grandes Entreprises en Embarqué - Club of Large Embedded Companies
- W. K. Holstein, (2008), Production management, Britannica
- Allan M de Souza, Celso ARL Brennand, Roberto S Yokoyama, Erick A Donato, Edmundo RM Madeira, Leandro A Villas, (2017). Traffic management systems: A classification, review, challenges, and future perspectives, Sao Paulo Research Foundation (FAPESP), European Union’s Horizon 2020, Brazilian Ministry of Science, Technology and Innovation (MCTI)

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The information and views set out in this document are those of the author(s) and do not necessarily reflect the official opinion of Shift2Rail Joint Undertaking.

The JU does not guarantee the accuracy of the data included in this article.

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Annex 1: Proposal 1 of segmentation: Hierarchy of transportation modes

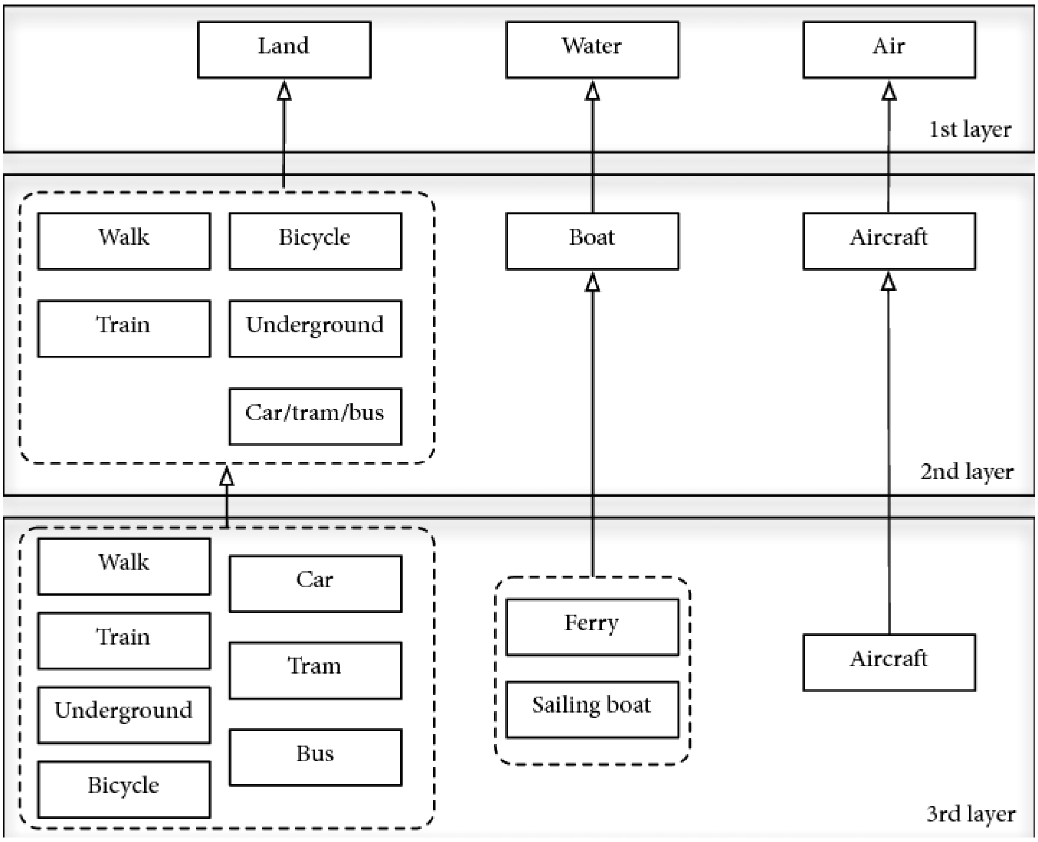

Figure 63. Proposal 1 of Segmentation: Hierarchy of transportation modes. Source: Biljecki, F., Ledoux, H., Van Oosterom, P. (2013): Transportation mode-based segmentation and classification of movement trajectories. International Journal of Geographical Information *Science*, vol. 27(2), pp. 385-407.

Annex 2: Proposal 2 of segmentation: Classification of transports by kind and category

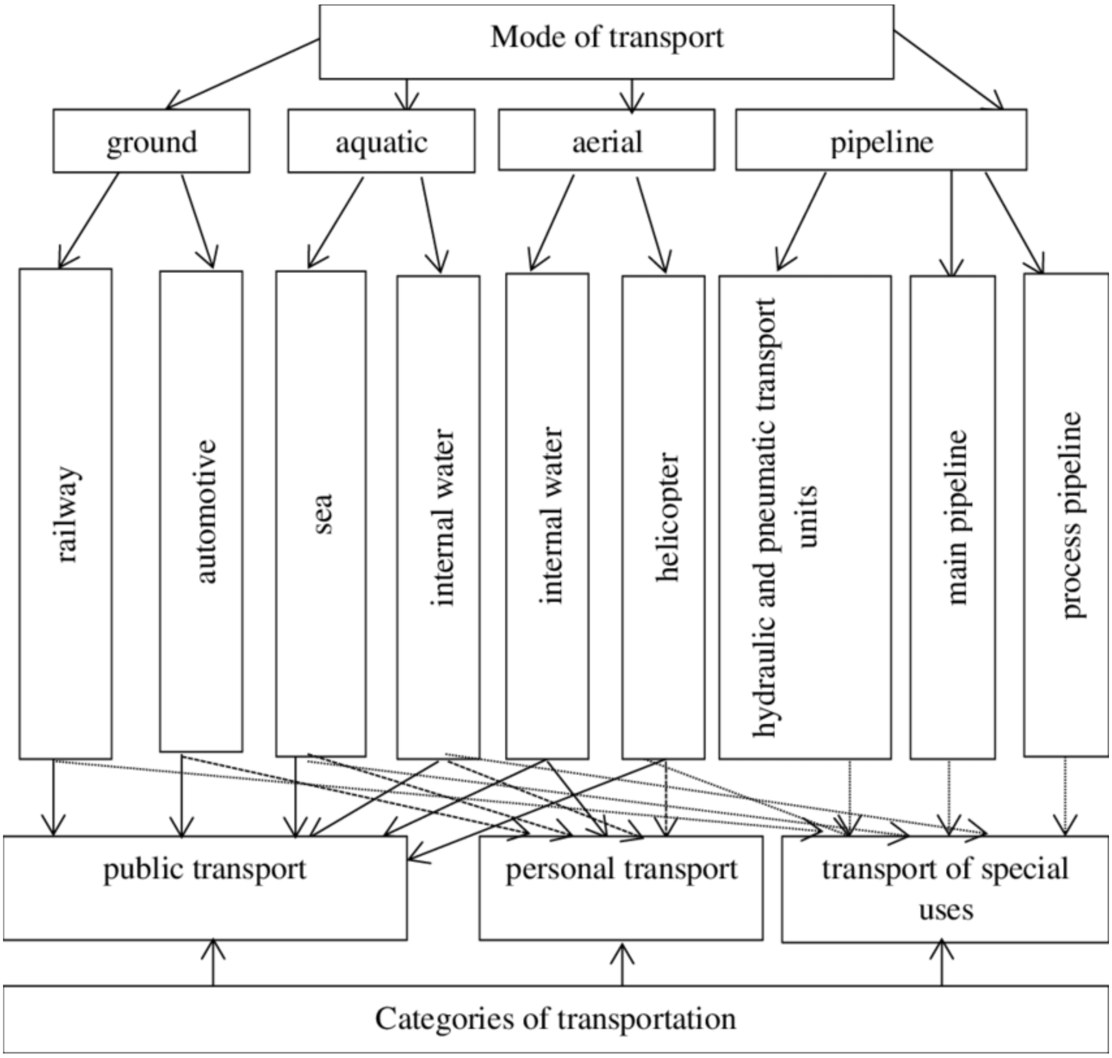

Figure 64. Proposal 2 of Segmentation: Classification of transports by kind and category. Source: Vitalina Barashyan, Marina Kuzina, Ekaterina Vasilenko, Sergey Magomedov, Vladimir Abramov, (2019). The impact of transport systems on the economic security of the enterprise, *SCTCMG International Scientific Conference «Social and Cultural Transformations in the Context of Modern Globalism»*, p.220

Annex 3: Work breakdown structure examples

Table 18. Work Breakdown structure examples. Source: Mr. Wayne F. Abba, (1998). Work breakdown structure, Department of defence handbook, MIL-HDBK-881, p40-106

Level 1	Level 2	Level 3
Aircraft System		
	Air Vehicle (AV)	
		Airframe
		Propulsion
		AV Applications Software
		AV System Software
		Communications/Identification
		Navigation/Guidance
		Central Computer
		Fire Control
		Data Display and Controls
		Survivability
		Reconnaissance
		Automatic Flight Control
		Central Integrated Checkout
		Antisubmarine Warfare
		Armament
		Weapons Delivery
		Auxiliary Equipment
	Sys Engineering/Program Management	
	System Test and Evaluation	
		Development Test and Evaluation
		Operational Test and Evaluation
		Mock-ups
		Test and Evaluation Support
		Test Facilities
	Training	
		Equipment
		Services
		Facilities
	Data	
		Technical Publications
		Engineering Data
		Management Data
		Support Data
		Data Depository
	Peculiar Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Common Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Operational/Site Activation	
		System Assembly, Installation and Checkout on Site
		Contractor Technical Support
		Site Construction
		Site/Ship/Vehicle Conversion
	Industrial Facilities	
		Construction/Conversion/Expansion
		Equipment Acquisition or Modernization
		Maintenance (Industrial Facilities)

Level 1	Level 2	Level 3
Ship System		
	Ship	
		Hull Structure
		Propulsion Plant
		Electric Plant
		Command and Surveillance
		Auxiliary Systems
		Outfit and Furnishings
		Armament
		Integration/Engineering
		Ship Assembly and Support Services
	Systems Engineering/Program Management	
	System Test and Evaluation	
		Development Test and Evaluation
		Operational Test and Evaluation
		Mock-ups
		Test and Evaluation Support
		Test Facilities
	Training	
		Equipment
		Services
		Facilities
	Data	
		Technical Publications
		Engineering Data
		Management Data
		Support Data
		Data Depository
	Peculiar Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Common Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Operational/Site Activation	
		System Assembly, Installation and Checkout on Site
		Contractor Technical Support
		Site Construction
		Site/Ship/Vehicle Conversion
	Industrial Facilities	
		Construction/Conversion/Expansion
		Equipment Acquisition or Modernization
		Maintenance (Industrial Facilities)
	Initial Spares and Repair Parts	

Level 1	Level 2	Level 3
Space System		
	Launch Vehicle	Propulsion (Single Stage Only) Stage I Stage II...n (As Required) Strap-On Units (As Required) Shroud (Payload Fairing) Guidance and Control Integration, Assembly, Test and Checkout
	Orbital Transfer Vehicle	Propulsion (Single Stage Only) Stage I Stage II...n (As Required) Strap-On Units (As Required) Guidance and Control Integration, Assembly, Test and Checkout
	Space Vehicle	Spacecraft Payload I...n (As Required) Reentry Vehicle Orbit Injector/Dispenser Integration, Assembly, Test and Checkout
	Ground Command, Control, Communications and Mission Equipment	Sensor I...n (As Required) Telemetry, Tracking and Control External Communications Data Processing Equipment Launch Equipment Auxiliary Equipment
	Flight Support Operations and Services	Mate/Checkout/Launch Mission Control Tracking and C^3 Recovery Operations and Services Launch Site Maintenance/Refurbishment
	Storage	Planning and Preparation Storage Transfer and Transportation
	Systems Engineering/Program Management	
	System Test and Evaluation	Development Test and Evaluation Operational Test and Evaluation Mock-ups Test and Evaluation Support
	Training	Equipment Services Facilities

Level 1	Level 2	Level 3
Surface Vehicle System		
	Primary Vehicle	
		Hull/Frame
		Suspension/Steering
		Power Package/Drive Train
		Auxiliary Automotive
		Turret Assembly
		Fire Control
		Armament
		Body/Cab
		Automatic Loading
		Automatic/Remote Piloting
		Nuclear, Biological, Chemical
		Special Equipment
		Navigation
		Communications
		Integration, Assembly, Test and Checkout
	Secondary Vehicle	
		(Same as Primary Vehicle)
	Systems Engineering/ Program Management	
	System Test and Evaluation	
		Development Test and Evaluation
		Operational Test and Evaluation
		Mock-ups
		Test and Evaluation Support
		Test Facilities
	Training	
		Equipment
		Services
		Facilities
	Data	
		Technical Publications
		Engineering Data
		Management Data
		Support Data
		Data Depository
	Peculiar Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Common Support Equipment	
		Test and Measurement Equipment
		Support and Handling Equipment
	Operational/Site Activation	
		System Assembly, Installation and Checkout on Site
		Contractor Technical Support
		Site Construction
		Site/Ship/Vehicle Conversion
	Industrial Facilities	
		Construction/Conversion/Expansion
		Equipment Acquisition or Modernization
		Maintenance (Industrial Facilities)
	Initial Spares and Repair Parts	

Annex 4: Relevant standards

In the next Table 19 an initial list of relevant standards is included.

Table 19. Example of relevant existing standards

Industry	Standard	Version	Title	Scope
Aviation	AC 25.1309-1A	1988	FAA document: describes acceptable means for showing compliance with those airworthiness requirements	This Advisory Circular (AC) describes various acceptable means for showing compliance with the requirements of 25.1309(b), (c), and (d) of the Federal Aviation Regulations (FAR). This AC has since been cancelled.
Aviation	AMC-20		General Acceptable Means of Compliance for Airworthiness of Products, Parts and Appliances	
Aviation	ARP 5150	2013	Safety Assessment of Transport Airplanes in Commercial Service	Provides guidelines, methods and tools used to perform the ongoing safety assessment process for transport airplanes in commercial service.
Aviation	ARP 5429A	2017	Landing Gear Fatigue Tests With Equivalent Damage Spectra	
Aviation	ARP 6128	2013	Unmanned Systems Terminology Based on the ALFUS Framework	The purpose of this Aerospace Recommended Practice is to determine a common set of terminology and definitions that can be used as guidance for designing, developing, testing, or otherwise describing an unmanned system or any of its subsystems.

Industry	Standard	Version	Title	Scope
Aviation	ARP1311C	2015	Landing Gear Structures and Mechanisms	This SAE Aerospace Recommended Practice (ARP) applies to landing gear structures and mechanisms (excluding wheels, tires, and brakes and other landing gear systems) for all types and models of civil and military aircraft. All axles, wheel forks, links, arms, mechanical and gas/oil shock struts, downlock and uplock assemblies, braces, trunnion beams, and truck beams etc., that sustain loads originating at the ground, and that are not integral parts of the airframe structure, should be designed and validated in accordance with this document. Hydraulic actuators (retraction, main and nose gear steering, positioning, damping, etc.) should also be included in this coverage.
Aviation	ARP4242A	2013	Electromagnetic Compatibility Control Requirements Systems	This aerospace recommended practice defines overall system electromagnetic compatibility control requirements. This document is no longer reviewed for currency, so users are required to verify references and suitability of technical recommendations
Aviation	ARP4754A	2010	Guidelines For Development of Civil Aircraft and Systems	This document discusses the development of aircraft systems taking into account the overall aircraft operating environment and functions. This includes validation of requirements and verification of the design implementation for certification and product assurance. It provides practices for showing compliance with the regulations and serves to assist a company in developing and meeting its own internal standards by considering the guidelines therein. The guidelines are directed toward systems that support aircraft-level functions and have failure modes with the potential to affect the safety of the aircraft. Typically, these systems involve significant interactions with other systems in a larger integrated environment. Frequently, significant elements of these systems are developed by separate individuals, groups or organizations. These systems require added design discipline and development structure to ensure that safety and operational requirements can be fully realized and substantiated. A top-down iterative approach from aircraft level downwards is key to initiating the processes is outlined.

Industry	Standard	Version	Title	Scope
Aviation	ARP4761	1996	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment	This document describes guidelines and methods of performing the safety assessment for certification of civil aircraft. It presents guidelines for conducting an industry accepted safety assessment consisting of: -Functional Hazard Assessment (FHA) -Preliminary System Safety Assessment (PSSA), and -System Safety Assessment (SSA). This document also presents information on the safety analysis methods needed to conduct the safety assessment. These methods include: -Fault Tree Analysis (FTA) -Dependence Diagram (DD) -Markov Analysis (MA) -Failure Modes and Effect Analysis (FMEA) -Failure Modes and Effects Summary (FMES), and -Common Cause Analysis (CCA). [CCA is composed of Zonal Safety Analysis (ZSA), Particular Risks Analysis (PRA), and Common Mode Analysis (CMA)]
Aviation	CS-25	2007	Large Aeroplanes	This Airworthiness Code is applicable to turbine powered Large Aeroplanes.
Aviation	DO-178C	2012	Software Considerations in Airborne Systems and Equipment Certification	Provides guidance for the design of software intended for airborne systems to meet airworthiness requirements.
Aviation	DO-254	2000	Design Assurance Guidance for Airborne Electronic Hardware	Provides design assurance guidance for the development of airborne electronic hardware such that it safely performs its intended function in a specific environment.
Aviation	EN 2245	2012	Aerospace series. Pipelines for liquids and gases. Definitions	This standard specifies the nominal sizes, pressure terms and pressure classes concerning pipelines and types and temperature range of flexible non-metallic hose assemblies used on board aircraft to convey liquids and gases as well as for the transmission of forces.

Industry	Standard	Version	Title	Scope
Aviation	EN 2283	2010	Aerospace series. Testing of aircraft wiring	This standard covers the tests for finished wiring, including connectors and, if necessary, terminals, terminal ends, junction boxes, circuit breakers, etc. as well as the requirements for verification of aircraft electrical wiring for the following: • continuity of circuits; • dielectric strength; • insulation resistance. These tests do not concern equipment installed in the aircraft.
Aviation	EN 3197	2010	Aerospace series. Design and installation of aircraft electrical and optical interconnection systems	This standard provides instructions on the methods to be used when designing, selecting, manufacturing, installing, repairing or modifying the aircraft electrical and optical interconnection networks (Electrical Wiring Interconnection System (EWIS), and Optical Fibre Interconnection Systems (OFIS)).
Aviation	EN 3375-002	2012	Aerospace series. Cable, electrical, for digital data transmission. Part 002: General	This standard specifies the list of product standards and common characteristics of signal data transmission electrical cables for use in the on-board electrical systems of aircraft, at operating temperatures between -65°C and 150°C or 200°C or 260°C (as specified in product standards).
Aviation	EN 3475-100	2010	Aerospace series. Cables, electrical, aircraft use. Test methods. Part 100: General	This standard gives general information and the list of test methods for the different characteristics required for cables used in aircraft electrical circuits.
Aviation	EN 3745-100	2008	Aerospace series. Fibres and cables, optical, aircraft use. Test methods. Part 100: General	This standard defines terms for optical fibres and cable.
Aviation	EN 4660-001	2011	Aerospace series. Modular and Open Avionics Architectures. Part 001: Architecture	The purpose of this standard is to establish uniform requirements for the architecture for Integrated Modular Avionic (IMA) systems as defined by the ASAAC Programme. The IMA architecture can be built by using common components. These components are specified in separate standards. Ways of using these components are described in a set of guidelines. This document gives references to these Standards and Guidelines as well as a short introduction to IMA.

Industry	Standard	Version	Title	Scope
Aviation	EN 4660-002	2011	Aerospace series. Modular and Open Avionics Architectures. Part 002: Common Functional Modules	This standard defines the functionality and principle interfaces for the Common Functional Module (CFM) to ensure the interoperability of Common Functional Modules and provides design guidelines to assist in implementation of such a CFM. It is one of a set of standards that define an ASAAC (Allied Standard Avionics Architecture Council) Integrated Modular Avionics System.
Aviation	EN 4660-003	2011	Aerospace series. Modular and Open Avionics Architectures. Part 003: Communications/ Network	This standard details the functionality and principle interfaces for the ASAAC (Allied Standard Avionics Architecture Council) Network to ensure the interoperability of Common Functional Modules and design guidelines to assist in implementation of such a network. It is one of a set of standards that define an ASAAC Integrated Modular Avionics (IMA) System. The purpose of this standard is to establish by means of well-defined interfaces and functionality, a network design that is technology transparent, which is open to a multi-vendor market and that can make the best use of Commercial Off The Shelf (COTS) technologies.
Aviation	EN 4660-004	2011	Aerospace series. Modular and Open Avionics Architectures. Part 004: Packaging	The purpose of this standard is to establish uniform requirements for Packaging for the Common Functional Modules (CFM) within an Integrated Modular Avionic (IMA) system, as defined per ASAAC. It comprises the module physical properties and the Module Physical Interface (MPI) definitions together with guidelines for IMA rack and the operational environment. The characteristics addressed by the Packaging Standard are interchangeability and maintainability.
Aviation	EN 4660-005	2011	Aerospace series. Modular and Open Avionics Architectures. Part 005: Software	The purpose of this standard is to establish uniform requirements for design and development of software architecture for modular avionics systems as defined per ASAAC.
Aviation	EN 4697	2016	Aerospace series. General and installation requirements for passenger seat fittings	This standard specifies the installation and removal requirements and the space envelopes for passenger seat fittings on aircraft. The purpose is to reduce the installation time and the tooling required for seat installation by standardizing the seat attachment fasteners (fittings).

Industry	Standard	Version	Title	Scope
Aviation	EN 4723	2015	Aerospace series. Standardized measurement methods for comfort and living space criteria for aircraft passenger seats	This standard specifies requirements and measurement methods for the assessment of passenger living space and comfort. Its aim is to improve the passenger comfort quality of aircraft cabins and provide measurement methods to compare cabin seat layouts and seats.
Aviation	EN 4726	2015	Aerospace series. Acceptance of the cosmetic variations in appearance of aircraft cabin parts	This standard defines surfaces on visible components in the aircraft cabin. Surfaces will be considered under the aspects of technical feasibility of the industrial design. This standard is a guideline between airlines, supplier and OEMs with regard to cosmetic issues. This document aims to: a) Provide the supplier with quality criteria, which need to be met during the production, testing and quality inspection process b) Guide airline, OEM and supplier quality assurance with a description of cosmetic standards for the following inspections: Supplier internal QA inspection; • First article inspection; • Source inspection; • Incoming inspection; • Final assembly line cabin inspection
Aviation	FAR - Part 25	1958	Airworthiness standards: Transport Category Airplanes	
Aviation	GEIASTD0010	2008	Standard Best Practices for System Safety Program Development and Execution	
General	EN 60529	2014	Specification for degrees of protection provided by enclosures (IP Code)	

Industry	Standard	Version	Title	Scope
General	EN 61508-1 / IEC 61508-1	2010	Functional safety of electrical/electronic/ programmable electronic safety-related systems. Part 1: General requirements	This International Standard covers those aspects to be considered when electrical/electronic/programmable electronic (E/E/PE) systems are used to carry out safety functions. A major objective of this standard is to facilitate the development of product and application sector international standards by the technical committees responsible for the product or application sector. This will allow all the relevant factors, associated with the product or application, to be fully taken into account and thereby meet the specific needs of users of the product and the application sector. A second objective of this standard is to enable the development of E/E/PE safety-related systems where product or application sector international standards do not exist.
General	IEC 61000-4-1	2006	Electromagnetic compatibility (EMC). Part 4-1: Testing and measurement techniques. Overview of IEC 61000-4 series	The object of this part of IEC 61000 is to give applicability assistance to the technical committees of IEC or other bodies, users and manufacturers of electrical and electronic equipment on EMC standards within the IEC 61000-4 series on testing and measurement techniques and to provide general recommendations concerning the choice of relevant tests.
General	IEC 61000-4-2	2008	Electromagnetic compatibility (EMC). Part 4-2: Testing and measurement techniques. Electrostatic discharge immunity test	IEC 61000-4-2:2008 relates to the immunity requirements and test methods for electrical and electronic equipment subjected to static electricity discharges, from operators directly, and from personnel to adjacent objects. It additionally defines ranges of test levels which relate to different environmental and installation conditions and establishes test procedures. The object of IEC 61000-4-2:2008 is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to electrostatic discharges. In addition, it includes electrostatic discharges which may occur from personnel to objects near vital equipment. IEC 61000-4-2:2008 defines typical waveform of the discharge current, range of test levels, test equipment, test setup, test procedure, calibration procedure and measurement uncertainty. IEC 61000-4-2:2008 gives specifications for test performed in "laboratories" and "post-installation tests" performed on equipment in the final installation.

Industry	Standard	Version	Title	Scope
General	IEC 61000-4-3	2006 +AMD1:2007 +AMD2:2010	Electromagnetic compatibility (EMC). Part 4-3: Testing and measurement techniques. Radiated, radio-frequency, electromagnetic field immunity test	IEC 61000-4-3:2006+A1:2007+A2:2010 is applicable to the immunity requirements of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures. The object of this standard is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to radiated, radio-frequency electromagnetic fields. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon. This part deals with immunity tests related to the protection against RF electromagnetic fields from any source. Particular considerations are devoted to the protection against radio-frequency emissions from digital radiotelephones and other RF emitting devices. It has the status of a basic EMC publication.
General	IEC 61000-4-4	2012	Electromagnetic compatibility (EMC). Part 4-4: Testing and measurement techniques. Electrical fast transient/burst immunity test	IEC 61000-4-4:2012 relates to the immunity of electrical and electronic equipment to repetitive electrical fast transients. It has the status of a basic EMC publication in accordance with IEC Guide 107. It gives immunity requirements and test procedures related to electrical fast transients/bursts. It additionally defines ranges of test levels and establishes test procedures. The object of this standard is to establish a common and reproducible reference in order to evaluate the immunity of electrical and electronic equipment when subjected to electrical fast transient/bursts on supply, signal, control and earth ports. The test method documented in this standard describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.
General	IEC 61000-4-5	2017	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test	This part of IEC 61000 relates to the immunity requirements, test methods, and range of recommended test levels for equipment with regard to unidirectional surges caused by overvoltages from switching and lightning transients. Several test levels are defined which relate to different environment and installation conditions. These requirements are developed for and are applicable to electrical and electronic equipment. The object of this standard is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to surges. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

Industry	Standard	Version	Title	Scope
General	IEC 61000-4-6	2015	Electromagnetic compatibility (EMC). Part 4-6: Testing and measurement techniques. Immunity to conducted disturbances, induced by radio-frequency fields	This part of IEC 61000 relates to the conducted immunity requirements of electrical and electronic equipment to electromagnetic disturbances coming from intended radio-frequency (RF) transmitters in the frequency range 150 kHz up to 80 MHz. Equipment not having at least one conducting wire and/or cable (such as mains supply, signal line or earth connection) which can couple the equipment to the disturbing RF fields is excluded from the scope of this publication. NOTE 1 Test methods are defined in this part of IEC 61000 to assess the effect that conducted disturbing signals, induced by electromagnetic radiation, have on the equipment concerned. The simulation and measurement of these conducted disturbances are not adequately exact for the quantitative determination of effects. The test methods defined are structured for the primary objective of establishing adequate repeatability of results at various facilities for quantitative analysis of effects. The object of this standard is to establish a common reference for evaluating the functional immunity of electrical and electronic equipment when subjected to conducted disturbances induced by RF fields. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon. NOTE 2 As described in IEC Guide 107, this standard is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard should be applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria.
General	IEC 62262	2002	International Standard. Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK Code)	Refers to the classification of the degrees of protection provided by enclosures against external mechanical impacts when the rated voltage of the protected equipment is not greater than 72,5 kV. This standard is only applicable to enclosures of equipment where the specific standard establishes degrees of protection of the enclosure against mechanical impacts (expressed in this standard as "impacts").
General	IEC 62305-1	2010	Protection against lightning. Part 1: General principles	IEC 62305-1:2010 provides general principles to be followed for protection of structures against lightning, including their installations and contents, as well as persons.

Industry	Standard	Version	Title	Scope
General	IEC 62305-2	2010	Protection against lightning. Part 2: Risk management	IEC 62305-2:2010 is applicable to risk assessment for a structure due to lightning flashes to earth. Its purpose is to provide a procedure for the evaluation of such a risk. Once an upper tolerable limit for the risk has been selected, this procedure allows the selection of appropriate protection measures to be adopted to reduce the risk to or below the tolerable limit.
General	IEC 62305-3	2010	Protection against lightning. Part 3: Physical damage to structures and life	IEC 62305-3:2010 provides the requirements for protection of a structure against physical damage by means of a lightning protection system (LPS), and for protection against injury to living beings due to touch and step voltages in the vicinity of an LPS (see IEC 62305-1).
General	IEC 62305-4	2010	Protection against lightning. Part 4: Electrical and electronic systems within structures	IEC 62305-4:2010 provides information for the design, installation, inspection, maintenance and testing of electrical and electronic system protection (SPM) to reduce the risk of permanent failures due to lightning electromagnetic impulse (LEMP) within a structure.
General	EN ISO 3745	2012	Acoustics. Determination of sound power levels and sound energy levels of noise sources using sound pressure. Precision methods for anechoic rooms and hemi-anechoic room	This International Standard specifies methods for measuring the sound pressure levels on a measurement surface enveloping a noise source (machinery or equipment) in an anechoic room or a hemi- anechoic room. The sound power level (or, in the case of impulsive or transient noise emission, the sound energy level) produced by the noise source, in frequency bands of width one-third octave or with frequency weighting-A applied, is calculated using those measurements, including corrections to allow for any differences between the meteorological conditions at the time and place of the test and those corresponding to a reference characteristic acoustic impedance. In general, the frequency range of interest includes the one-third-octave bands with mid-band frequencies from 100 Hz to 10 000 Hz. In practice, the range is extended or restricted to frequencies beyond or within these limits, to those between which the test room is qualified for the purposes of the measurements.
General	ISO 2041	2018	Vibration and Shock. Vocabulary	Defines terms and expressions unique to the areas of mechanical vibration, shock and condition monitoring.

Industry	Standard	Version	Title	Scope
General	ISO/IEC/IEEE 15288	2015	Systems and software engineering. System life cycle processes	ISO/IEC/IEEE 15288:2015 establishes a common framework of process descriptions for describing the life cycle of systems created by humans. It defines a set of processes and associated terminology from an engineering viewpoint. These processes can be applied at any level in the hierarchy of a system's structure. Selected sets of these processes can be applied throughout the life cycle for managing and performing the stages of a system's life cycle. This is accomplished through the involvement of all stakeholders, with the ultimate goal of achieving customer satisfaction.
General	ISO 6780	2003	Flat pallets for intercontinental materials handling. Principal dimensions and tolerances	ISO 6780:2003 specifies the principal dimensions and tolerances for new single-deck and double-deck, reversible and non-reversible flat pallets, of all entry types and made of any material, related to their transportation and handling by pallet trucks, fork-lift trucks and other appropriate equipment. The requirements for features such as openings, clearances, chamfers and wings that are required for efficient handling are also included. The applicability of ISO 6780:2003 to reversible pallets can be affected by their use in field conditions.
Railway	CEN/TR 16251	2016	Railway applications. Environmental conditions. Design guidance for rolling stock	
Railway	EN 12299	2008	Railway applications. Ride comfort for passengers. Measurement and evaluation	ISO/IEC/IEEE 15288:2015 also provides processes that support the definition, control and improvement of the system life cycle processes used within an organization or a project. Organizations and projects can use these processes when acquiring and supplying systems.
Railway	EN 12663-1		Railway applications. Structural requirements of railway vehicle bodies. Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons)	

Industry	Standard	Version	Title	Scope
Railway	EN 13802	2014	Railway applications. Suspension components. Hydraulic dampers	ISO/IEC/IEEE 15288:2015 concerns those systems that are man-made and may be configured with one or more of the following system elements: hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials and naturally occurring entities.
Railway	EN 13816	2002	Transportation. Logistics and services. Public passenger transport. Service quality definition, targeting and measurement	This standard specifies the requirements to define, target and measure the quality of service required for public passenger transport, and provides guidance for the selection of related measurement methods.
Railway	EN 14531-1	2015	Railway applications. Methods for calculation of stopping and slowing distances and immobilization braking. Part 1: General algorithms utilizing mean value calculation for train sets or single vehicles	This standard describes general algorithms for the brake performance calculations to be used for all types of train sets, units or single vehicles, including high speed, locomotive and passenger coaches, conventional vehicles and wagons.
Railway	EN 14531-2	2015	Railway applications. Methods for calculation of stopping and slowing distances and immobilization braking. Part 2: Step by step calculations for train sets or single vehicles	This standard describes general algorithms for the brake performance calculations to be used for all types of train sets, units or single vehicles, including high speed, locomotive and passenger coaches, conventional vehicles and wagons.
Railway	EN 15085-1	2007 +A1:2013	Railway applications. Welding of railway vehicles and components. Part 1: General	
Railway	EN 15085-2	2007	Railway applications. Welding of railway vehicles and components. Part 2: Quality	

Industry	Standard	Version	Title	Scope
			requirements and certification of welding manufacturer	
Railway	EN 15085-3	2007 /AC:2009	Railway applications. Welding of railway vehicles and components. Part 3: Design requirements	
Railway	EN 15085-4	2007	Railway applications. Welding of railway vehicles and components. Part 4: Production requirements	
Railway	EN 15085-5	2007	Railway applications. Welding of railway vehicles and components. Part 5: Inspection, testing and documentation	
Railway	EN 15140	2006	Public passenger transport. Basic requirements and recommendations for systems that measure delivered service quality	This document provides basic requirements and recommendations for systems that measure delivered service quality of public passenger transport to be applied in the framework of EN 13816 (Transportation. Logistics and services. Public passenger transport. Service quality definition, targeting and measurement)
Railway	EN 15227	2008 +A1:2010	Railway applications. Crashworthiness requirements for railway vehicle bodies	
Railway	EN 15734-1	2010 /AC:2013	Railway applications. Braking systems of high speed trains. Part 1: Requirements and definitions	

Industry	Standard	Version	Title	Scope
Railway	EN 15734-2	2010 /AC:2012	Railway applications. Braking systems of high speed trains. Part 2: Test methods	
Railway	EN 16585-1	2017	Railway applications. Design for PRM use. Equipment and components onboard rolling stock. Part 1: Toilets	
Railway	EN 16585-2	2016	Railway applications. Design for PRM use. Equipment and components on board rolling stock. Part 2: Elements for sitting, standing and moving	
Railway	EN 16585-3	2016	Railway applications. Design for PRM use. Equipment and components on board rolling stock. Part 3: Clearways and internal doors	
Railway	EN 17261	2012	Intelligent transport systems. Automatic vehicle and equipment identification. Intermodal goods transport architecture and terminology	This standard describes the conceptual and logical architecture for automatic vehicle and equipment identification (AVI/AEI) and supporting services in an intermodal/multimodal environment. It presents a high level view of AEI intermodal and multimodal system architecture, and describes the key sub systems, their associated interfaces and interactions and how they fit into system wide functions such as management, security and information flow.

Industry	Standard	Version	Title	Scope
Railway	EN 50119	2009 +A1:2013	Railway applications. Fixed installations. Electric traction overhead contact lines	This European Standard applies to electric traction overhead contact line systems in heavy railways, light railways, trolley busses and industrial railways of public and private operators. It applies to new installations of overhead contact line systems and for the complete reconstruction of existing overhead contact line systems. This standard contains the requirements and tests for the design of overhead contact lines, requirements for structures and their structural calculations and verifications as well as the requirements and tests for the design of assemblies and individual parts.
Railway	EN 50121 (Series)	2017	Railway applications. Electromagnetic compatibility (EMC)	This European standard outlines the structure and the content of the whole set. It specifies the performance criteria applicable to the whole standards series. EN 50121-1, Electromagnetic compatibility. Part 1: General. EN 50121-2, Electromagnetic compatibility. Part 2: Emission of the whole railway system to the outside world. EN 50121-3-1, Electromagnetic compatibility. Part 3-1: Rolling stock. Train and complete vehicle. EN 50121-3-2, Electromagnetic compatibility. Part 3-2: Rolling stock. Apparatus. EN 50121-4, Electromagnetic compatibility. Part 4: Emission and immunity of the signalling and telecommunications apparatus. EN 50121-5, Electromagnetic compatibility. Part 5: Emission and immunity of fixed power supply installations and apparatus.
Railway	EN 50122-1	2011 +A4:2017	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	This European Standard specifies requirements for the protective provisions relating to electrical safety in fixed installations associated with a.c. and/or d.c. traction systems and to any installations that can be endangered by the traction power supply system. It also applies to all aspects of fixed installations that are necessary to ensure electrical safety during maintenance work within electric traction systems. This European Standard applies to all new lines and to all major revisions to existing lines for the following electric traction systems: 1) railways; 2) guided mass transport systems such as a. tramways, b. elevated and underground railways,

Industry	Standard	Version	Title	Scope
				c. mountain railways, d. trolleybus systems, and e. magnetically levitated systems, which use a contact line system, 3) material transportation systems.
Railway	EN 50122-2	2010	Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Part 2: Provisions against the effects of stray currents caused by D.C. traction systems	This European Standard specifies requirements for protective provisions against the effects of stray currents, which result from the operation of D.C. traction systems. As experience for several decades has not shown evident corrosion effects from A.C. traction systems and actual investigations are not completed, this European Standard only deals with stray currents flowing from a D.C. traction system. This European Standard applies to all metallic fixed installations which form part of the traction system, and also to any other metallic components located in any position in the earth, which can carry stray currents resulting from the operation of the railway system. This European Standard applies to all new D.C. lines and to all major revisions to existing D.C. lines. The principles may also be applied to existing electrified transportation systems where it is necessary to consider the effects of stray currents. It provides design requirements to allow maintenance. The range of application includes: a) railways, b) guided mass transport systems such as: 1) tramways, 2) elevated and underground railways, 3) mountain railways, 4) trolleybus systems, and 5) magnetically levitated systems, which use a contact line system, c) material transportation systems.

Industry	Standard	Version	Title	Scope
Railway	EN 50124-1	2017	Railway applications. Insulation coordination. Part 1: Basic requirements. Clearances and creepage distances for all electrical and electronic equipment	The whole document deals with insulation coordination in railways. It applies to equipment for use in signalling, rolling stock and fixed installations up to 2000 m above sea level. Insulation coordination is concerned with the selection, dimensioning and correlation of insulation both within and between items of equipment. In dimensioning insulation, electrical stresses and environmental conditions are taken into account. For the same conditions and stresses these dimensions are the same. An objective of insulation coordination is to avoid unnecessary over dimensioning of insulation. This standard specifies: - requirements for clearances and creepage distances for equipment; - general requirements for tests pertaining to insulation coordination.
Railway	EN 50126	2011	Railway applications. The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)	This European Standard: - defines RAMS in terms of reliability, availability, maintainability and safety and their interaction; - defines a process, based on the system lifecycle and tasks within it, for managing RAMS; - enables conflicts between RAMS elements to be controlled and managed effectively; - defines a systematic process for specifying requirements for RAMS and demonstrating that these requirements are achieved; - addresses railway specifics. This European Standard is applicable: - to the specification and demonstration of RAMS for all railway applications and at all levels of such an application, as appropriate, from complete railway routes to major systems within a railway route, and to individual and combined sub-systems and components within these major systems, including those containing software; in particular: - to new systems; - to new systems integrated into existing systems in operation prior to the creation of this standard, although it is not generally applicable to other aspects of the

Industry	Standard	Version	Title	Scope
				existing system; - to modifications of existing systems in operation prior to the creation of this standard, although it is not generally applicable to other aspects of the existing system. - at all relevant phases of the lifecycle of an application; - for use by Railway Authorities and the railway support industry.
Railway	EN 50128	2011	Railway applications. Communication, signalling and processing systems. Software for railway control and protection systems	This European Standard specifies the process and technical requirements for the development of software for programmable electronic systems for use in railway control and protection applications. It is aimed at use in any area where there are safety implications. These systems can be implemented using dedicated microprocessors, programmable logic controllers, multiprocessor distributed systems, larger scale central processor systems or other architectures.
Railway	EN 50129	2003	Railway applications. Communication, signalling and processing systems. Safety related electronic systems for signalling	This standard is applicable to safety-related electronic systems (including sub-systems and equipment) for railway signalling applications. This standard is intended to apply to all safety-related railway signalling systems/sub-system/equipment. However, the hazard analysis and risk assessment processes defined in EN 50126 and this standard are necessary for all railway signalling systems/sub-systems/equipment, in order to identify any safety requirements. If analysis reveals that no safety requirements exist (i.e.: that the situation is non-safety-related), and provided the conclusion is not revised as a consequence of later changes, this safety standard ceases to be applicable. This standard applies to the specification, design, construction, installation, acceptance, operation, maintenance and modification/extension phases of complete signalling systems, and also to individual sub-systems and equipment within the complete system. Annex C includes procedures relating to electronic hardware components. This standard applies to generic sub-systems and equipment (both application-independent and those intended for a particular class of application), and also to systems/sub-systems/equipment for specific applications.

Industry	Standard	Version	Title	Scope
Railway	EN 50153	2014 /A1:2017	Railway applications. Rolling stock. Protective provisions relating to electrical hazards	This European Standard defines requirements to be applied in the design and manufacture of electrical installations and equipment to be used on rolling stock to protect persons from electric shocks. This European Standard is applicable to rolling stock of rail transport systems, road transport systems, if they are powered by an external supply (e.g. trolley buses), magnetically levitated transport systems and to the electrical equipment installed in these systems.
Railway	EN 50155	2017	Railway applications. Rolling stock. Electronic equipment	
Railway	EN 50159	2010	Railway applications. Communication, signalling and processing systems. Safety-related communication in transmission systems	This European Standard is applicable to safety-related electronic systems using for digital communication purposes a transmission system which was not necessarily designed for safety-related applications and which is - under the control of the designer and fixed during the lifetime, or - partly unknown or not fixed, however unauthorised access can be excluded, or - not under the control of the designer, and also unauthorised access has to be considered. Both safety-related equipment and non safety-related equipment can be connected to the transmission system. This standard gives the basic requirements needed to achieve safety-related communication between safety-related equipment connected to the transmission system. This European Standard is applicable to the safety requirement specification of the safety related equipment connected to the transmission system, in order to obtain the allocated safety integrity requirements. Safety requirements are generally implemented in the safety-related equipment, designed according to EN 50129. In certain cases these requirements may be implemented in other equipment of the transmission system, as long as there is control by safety measures to meet the allocated safety integrity requirements.

Industry	Standard	Version	Title	Scope
Railway	EN 50160	2011	Voltage characteristics of electricity supplied by public distribution systems	This European Standard defines, describes and specifies the main characteristics of the voltage at a network user's supply terminals in public low voltage, medium and high voltage AC electricity networks under normal operating conditions. This standard describes the limits or values within which the voltage characteristics can be expected to remain at any supply terminal in public European electricity networks and does not describe the average situation usually experienced by an individual network user.
Railway	EN 50163	2014	Railway applications. Supply voltages of traction systems	This European Standard specifies the main characteristics of the supply voltages of traction systems, such as traction fixed installations, including auxiliary devices fed by the contact line, and rolling stock, for use in the following applications : – railways; – guided mass transport systems such as tramways, elevated and underground railways mountain railways, and trolleybus systems; – material transportation systems.
Railway	EN 50367	2004	Railway applications. Current collection systems. Technical criteria for the interaction between pantograph and overhead line (to achieve free access)	This European Standard specifies requirements for the interaction between pantographs and overhead contact lines, to achieve interoperability. NOTE: These requirements are defined for a limited number of pantograph types, referred to as 'interoperable pantograph', together with the geometry and characteristics of compatible overhead contact lines. This European Standard describes parameters and values for all planned lines and future lines.
Railway	EN 60068-2-1	2007	Railway applications. Environmental testing. Part 2: Tests. Test A: Cold	
Railway	EN 60068-2-2	2007	Railway applications. Environmental testing. Part 2: Tests. Test B: Dry heat	

Industry	Standard	Version	Title	Scope
Railway	EN 60068-2-3	2005	Railway applications. Environmental testing. Part 2: Tests. Test Ca: Damp heat, steady state	
Railway	EN 61287-1	2014	Railway applications. Rolling stock. Power converters. Part 1: Characteristics and test methods	
Railway	EN 61373	1999	Railway applications. Rolling stock. Shock and vibration tests	
Railway	UIC 505-1	2006	Railway transport stock. Rolling stock construction gauge	
Road	EN 13149-1	2004	Public transport. Road vehicle scheduling and control systems. Part 1: WORLDFIP definition and application rules for onboard data transmission	This document specifies rules for an on-board data transmission bus between the different equipment for service operations and monitoring of the fleet. This applies to equipment installed onboard buses, trolleybuses and tramways only as part of a bus fleet operation. It excludes tramways when they are operated as part of a train, subway or metro operation. The equipment includes operations aid systems, automatic passenger information systems, fare collection systems, etc.
Road	EN 13149-2	2004	Public transport. Road vehicle scheduling and control systems. Part 2: WORLDFIP cabling specifications	This document defines the cabling specifications for an on-board data transmission bus between the different parts of equipment for service operations and monitoring of the fleet. This document is applicable to equipment installed on-board buses, trolley buses and tramways only as part of a bus fleet operation. This equipment includes operations aid systems, automatic passenger information systems, fare collection systems, etc.

Industry	Standard	Version	Title	Scope
Road	EN 13149-4	2004	Public transport. Road vehicle scheduling and control systems. Part 4: General application rules for CANopen transmission buses	This document specifies the rules for an on-board data transmission bus between the different equipment for service operations and monitoring of the fleet. This applies to equipment installed on-board buses, trolleybuses and tramways only as part of a bus fleet operation. It excludes tramways when they are operated as part of a train, subway or metro operation. This equipment includes operation aid systems, automatic passenger information systems, fare collection systems, etc. The equipment directly related to the safety-related functioning of the vehicle (propulsion management, brake systems, door opening systems, etc.) is excluded from the scope of the present document and are dealt with in other standardization bodies.
Space	ECSS-E-ST-10-02C (FprEN 16603-10-02?)	2009	Space engineering. Verification	This Standard establishes the requirements for the verification of a space system product. It defines the fundamental concepts of the verification process, the criteria for defining the verification strategy and specifies the requirements for the implementation of the verification programme. It includes also the list of the expected documentation (i.e. Document requirements definitions, DRDs). This Standard is intended to apply to different products at different levels from a single equipment to the overall system (including space segment hardware and software, ground segment, launchers and transportation systems, Verification tools and GSE).

Industry	Standard	Version	Title	Scope
Space	ECSS-E-ST-10-03C (EN 16603-10-03:2014)	2012	Space engineering. Testing	This standard addresses the requirements for performing verification by testing of space segment elements and space segment equipment on ground prior to launch. The document is applicable for tests performed on qualification models, flight models (tested at acceptance level) and protoflight models. The standard provides: · Requirements for test programme and test management, · Requirements for retesting, · Requirements for redundancy testing, · Requirements for environmental tests, · General requirements for functional and performance tests, · Requirements for qualification, acceptance, and protoflight testing including qualification, acceptance, and proto-fight models' test margins and duration, · Requirements for test factors, test condition, test tolerances, and test accuracies, · General requirements for development tests pertinent to the start of the qualification test programme, · Content of the necessary documentation for testing activities (e.g. DRD).
Space	ECSS-E-ST-10C (EN 16603-10:2018)	Rev.1: 2017	Space engineering. System engineering general requirements	This standard specifies the system engineering implementation requirements for space systems and space products development. Specific objectives of this standard are: • to implement the system engineering requirements to establish a firm technical basis and to minimize technical risk and cost for space systems and space products development; • to specify the essential system engineering tasks, their objectives and outputs; • to implement integration and control of engineering disciplines and lower level system engineering work; • to implement the "customer-system-supplier model" through the development of systems and products for space applications.

Industry	Standard	Version	Title	Scope
Space	ECSS-E-ST-20C (FrpEN16603-20?)	2008	Space engineering. Electrical and electronic	This Standard establishes the basic rules and general principles applicable to the electrical, electronic, electromagnetic, microwave and engineering 'processes. It specifies the tasks of these engineering processes and the basic performance and design requirements in each discipline. It defines the terminology for the activities within these areas. It defines the specific requirements for electrical subsystems and payloads, deriving from the system engineering requirements laid out in ECSS-E-ST-10 "Space engineering. System engineering general requirements".
Space	ECSS-E-ST-31C (EN 16603-31:2015)	2008	Space engineering. Thermal control general requirements	ECSS-E-ST-31 defines requirements for the discipline of thermal engineering. This Standard defines the requirements for the definition, analysis, design, manufacture, verification and in-service operation of thermal control subsystems of spacecraft and other space products. For this Standard, the complete temperature scale is divided into three ranges: • Cryogenic temperature range • Conventional temperature range • High temperature range. The requirements of this Standard are applicable to the complete temperature scale. However, where applicable, requirements are stated to be applicable only for the cryogenic or high temperature range. References to these specific requirements have been summarized in Annex G and Annex H. This standard is applicable to all flight hardware of space projects, including spacecraft and launchers.
Space	ECSS-E-ST-32C (EN 16603-32:2014)	Rev.1: 2008	Space engineering. Structural general requirements	ECSS-E-ST-32C (Space engineering – Structural) defines the mechanical engineering requirements for structural engineering. This Standard specifies the requirements to be considered in all engineering aspects of structures: requirement definition and specification, design, development, verification, production, in-service and eventual disposal. The Standard applies to all general structural subsystem aspects of space products including: launch vehicles, transfer vehicles, re-entry vehicles, spacecraft, landing probes and rovers, sounding rockets, payloads and instruments, and structural parts of all subsystems.

Industry	Standard	Version	Title	Scope
Space	ECSS-E-ST-40C (EN 16603-40:2014)	2009	Space engineering. Software general requirements	This software engineering Standard concerns the “product software”, i.e. software that is part of a space system product tree and developed as part of a space project. This Standard is applicable, to the extent defined by the tailoring process, to all the elements of a space system, including the space segment, the launch service segment and the ground segment. This Standard covers all aspects of space software engineering including requirements definition, design, production, verification and validation, transfer, operations and maintenance.
Space	ECSS-E-ST-50C (EN 16603-50:2014)	2008	Space engineering. Communications	This Standard specifies the requirements for the development of the end-to-end data communications system for spacecraft. Specifically, this standard specifies: • The terminology to be used for space communication systems engineering. • The activities to be performed as part of the space communication system engineering process, in accordance with the ECSS-E-ST-10 standard. • Specific requirements on space communication systems in respect of functionality and performance. The communications links covered by this Standard are the space-to-ground and space-to-space links used during spacecraft operations, and the communications links to the spacecraft used during the assembly, integration and test, and operational phases.
Space	ECSS-E-ST-60-10C (EN 16603-60-10:2014)	2008	Space engineering. Control performances	This standard deals with control systems developed as part of a space project. It is applicable to all the elements of a space system, including the space segment, the ground segment and the launch service segment. It addresses the issue of control performance, in terms of definition, specification, verification and validation methods and processes. The standard defines a general framework for handling performance indicators, which applies to all disciplines involving control engineering, and which can be applied as well at different levels ranging from equipment to system level. It also focuses on the specific performance indicators applicable to the case of closed-loop control systems – mainly stability and robustness.

Industry	Standard	Version	Title	Scope
Space	ECSS-M-ST-10C (EN 16601-10:2015)	Rev.1: 2009	Space project management. Project planning and implementation	The scope of this ECSS Standard is limited to describing the key elements of project planning and implementation and identifying the top level requirements and products that together provide a coherent and integrated project planning across the 3 ECSS branches.
Space	ECSS-M-ST-80C (EN 16601-80:2014)	2008	Space project management. Risk management	This Standard defines the principles and requirements for integrated risk management on a space project; it explains what is needed to implement a project–integrated risk management policy by any project actor, at any level (i.e. customer, first level supplier, or lower level suppliers). This Standard contains a summary of the general risk management process, which is subdivided into four (4) basic steps and nine (9) tasks. The risk management process requires information exchange among all project domains, and provides visibility over risks, with a ranking according to their criticality for the project; these risks are monitored and controlled according to the rules defined for the domains to which they belong.
Space	ECSS-Q-ST-10C (EN 16602-10:2017)	2008	Space product assurance. Product assurance management	The ECSS standards of the Q branch describe a set of requirements for a Product Assurance programme to be implemented throughout the phases of a space project. This document defines the Product assurance management requirements for space projects. This document is structured in two main parts, the first part presenting the principles of Product Assurance management and the second providing the detailed requirements.
Space	ECSS-Q-ST-20C (EN 16602-20:2018)	Rev.2: 2018	Space product assurance. Quality assurance	This Standard defines the quality assurance (QA) requirements for the establishment and implementation of a Quality Assurance programme for products of space projects.
Space	ECSS-Q-ST-40C (EN 16602-40:2018)	Rev.1: 2017	Space product assurance. Safety	This Standard defines the safety programme and the safety technical requirements aiming to protect flight and ground personnel, the launch vehicle, associated payloads, ground support equipment, the general public, public and private property, the space system and associated segments and the environment from hazards associated with European space systems.

Industry	Standard	Version	Title	Scope
Space	ECSS-Q-ST-60C (EN 16602-60:2015)	Rev.2: 2013	Space product assurance. Electrical, electronic and electromechanical (EEE) components	The objective of the EEE component selection, control, procurement and use requirements is to ensure that EEE components used in a space project enables the project to meet its mission requirements. Important elements of EEE component requirements include: a. component programme management, b. component selection, evaluation and approval, c. procurement, d. handling and storage, e. component quality assurance, f. specific components, and g. documentation.
Space	ECSS-Q-ST-70C (EN 16602-70:2016)	Rev.1: 2014	Space product assurance. Materials, mechanical parts and processes	This Standard specifies the requirements and statements applicable to materials, mechanical parts and processes to satisfy the mission performance requirements. This Standard also specifies the documentation requirements and the procedures relevant to obtaining approval for the use of materials, mechanical parts and processes in the fabrication of space systems and associated equipment. This Standard covers the following: • management, including organization, reviews, acceptance status and documentation control; • selection criteria and rules; • evaluation, validation and qualification, or verification testing; • procurement and receiving inspection; • utilization criteria and rules.

Industry	Standard	Version	Title	Scope
Space	ECSS-Q-ST-80C (EN 16602-80:2017)	Rev.1: 2017	Space product assurance. Software product assurance	This Standard defines a set of software product assurance requirements to be used for the development and maintenance of software for space systems. Space systems include manned and unmanned spacecraft, launchers, payloads, experiments and their associated ground equipment and facilities. Software includes the software component of firmware. This Standard also applies to the development or reuse of non-deliverable software which affects the quality of the deliverable product or service provided by a space system, if the service is implemented by software.
Construction	EN 13445	2016	Unfired pressure vessels	Provides rules for the design, fabrication, and inspection of pressure vessels.
Construction	EN 13480	2017	Metallic industrial piping (Parts 1 to Part 7)	Define the requirements for design, manufacture, installation.
Construction	EN 1990	2002	Eurocode: Basis of structural design	Establishes principles and requirements for the safety, serviceability and durability of structures, describes the basis for their design and verification and gives guidelines for related aspects of structural reliability.
Construction	EN ISO 1101	2017	Geometrical product specifications (GPS). Geometrical tolerancing. Tolerances of form, orientation, location and run-out	Defines the symbol language for geometrical specification of work pieces and the rules for its interpretation. It provides the foundation for geometrical specification. The illustrations in this document are intended to illustrate how a specification can be fully indicated with visible annotation (including e.g. TEDs).
Construction	EN ISO 2768-1	1990	General tolerances. Part 1: Tolerances for linear and angular dimensions without individual indications	Simplifies drawing indications and specifies general tolerances in four tolerance classes. It applies to the dimensions of work pieces that are produced by metal removal or are formed from sheet metal. It contains three tables and an informative annex with regard to concepts behind general tolerancing of dimensions.