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Review Article

Comparison of conventional high speed railway, maglev and hyperloop transportation systems

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ABSTRACT

Increasing the speed of transportation has been a subject that human beings have been working on for many years. Because of insufficient traffic corridors, the interest of more passenger in limited time and the advancement of railway technology, the high-speed ground transportation systems have developed. Nowadays, these time-saving transportation systems are becoming important increasingly and systems that will ensure these are implemented and new ones are being researched. High speed ground transportation systems can be divided into three categories: Conventional high-speed railway, Maglev and Hyperloop transportation system. Within the scope of this study, it is aimed to investigate the advantages and disadvantages aspects of high speed transportation systems by comparing in terms of speed, capacity, energy consumption, cost and environmental effects. Conventional high-speed railways can provide high capacity, comfort and safety and reliability thanks to enormous operational experience as regards other systems. The Maglev technology can offer more remarkable travel times, energy efficient and better operational performance. However, high investment cost and incompatibility with other modes are seen the disadvantage features of this technology. The Hyperloop technology is a considerable innovative transportation system which is popularized with publishing design document by Elon Musk in 2013. Projected high-speed and appealing travel times can be evaluated as the advantages of the Hyperloop transportation system. However, there are safety, reliability, comfort and engineering design challenges to overcome in this technology. Taking everything into consideration, the Hyperloop transportation system has potential to be an alternative mode to other systems.

1. Introduction

Increasing the speed of transportation has taken an important place among the efforts of human being for a long time. Because of incremental environmental impacts such as traffic jams, prolonged travel times, air pollution and noise caused by existing modes of transportation, countries have changed transport policies. As a result of inadequate traffic corridors, the demand of more passenger in shorter time and the evolution of the railway technology, the high-speed ground transportation systems have developed [1]. High-speed ground transportation systems can be divided into three categories based on the type of technology which is used. These are Conventional high speed railway, Maglev and Hyperloop transportation system.

In Conventional high-speed railway transportation systems, steel-rail and steel-wheel technology is used. Conventional high-speed railways can be defined in terms of infrastructure, rolling stock and operating conditions. With respect to minimum speed limitations, it is described that a high-speed rail line allows to operate at speeds of over 250 km/h for newly constructed lines or over 200 km/h on existing lines [2].

Maglev technology is described as an abbreviation of the word “magnetic levitation” which is a transportation system comprises of a vehicle that is lifted and pushing by means of magnetic forces along a guideway without physical contact. The main idea behind of Maglev

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technology is that the identical pole of magnets repels while opposite pole of magnets attracts each other. The working principle of the Maglev train is based on three basic principles. These are magnetic levitation, lateral guiding and propulsion principle.

Although the Hyperloop transportation framework was brought to public attention in 2013 by Elon Musk as a fifth mode of transportation after car, airplane, train and ship, the idea of this technology dates back to 1900s. In 1910s, the American rocket pioneer Robert Goddard proposed a floating train was named as vactrain (vacuum train) inside a vacuum-sealed tunnel from Boston to New York [3,4]. The idea was popularized by Elon Musk with introducing Hyperloop Alpha concept. The main philosophy of Hyperloop technology is that movement of the capsules in lower pressurized tube by means of linear asynchronous motors fed by solar energy. The goal is to reach supersonic speed (1220 km/h) by minimizing air resistance and friction [5].

There are many previous studies on these types of transportation system. While most of these studies compare Maglev and Conventional high speed railway from different technical aspects, few studies aim to contrast these three types of transportation system together. In the study of Liu and Deng [1], the aim is to compare of Maglev and Conventional high speed railway system from operating perspective given corridor from Beijing to Shanghai. As a result of this study, the positive and negative sides of both transportation systems are overviewed in order to select the proper technology for giving corridor.

In the master thesis [6], Maglev and Conventional high speed railway systems are analyzed and contrasted to improve current transportation networks in the United States of America. The results indicate that Maglev technology has more positive sides than Conventional high speed system. In the other master thesis [7], three high speed transportation systems are evaluated in terms of energy consumption and sustainability. The simulation results show that Hyperloop system is best high-speed transportation system with regard to consuming and regenerating of energy.

In the study of Çodur [8], features of Maglev technology and its applications in terms of cost around the word are included. As a result of this study, it is concluded that at which distances Maglev technology is more feasible.

The study [9], comprises of features and history of three transportation systems. It evaluates challenges of application about three systems.

Janić [10] evaluates the three transportation systems, assuming corridor between Moscow-St. Petersburg. It is indicated that Hyperloop system can be an alternative to Transrapid Maglev and Conventional high speed rail. Contreras [11] reviews of features of three systems and emphasizes current and future challenges.

The study of Armağan [12] presents a review of the Hyperloop transportation system. In the study, safety, resistance of weather and earthquake are remarked as the advantage side of Hyperloop. However, in terms of the cost issue, this technology is remarked as expensive.

In the scope of this study, it is aimed to reveal advantage and disadvantage aspects of three transportation systems by comparing in terms of speed, capacity, energy consumption, cost and environmental impacts. The contribution of this paper is to highlight benefits and challenges of these three high speed transportation systems by presenting state of art review.

2. Conventional High Speed Railways

Due to rapid urbanization process across the globe, congestion and inadequate capacity in existing highway and airway modes of transportation, have enabled Conventional high speed railways to be promoted in transport policies. Moreover, reduced travel times thanks to high speed offered by Conventional high speed railways, as well as providing a safe and comfortable trip have increased the popularity of high speed railway system [1].

It is not possible that define Conventional high speed railway based on only one factor. The high-speed railway technology is a complex system that consists of many components such as infrastructure, rolling stock, telecommunication, operating conditions and equipment etc. According to European Union Directive 96/48/EC Annex 1, in terms of infrastructure, it is defined as building track specially or upgraded for high speed travel. In terms of minimum speed limit, it is defined as minimum speed of 250 km/h for newly constructed lines and about 200 km/h on existing lines which have been particularly promoted. This must apply to at any rate segment of the track. Regarding to operating conditions, rolling stock needs to be designed along its infrastructure for whole compatibility [2].

The history of conventional high speed railway traced back to 1964 with the opening of Tokaido Shinkansen in Japan. After Shinkansen enormous success, many European countries, especially France, Germany, Italy developed new technologies in order to increase share of railway in the transportation sector. France in 1981, Italy and Germany in 1988, Spain in 1992, China in 2003, Turkey and Netherland in 2009 opened first high-speed lines all around world. As a result of huge investment by China, this country has a largest conventional railway network in today [2].

Nowadays, there are tens of thousand kilometer lines in operation or plan from different countries around the world. Table 1 presents that the total current length of high-speed lines of some countries according to International Union of Railway (UIC) data in 2020.

3. Maglev Technology

The Maglev term is an abbreviation of "magnetic levitation". Magnetic levitation is defined as a transportation system consisting of a vehicle that is lifted and pushed with help of magnetic forces along a guideway without physical contact.

The main working principle of Maglev trains is based on repelling of equal polar magnets and attraction of opposite polar magnets each other. Magnetic levitation, lateral guiding and propulsion functions are provided by means of magnetic force. The force generated by electromagnets creates a distance of approximately 1 centimeter between the guideway and bottom of the train. The distance between train and guideway is controlled precisely. Owing to lateral guiding, the lateral stability and straddling of the train are ensured. The forward motion and braking of train are same principle as the electric motor. Motor windings lined along guideway acts as a stator and electromagnets on the train acts as a rotor. The alternating current supplied to motor windings creates a magnetic field that moves the train.

The speed of Maglev trains can be adjusted depending on the frequency of the alternating current supplied. Braking and stopping of the train are performed by generating a magnetic force in the opposite direction [14, 15].

There are two major types of Maglev technology. These are Electromagnetic Suspension System (EMS) and Electrodynamic Suspension System (EDS). Fundamentally, while EMS uses magnetic attraction force to move in the air, magnetic repulsion force is used in EDS system (Figure 1). Table 2 summarizes that difference of Maglev technology types.

The history of Maglev train can be dated from 1934 with the patent of Hermann Kemper from Germany. In the past few decades since then, as a result of human endeavor's, first commercial Maglev line is opened in Shanghai [18]. There are six commercial Maglev lines around world by the year of 2020 (Table 3) [17].

Table 1. The lengths of conventional high speed lines of some countries from around world [13]

Country	In Operation (km)	Under Const.(km)	Total (km)
China	35,388	5,250	40,638
Japan	3,041	402	3,443
France	2,734	-	2,734
Germany	1,571	147	1,718
Italy	921	327	1,248
Spain	3,330	1,293	4,623
Turkey	594	1,652	2,246
USA	735	763	1,528

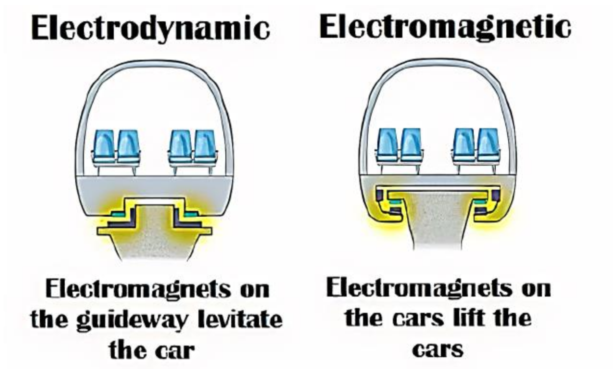

Figure 1. Comparison of EMS and EDS [16]

Table 2. Comparison of maglev technology types [16]

EMS	EDS
Using of conventional magnets	Using of superconducting magnets
About 15 mm air gap between train and guideway	About 15 cm air gap between train and guideway
Need precise control systems	Less sensitive to earthquake
Work at all speeds	Only work at minimum speed about 30 km/h
Less energy consumption	Reaching higher speeds

Table 3. Existing maglev lines around world [17]

Country/City	Line	Opening	Length (km)
China, Shanghai	Airport Maglev	2004	30.5
Japan, Nagoya	Linimo Metro	2005	8.9
South Korea, Daejeon	Museum Maglev	2008	1
South Korea, Incheon	Airport Maglev	2016	6.1
China, Changsha	Airport Maglev	2016	18.6
China, Beijing	S1 Metro	2017	10.2

4. Hyperloop

The Hyperloop technology was announced in a design document called Hyperloop Alpha as a new high-speed transportation concept in 2013 by Elon Musk, CEO of SpaceX and Tesla companies. This new system is based on the movement of the capsule with the help of linear electromagnetic motors through tube with low air pressure at similar or higher speeds than air travel. It is stated that Hyperloop can travel between Los Angeles and San Francisco in 35 minutes [5].

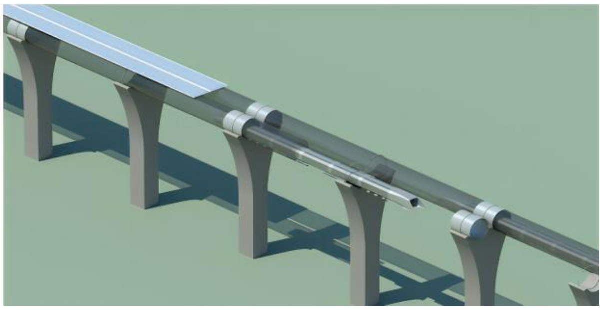

Figure 2. Hyperloop vacuum tube design [3]

The main working principle of this emerging technology is to minimize air friction in a vacuum tube with magnetically levitated capsule. The Hyperloop technology consists of vehicle (capsule) which is used for passenger or cargo transportation, vacuum tube and propulsion system. The capsule is the main component of Hyperloop technology responsible for passenger or cargo transport.

Due to the targeted high speed, use of wheels is not possible in capsule design. The shape of capsule is chosen so that there is a minimal resistance to air friction during movement. The Hyperloop route consists of a cylinder vacuum tube. It is proposed to reduce the cost of construction and keep the required construction area size to a minimum, vacuum tube is built on columns that are constructed at intervals (Figure 2). In order to speed up and slow down the capsule, the linear asynchronous motor would be used. The stationary motor element (stator) would be constructed at various positions along the length of the tube to accelerate the capsule, while the movable motor element (rotor) would be placed in capsules to transfer momentum to the capsule through linear accelerators [5].

The Hyperloop Alpha design document which was announced by Elon Musk in 2013, attracted great attention worldwide. After releasing of design document, many companies and academic teams were established to work on the Hyperloop technology. Some of these prominent companies; Hyperloop One, Hyperloop Transportation Technologies, Delft Hyperloop, Hardt Hyperloop etc. In this context, the first test track called DevLoop was built by Hyperloop One company in the Nevada desert in the north of Las Vegas. This test track is approximately 500 meters long, and it is used to test prototypes of passenger and cargo capsules [19]. While the United States mostly leads work on the Hyperloop technology, countries such as the United Arab Emirates, India, France and Netherlands are conducting research and studies on the application of this system to their own countries.

5. Comparison of Transportation Systems

It is possible to compare Conventional high speed railway, Maglev and Hyperloop transportation systems from different technical aspects. Comparison of these three high speed transportation systems can be categorized as listed below;

- General comparison of three transportation systems in terms of speed, capacity, compatibility of system etc.
- Comparison in terms of geometric standards
- Comparison in terms of cost
- Comparison in terms of energy consumption
- Comparison in terms of environmental effects

5.1 General Comparison of Transportation Systems

Travel time is one of the most important parameters that cause passengers to choose one mode of transportation instead of another. The design and operating speed of each mode of transportation play vital role in terms of travel time. While design speed is generally dependent on infrastructure, maximum operating speed varies depending on technical characteristics and operating models of the train. The average speed is defined as track length divided by total travel time.

Table 4 shows that a comparison of the design speed, operating speed and average speed of Shanghai Maglev, TGV, ICE high speed railway trains and Hyperloop. For the Hyperloop transportation system, speed values which are stipulated in the Alpha report were used. It is desired to make comparison based on Table 4, Maglev technology has advantage over Conventional high speed railways in terms of maximum operating speed. Although there is not a commercially operated line with Hyperloop, development studies on speed continue. Currently, the highest speed pod which is nearly 463 km/h, is acquired by a team from Technical University of Munich during the Hyperloop pod competition [20]. If desired speeds would be reached, the Hyperloop transportation system could be the most advantageous type of transportation.

Capacity is a parameter that affects the choice of types of transportation system by passenger. The capacity of a railway line can be determined by factors such as the number of passenger per train section, the number of train section and headway. While these factors mostly depend on technical characteristics, concepts such as population density and passenger demand, have a role in determining the capacity of the line. When comparing among Conventional high speed trains with regarding capacity, Shinkansen trains stand out as the highest capacity train. While the Shanghai Maglev train has a capacity of 574 passengers, 28 passengers per capsule is proposed in the Hyperloop transportation system. [5, 21].

Table 5 shows that comparison of evaluated transportation systems in terms of capacity and headway. The value of capacity in the table, is obtained as maximum passenger per hour in one direction.

Table 4. Comparison in terms of speed [1, 5]

Speed (km/h)	TGV	ICE	Shanghai Maglev	Hyperloop
Design Speed	350	330	550	1220 (theoretical)
Operating Speed	300	280	430	Not Available
Average Speed	250	200	290	965 (theoretical)

Table 5. Comparison in terms of capacity, headway [1, 5]

Type	TGV-D	SKS-E4	Shanghai Maglev	Hyper loop
Number of Section	12	16	6	1 capsule
Seat Capacity	1090	1634	574	28
Headway (min)	5	3	15	2
Capacity	13080	32680	2296	840

It is observed that Conventional high speed trains are advantageous in terms of capacity based on data in Table 5.

When the three modes of transportation are evaluated in terms of the compatibility of the system, Conventional high-speed railways have a superior advantage over the Maglev and Hyperloop transportation systems, thanks to offering the opportunity to use existing infrastructure and thus connect with existing rail networks. Since Hyperloop and Maglev transportation systems have their own special tracks, it is not possible to work with other available modes. This feature can be shown as one of the disadvantages of Hyperloop and Maglev transportation systems.

Conventional high speed railway is a type of transportation that has proven itself in terms of safety and reliability, along with lines operating in many countries around the world. To illustrate, Shinkansen trains from Japan, TGV trains from France and ICE trains from Germany have been serving passengers safely and comfortably for years .In the Maglev transportation system, it is designed to largely eliminate security risks. Examples of these design patterns are the train's motion with wrapping guide-way and precise control of the distance between the train and the guide-way. No fatal accident has occurred since the Shanghai Maglev line was commissioned. In the Hyperloop transportation system, the design is planned to be done so that the tube and capsule are not affected by natural disasters such as earthquakes. When evaluating in terms of passenger comfort, safety and reliability among three modes of transportation, Conventional high-speed railways and the Maglev transportation system offer a safe and comfortable trip. In the Hyperloop concept, although there are concerns in terms of comfort at the targeted sound levels, there is no data that can be compared since there is no commercially operated Hyperloop line for now.

5.2 Comparison in terms of Geometric Standards

Track geometry is a very important factor for train behavior. The notions related to track geometry can be sorted as track gauge, cant, transition curve, horizontal and vertical curve radius, longitudinal grade. In case of comparing with regarding geometric standards, Maglev and Hyperloop have advantages such as moving at the lower curve radius with the same speed and travelling at higher speeds in the same curve radius, and climbing higher slopes compared to Conventional high speed railways (Table 6) [22].

In the Hyperloop Alpha study report, in order to control g-force which arises from acceleration-deceleration and change of direction, the velocity plan and optimum horizontal curve radius were stated in a table. This table is obtained based on minimizing the effects of g-force, curvature radius and speeds specific to terrain between San Francisco and Los Angeles and the maximum 0.5 g force on passengers. These values are given in Table 7.

In the comparison of cant, the maximum allowable value in the Conventional high speed railways is taken as 180 mm. In the Maglev transportation system, cant is not represented in mm. The maximum allowable cant is 12° equivalent to approximately 310 mm. In some exceptional cases, it can be increased to 16°, that is approximately 410 mm. This advantage enables Maglev to increase alignment flexibility according to Conventional high speed railway [23]. In the Hyperloop Alpha report, there is not information about cant. It is a one of the uncertain issues for Hyperloop technology.

Table 8 compares the minimum vertical curve radius that Conventional high speed railways and Maglev transportation systems should provide at given speeds.

Table 6. Comparison in terms of horizontal curve radius (m) [22]

Design Speed (km/h)	ICE-03	Transrapid Maglev
Max. Side Acceleration	1 m/s^2	1,5 m/s^2
200	1400	705
250	2250	1100
300	3200	1590
350	-	2160
400	-	2825
450	-	3580

Table 7. Minimum horizontal curve radius in Hyperloop [5]

Track Route	Design Speed (km/h)	Min. horizontal curve radius (m)
L.Angeles-Grapevine South	480	3670
L.Angeles-Grapevine North	890	12550
I-580/San Francisco Bay	1220	23500

Table 8. Comparison in terms of vertical curve radius (m) [22]

Design Speed (km/h)	ICE-03		Transrapid Maglev	
	Crest	Sag	Crest	Sag
Max. Vertical Acceleration	0,5 m/s^2	0,6 m/s^2	0,6 m/s^2	1,2 m/s^2
200	6400	5200	5150	2600
300	14400	11700	11600	5790
330	17400	14200	14000	7000
400	-	-	20600	10300
450	-	-	26000	13000

For the Hyperloop technology, the vertical curve radius is not explicitly given in the Alpha design document. However, in order to diminish earthworks, pipelines are constructed as compatible with road geometry. Therefore, the grade of vertical curve will not exceed %6 according to the AASHTO highway specification.

5.3 Comparison in terms of Cost

Cost plays an important role in selecting and evaluating any mode of transportation. There are different cost concepts such as construction, operating and maintaining cost for a mode of transport. The cost of construction includes the cost of constructing the line and stations, the train control system, and the purchase of the trains. The operating cost includes the expenses required to keep the line operating. Maintenance costs include the necessary expenses to operate the line properly and efficiently.

It is seen that the construction cost of Conventional high speed railways varies around the world. The total construction cost of a mode of transport depends on the chosen technology, design speed, land topography, land acquisition requirements, the need for special structures and auxiliary facilities. To illustrate, in the study conducted on 45 projects, it is seen that the construction costs of Conventional high speed railways vary between 6 and 45 million Euros per kilometer. The average cost was found to be 17.5 million Euros. It is occurred that Conventional high speed railway construction costs in the Asian continent are higher than in the European continent. For the European continent, the construction costs in France and Spain are slightly lower than in Germany and Italy. Although the topography of land has an effect on this difference, the construction method also emerges as an important factor [24].

Maglev transport type has higher construction costs than Conventional high-speed rail due to the completely separate right of way, construction of special facilities and incompatible with existing transportation systems.

The fact that Maglev trains cannot run on normal train tracks that theyare not compatible with the existing railway infrastructure that they require a completely new line are important factors that increase the construction cost.

In the Hyperloop technology, the construction cost covers the construction of the guiding line, capsule production, station construction costs. The Hyperloop Alpha report foresees a construction cost of approximately $ 6 billion for the passenger-carrying version alone and $ 7.5 billion for the passenger + vehicle version [5]. It is not included earthwork and special station costs in this cost estimation. Additionally, a current project between Dubai and Abu Dhabi, which is planned to be completed soon, it is estimated to cost between $ 20 million to $ 40 million per kilometer [25].

When comparing the average construction costs between these transportation systems, it is seen that the highest construction costs per kilometer belong to the Maglev mode of transport. According to stipulated costs in the Hyperloop Alpha report, the Hyperloop transportation system has a lower construction cost than Maglev. After construction of the track, operation and maintenance costs come into play. Maglev train can be operated at very high speeds without any deterioration and therefore it is more economical to operate than Conventional high-speed railways that require regular maintenance. Transrapid Maglev has fully automatic operation and is driverless. For this reason, personnel costs which are a component of operating costs, are expected to be lower than Conventional high speed railways. Another positive feature of the Maglev transportation system is that maintenance costs are lower than Conventional high speed railways.

Table 9. Comparison in terms of construction cost [5,22]

Route	Transport Mode	Cost (billion $)	Length (km)	Cost per km (million $)
Tokyo-Osaka	HSR	0,92	570	1,6
Paris-Lyon	HSR	2,06	1000	2,06
Madrid-Barcelona	HSR	10,62	620	17,12
Beijing-Shanghai	HSR	35,80	1432	25
Shanghai	Maglev	1,58	30	52,67
Linimo	Maglev	0,92	8,8	104,77
L.Angeles-California	Hyper loop	6	563	10,66

Since Maglev trains move in suspension along the guideway, wear and tear damage caused by wheels in high speed railways are eliminated. Since the acceleration and deceleration of Maglev trains are provided by the magnetic force created by electromagnets, there is no contact with the rail.

Since there is no friction between the rail and the train, the maintenance cost of the rail is very low and frequent repairs and controls are not required.

In evaluating the Hyperloop operating cost, the energy consumption cost is expected to be low as the energy requirement will be met by solar panels installed on tubes. Due to the fact that the system has a fully automatic operation, personnel cost can be considered as minimum. In the Hyperloop transportation system, the maintenance cost is expected to be low due to the lack of mechanical friction and weather protection as in the Maglev system. Although there is not operating experience of Hyperloop technology, the operating plans are expected to similar by airplanes. However, the security checks and terminal waiting times will be shorter and maintenance cost will be less than aircraft.

From Figure 3, comparing the Germany ICE high-speed train and the Maglev Transrapid train in terms of maintenance costs; the Maglev transportation system has about 59%less regarding to the maintenance cost of the train, 71% less of the maintenance cost of the guide-way and totally66% less maintenance cost than the Conventional high-speed railway.

In the context of ticket fee, it is indicated as approximately $ 20 for one trip according to Elon Musk's math in the design document. Moreover, a study which is about the proposed route between Pittsburg and Chicago, ticket fee is stated approximately $60 [27]. However, the single ticket cost of Shanghai Maglev is 50 yuan, which equals approximately $8[28]. In the light of this information, it can be commented that ticket cost of Hyperloop will be higher than Maglev.

5.4 Comparison in terms of Energy Consumption

The transportation sector is an important source of greenhouse gas emissions. For this reason, new technologies that reduce energy consumption in the transport sector are supported. Examples of these technologies are weight reduction (producing lighter trains, etc.), energy efficient driving techniques, reducing aerodynamic friction, and regenerative braking system. Electricity is used as an energy source in both conventional high-speed railways and Maglev.

In the Hyperloop technology, it is planned to meet the energy need with solar panels built on tubes. The Maglev train is much more economical compared to Conventional high speed railways, without contact with the guideway, high efficiency linear motor and low aerodynamic resistance. In general, the Maglev transportation system consumes 20-30% less energy than Conventional high speed railways. Convenient aerodynamic features and non-contact technology make Maglev cost-effective about energy consumption. In the Hyperloop Alpha study report, it is emphasized that Hyperloop technology will operate entirely with solar energy. Therefore, it is expected to have less energy consumption than Maglev and Conventional high speed railways. However, since there is no operational experience in the Hyperloop transportation system yet, it is not known exactly how much the energy consumption will be. In the figure 4, it is given comparison of Conventional high speed railways and Maglev trains in terms of energy consumption at certain speeds.

When the energy consumption values of Conventional high speed railways and Maglev trains are compared at 330 km / h, the Transrapid Maglev train has the lowest energy consumption with 45 Watt hours / seat / km, while the ICE-3 train has 59 Watt-hour / seat / km has the highest energy consumption. As a result, it is seen that Maglev train has approximately 31% less energy consumption than Conventional high speed railways (Figure 4).

5.5 Comparison in terms of Environmental Effects

In recent years, concerns about environmental effects of the transportation sector have been increasing. Due to being environmentally friendly of the rail transport system, it has an advantage over other transport modes.

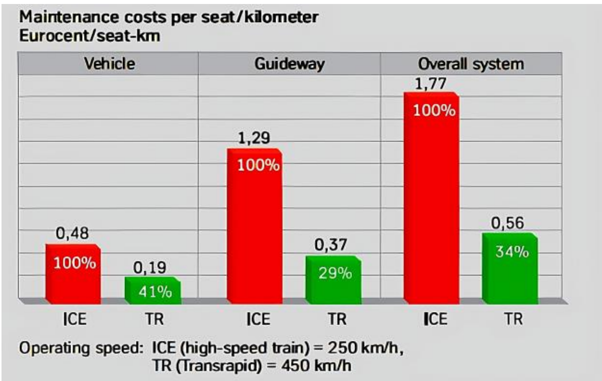

Figure 3.Comparison of maintenance cost [26]

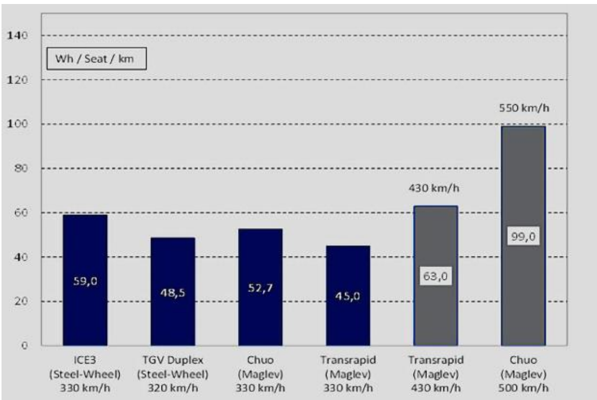

Figure 4. Energy consumption in Wh/Seat/km [29]

It is possible to divide the environmental impacts of Conventional high speed railways, Maglev and Hyperloop transportation types into sub-headings such as land use, noise, vibration.

The amount of land using depends on the type of transport system and the way the guideway is built. At grade tracks with land, consumes land which is below the track as well as catenary and signal poles are located next to it.

However, elevated track only uses the land holding columns supporting the track. The land below elevated track can be used for different purposes. As a result, elevated tracks have advantage in land using compared to track which is at grade with land. In the Maglev transportation type, lines are generally constructed as raised with columns. Therefore, Maglev transportation type has less land use than Conventional high-speed railways. In the Hyperloop concept, although the land use is not known due to lack of operational experience, as the construction method is similar to the Maglev, it is predicted to use less land compared to Conventional high speed railways. The Maglev transportation system has a distinct advantage over Conventional high speed railways in terms of land use in mountainous areas. Hyperloop transportation type is predicted to have land use values close to Maglev transportation type in terms of land use (Table 10).

Noise is a problem not only for passengers, but also for those living near the line corridor. Significant progress has been made in the control and mitigation of transport noise in recent years. Noise emissions can be grouped as noise from propulsion system, mechanical noise from wheel-rail interaction or guideway vibrations, and aerodynamic noise. Aerodynamic noise prevails at higher speeds, while at lower speeds (speeds below about 200 km/h) noise from the propulsion system or machinery is dominant. In the Maglev system, mechanical noise is not observed at low speeds since physical contact is eliminated with non-contact technology.

When the noise levels are compared at different speeds, it appears that Maglev technology is quieter than the Conventional high speed railway at speeds of 200-300 km/h. In the Hyperloop concept, it is prevented noise from moving the capsule thanks to low air pressure inside the tube. The sole possible source of noise is caused by vacuum pumps however; it is assumed to be minor [31].

Table 10. Comparison of land using [30]

Type	HSR	Maglev	Hyper loop
Average Land Consume (m^2/m)	26,2 (Plain) 43,5 (Hilly)	23,2 (Plain) 24,4 (Hilly)	Similar with Maglev

Thanks to non-contact technology in the Maglev transportation system, the Maglev train causes less vibration than Conventional high-speed trains. In the Hyperloop transportation system, as the capsule is aimed to move in the air inside the tube, it is predicted that the vibration level would be lower than Conventional high-speed trains.

6. Results and Discussion

These three high speed transportation systems are compared with regarding different factors such as speed, capacity, compatibility of the system, geometric standards cost, energy consumption and environmental effects in Table 11.

When it is made an evaluation based on parameters that are compared between examined transportation types; Hyperloop and Maglev transportation system have advantage over Conventional high speed railways in terms of speed, travel time, acceleration and braking rates. To illustrate, the route between San Francisco and Los Angeles takes 130 minutes with California high speed train, 116 minutes by Maglev train and 35 minutes by Hyperloop capsule. If target speed values for the Hyperloop concept could be reached, the Hyperloop technology would have a serious advantage in speed and travel time parameters.

If it is evaluated in terms of capacity and headway parameters, it is seen that Conventional high speed railways have a significant advantage over Maglev and Hyperloop. For instances, in the light of the data in Table 5, the maximum passenger capacity value per hour in one direction for Conventional high speed railways is approximately 14 times of the Maglev and approximately 38 times of the Hyperloop.

In terms of compatibility of the system, Maglev and Hyperloop transportation system are not compatible with existing lines because it requires its own special line structure. The Conventional high speed railway has advantage over other types of transportation thanks to their compatibility with existing lines.

When it is analyzed in terms of safety, reliability and comfort, Conventional high-speed railways offer comfortable and safe travel to millions of passenger in many countries since the first high-speed rail line in Japan was commissioned in 1964.In the Maglev transportation type, no accident was reported on the Shanghai Maglev line since 2004 and other urban lines operated in other countries.

In the matter of geometric standards, Maglev and Hyperloop have advantages such as moving at lower radius of curves at the same speed compared to Conventional high speed railways, and being able to travel at higher speeds in the same curve radius, and to climb higher slopes. Likewise, the maximum allowed cant value is higher.

Table 11. Summarizing comparison parameters

System Features	Conventional HSR	Maglev	Hyperloop (HL)
Maximum Speed (km/h)	241 Acela (Boston to Newyork) 270 TGV (Paris to Lyon)	430 (Shanghai)	1220 (theoretical)
Capacity	1000 per train (California HSR)	574 per Shanghai Maglev train	28 per capsule
Use of existing infrastructure	New lines combined with existing lines	Need special track	Need special track
Construction Cost	Lower than Maglev and higher than HL (likely)	Higher than HSR	Lower than HSR (likely)
Operating and Maintenance Cost	Higher than Maglev and HL	Lower than HSR	Lower than HSR (likely)
Energy Consumption	Higher than Maglev and HL	Less than HSR	Solar panels Less than HSR (likely)
Safety	Proven technology	Proven technology	At concept stage
Noise and Vibration	Higher than Maglev and HL	Less than HSR	Less than HSR (likely)
Land Consume	Higher than Maglev and HL	Less than HSR	Less than HSR

It is seen that highest construction cost belongs to the Maglev transportation type. Incompatibility with existing lines and high construction costs can be considered as negative aspects of the Maglev transportation system. In the Hyperloop Alpha report, the total construction cost of the 563-kilometer route between San Francisco and Los Angeles is stated as $ 6 billion. It should be noted that earthworks and construction of special station are not included in this cost estimation. Taking this average cost into consideration, the Hyperloop transportation system is cheaper than the Conventional high speed railway in terms of construction cost. However, cost issue is one of challenges to overcome for the Hyperloop transportation system.

Since Maglev train and Hyperloop capsule move without contact with guideway, the maintenance cost is less than Conventional high speed railways.

It is made a comparison based on energy consumption, Maglev trains consume 20-30% less energy than Conventional high speed trains thanks to aerodynamic feature of train and contactless technology. In the Hyperloop Alpha report, it is stated that Hyperloop capsule would run entirely on solar energy. As a result, Hyperloop mode of transport would be expected to have less energy consumption than Maglev and Conventional high speed rail.

When evaluating in terms of the land using, Maglev and Hyperloop transportation types are designed as elevated tracks. Thus, savings in the land use are provided.

Table 12. Comparison and classification of references

Major Areas	Economic Analysis	Engineering Design	Environmental Issues
Ref.	[5], [22], [24], [25], [26], [27], [28], [29]	[1], [2], [5], [14],[15],[16] [21],[22],[23]	[5], [29] [30], [31]

Moreover, thanks to the contactless technology used in the Maglev and Hyperloop transportation system, less noise and vibration values are achieved.

Finally, in this section, the used references in this study are categorized as economic analysis, engineering design and environmental issues. The classification and comparison of references are given in a table (Table 12).

7. Conclusions

Scientific and technological research continue throughout the world to develop increasingly faster transportation systems. As a result of these studies, after the Conventional high-speed railways, which are operated in many countries around the world and offer millions of passengers the opportunity of fast and comfortable travel, Maglev technology pioneered by Japan and Germany, and finally a new mode of transportation called as Hyperloop was introduced with Hyperloop Alpha report by Elon Musk in 2013. Within the scope of this study, the advantages and disadvantages of three transportation systems against each other were examined. As a result, although Hyperloop technology is a highly innovative mode of transportation, works on the development of the technology continue.

The projected low construction cost, speed and minimum environmental impacts made it stand out among the transportation types studied.

Reliability and comfort uncertainty due to not having operational experience yet, and the lack of capacity appear to be the negative aspects of this type of transportation. Taking all parameters into consideration, it is demonstrated that Hyperloop transportation system can be an alternative to Conventional high speed railways and Maglev.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

All authors reviewed the sources together. M.N. Yavuz wrote the manuscript. Z. Öztürk supervised the study and made proofreading of manuscript.

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