Technical Comparison of Maglev and Rail Rapid Transit Systems

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ABSTRACT: The need for rapid transit systems has become vital in both urban and intercity travels. There are two technologies for these systems, high-speed rail (HSR) and magnetic levitation (maglev). They are dramatically different in lots of terms. Despite demands for these types of transportation, no well-accepted report has been publicly presented for the technical comparison of these systems. This research is in response to such a necessity. The paper focuses only on the technical comparison of these technologies. For a comprehensive comparison, many criterions are included. It leads to a wider consideration and the development of the technical comparison. In fact, this research surveys technical advantages of the maglev systems over the HSR systems. The results obtained indicate that the maglev systems have more technical advantages than that of the HSR systems.

1 INTRODUCTION

The congestion in transportation modes associated with increased travel has caused many problems. These problems include the public concern, among which are prolonging travel time, growing accident rates, worsening environmental pollution, and accelerating energy consumption. On the contrary, high-speed ground transportation, characterized by high speed, operating reliability, passenger ride comfort, and excellent safety record, is considered one of the most promising solutions to alleviate the congestion. There are two distinguished technologies, HSR and maglev. Both provide higher operating speed. However, they have dramatically different technical specifications. Various organizations in the world are facing difficult decisions, when choosing or settling on a specific technology, in a particular corridor. Due to the complexities of HSR and maglev technology, it is not an easy task to select the most efficient technology in any given corridor.

A new rapid transit system influences the society, the industry and the ecology in various manners. A HSR or maglev system must prove its advantages. Therefore, extensive and detailed studies must be carried out. It must be examined in an intense planning process, with feasibility studies. The criterions for the decision must be evaluated in a multi-criteria procedure. This process delivers a master plan for new construction of the transportation network. The plan for the research and development of a rapid transit technology should be made at the national level. There are a few reports on the technical specifications of technologies and comparative studies dealing with HSR and maglev. This research presents an overview of HSR and maglev technologies. The paper focuses only on the technical comparison of these technologies. For a comprehensive comparison, a lot of criterions are included. It leads to a wider consideration and the development of the technical comparison. It comprehensively compares the characteristics of HSR and maglev in detail in different aspects. These aspects include geometrical requirements, speed, acceleration, RAMS, environmental impacts, energy consumption, noise emission, vibration level, land use, loading, etc. The obtained results clearly indicate that the maglev generally possesses better technical advantages over HSR.

As the maglev technology becomes mature day by day, countries all around the world are trying to build practical routes. Many systems have been proposed in different parts of the worlds, and a number of corridors have been selected and researched. A R&D project for a low-to-medium speed maglev system started in 1989 by Korea Institute of Machinery and Materials (KIMM) with the financial support from the Ministry of Science and Technology. In 1997, 1.1km long test track was constructed in KIMM, which was extended to 1.3 km in 2002. The pilot Urban Transit Maglev trainset (UTM-01) with two vehicles was developed in 1998. From 2003, Hyundai-Rotem, Korea's railcar manufacturing company, continued maglev development project to develop UTM-02 by the financial support from Ministry of Commerce, Industry and Energy. UTM-02 was developed to provide a shuttle service on the 1 km long single track between Expo Park and National Science Museum in Daejon. The line was constructed by upgrading a section of existing Expo'93 Maglev track. In 2006, the Ministry of Land, Transportation and Maritime Affairs (MLTM) initiated Urban Maglev Program to finalize the previous maglev R&D projects and to demonstrate the developed system for revenue service. The Center for Urban Maglev Program (CUMP) was set up to lead the program that is funded by MLTM with assistance from Ministry of Education, Science and Technology (MEST) and Ministry of Knowledge Economy (MKE) through Korea Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP) and also by matching funds from the participating companies (Shin et al. 2008).

In Iran, the Qom-Mashhad HSR plan with the speed of 350 km/h was opened in October 9, 2010 by Chinese's venture. This route covers two important cities of Esfahan and Tehran. There is also a decision for implementation of a maglev system between the two major cities of Mashhad (M) and Tehran (T). In this regard, on June the 22nd 2007, a contract was signed between Iran Ministry of Roads and Transportation authorities and a German company for implementation of a high-speed maglev system that should run between these two cities with the speed of 500 km/h. Majority of long-distance travels inside Iran often happens between these cities. The M-T maglev system is supposed to start from Mashhad in Khorasan Razavi province and by going through the city of Shahroud enters Tehran province. Estimated length of the guideway is 900km with the design speed of 500km/hr. The estimated number of passengers per annum is at least 10 million. The M-T maglev system will be as a double-track elevated route to support the ridership volumes, frequency of service, scheduling flexibility and delay recovery required. Mashhad and Tehran are the largest two cities in Iran. The M-T corridor passes through the most economically prosperous areas of Iran. This creates tremendous pressure on the existing rail line along the M-T Corridor. When the proposed maglev system is established, it will be possible to shift the passenger travel to the new line. Each of the metropolitan areas in the corridor becomes a hub within its own region (Yaghoubi 2010). This research also investigates the technical advantages of the long-distance and high-speed maglev system for the M-T route.

2 IMPORTANCE OF RAPID TRANSIT

Mobility and transportation infrastructure is a primary need for the population. They guarantee a high grade of freedom and quality for the citizens, for their work and leisure time. Infrastructure is an important location factor in the regional and global sense. It strongly influences the development of the society and the growth of the national economies. The mobility of individuals is impossible without an equivalent volume of traffic and transportation infrastructure. Against the background of increasing energy requirement, limited fossil resources and ever-growing CO_2-loads, the road traffic may not be the adequate answer for the challenges of the future developments. It is necessary to establish integrated and sustainable traffic systems for the effectively and environmentally acceptable handling of traffic (Naumann et al. 2006). Cities' developments lead to a considerable increase of the road, a capacity overloads of road traffic network, and an increase of stresses for people and environment. The transport policy must be faced up to this challenge and take appropriate measures in time. A major vision is the development and implementation of rapid transit systems, which can relocate certain parts of road and air traffic to these systems and to enhance growth of congested urban areas and coalescence of the area (Schach & Naumann 2007).

3 RAPID TRANSIT SYSTEMS

Rapid transit system is a definition that covers both HSR and maglev. It is defined as an intercity passenger transit system that is time-competitive with air and/or auto on a door-to-door basis. This is a market-based, not a speed-based, definition: it recognizes that the opportunities and requirements for high-speed transportation differ markedly among different pairs of cities (Liu & Deng 2004). The fundamental reason for considering the implementation of rapid transit systems is higher speed, which can easily equate to shorter travel time. Therefore, there is a need to look at the technical specifications of each technology. This examines the potential improvement of each technology in terms of speed, travel time and other advantages.

HSR trains represent wheel-on-rail passenger systems. These trains currently operate at maximum speeds of about 350 km/h in China, and have been tested at 574 km/h in France. Examples of HSR trains include the French Train à Grand Vitesse (TGV), the Japanese Shinkansen, the German Intercity Express (ICE), the Spanish AVE, etc. Maglev is an innovative transportation technology. It is the first fundamental innovation in the field of railway transportation technology. A maglev vehicle uses non-contact magnetic levitation, guidance and propulsion systems and has no wheels and axles. The replacement of mechanical components by wear-free electronics overcomes the technical restrictions of wheel-on-rail technology. The manned maglev vehicle has recorded the speed of travel equal to 581 km/hr (Yaghoubi 2011).

HSR and maglev systems are each developed for specific purposes. Selection of the appropriate technology will depend primarily on acceptable funding levels, transportation objectives, and implementation schedule (Najafi & Nassar 1996). Rapid transit systems must fulfill the major elements of the transport politics. The main aims consist in the increase of speed in the transportation corridors, flexibility, environmental acceptance, ride comfort, stresses (noise, pollutions, and vibrancies), etc. The two existing rapid transit systems must be evaluated and compared against the background of these requirements and the traffic demands.

The maglev vehicle is controlled using one of two suspension systems, electromagnetic suspension (EMS) or electrodynamic suspension (EDS), Figures 1, 2. The guideway is a structure that supports the maglev vehicle. It also provides guidance for the movement of the maglev vehicles. The guideway consists of a girder and two levitation rails. Guideways can be constructed on the ground or on columns with concrete or steel beams (Yaghoubi 2008, Yaghoubi & Sadat Hoseini 2010, Yaghoubi & Ziari 2010).

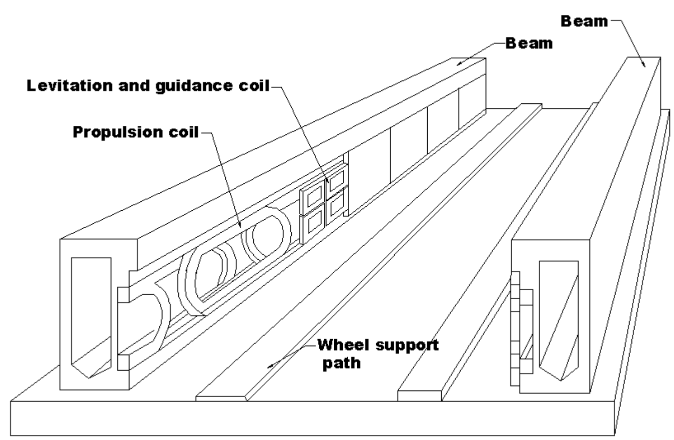

Figure 1. Schematic diagram of EDS maglev system.

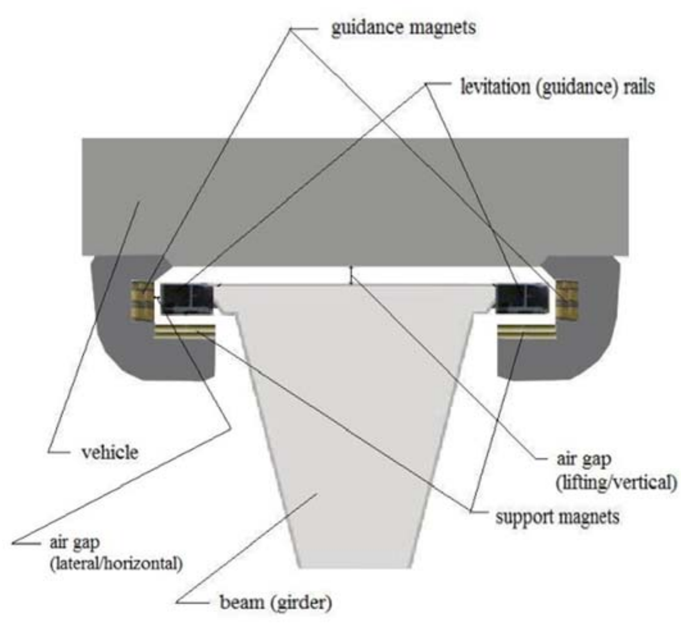

Figure 2. Caption schematic diagram of EMS maglev system.

4 TECHNICAL COMPARISON

HSR and maglev are guided ground transportation modes with very large capacity, and both use electric power from the utility grid for propulsion. They also exhibit some fundamental differences that distinguish them as very separable transportation modes. Maglev systems offer the unique combination of technical attributes. These include light weight vehicles, centralized and fully automated control of propulsion systems, non-reliance on adhesion for vehicle acceleration and braking forces, and the ability to operate with consists of as little as single cars. These cars carry fifty to one hundred passengers without the need for highly-skilled operators. The ability to use single or double-car allows even relatively small markets to be given high frequency, reliable service. This together with frequent, highly reliable service, are required to attract new ridership and divert passengers away from their cars. The maglev technology attracts a significantly greater ridership and provides more benefits than HSR systems (Rote 1998).

Figure 3 shows a classification to compare the different parameters for the rapid transit systems in this research. The paper focuses only on the technical comparison of the maglev and HSR systems. For a comprehensive comparison, a lot of criterions are included. It leads to a wider consideration and the development of the technical comparison. The purpose of this research is not to recommend one technology over the other. Actually, both technologies are highly advanced and have some advantages. Anyway, this research surveys technical advantages of the high-speed maglev systems over the HSR systems.

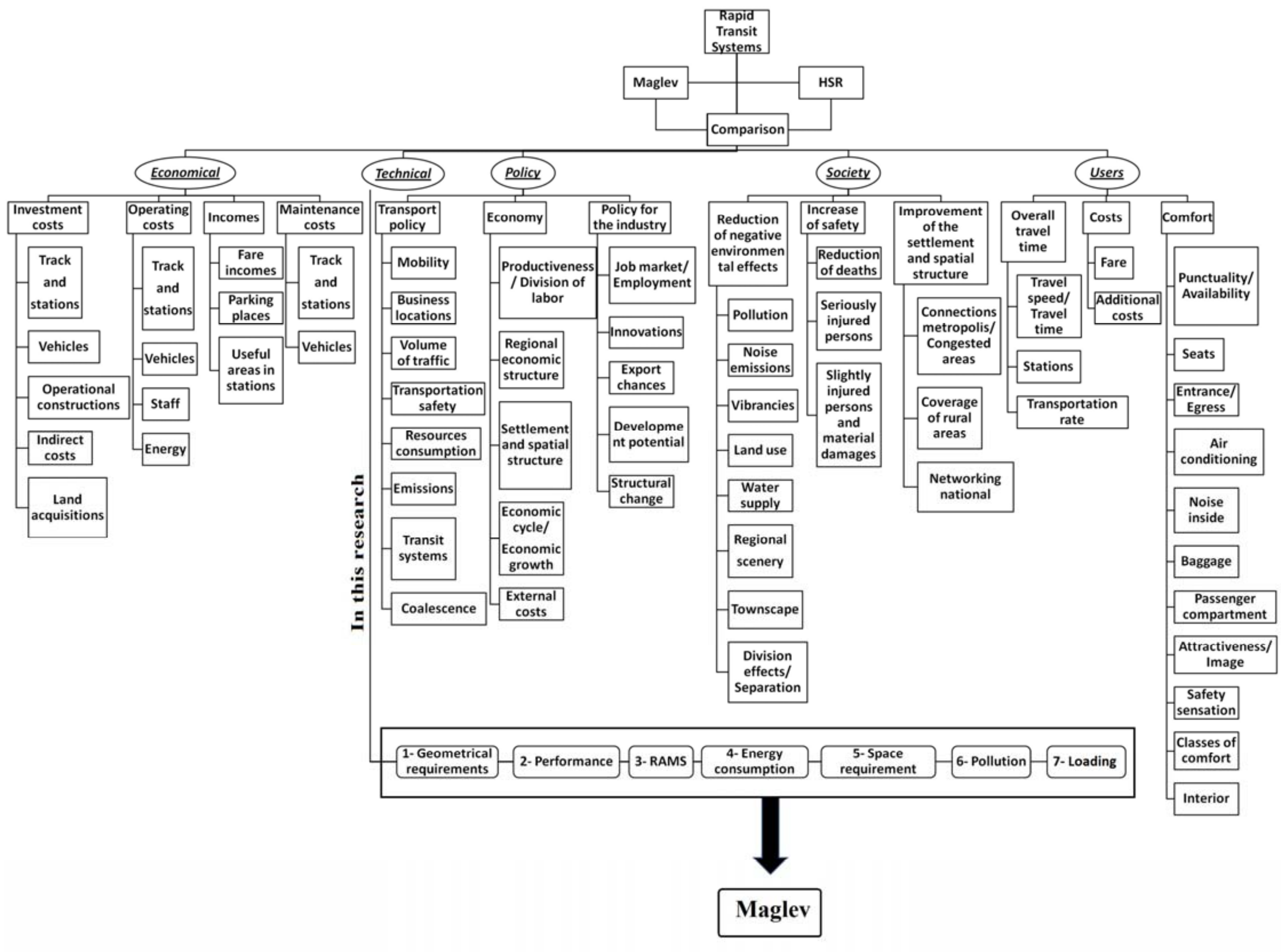

Figure 3. Classification to compare different parameters.

In general, there are many good reasons to turn to magnetically levitated trains. By lower levels of consuming energy, pollution, less noise emission and vibration level, maglev vehicles cause fewer disturbances to the nature and have increased compatibility with environmental issues. Possibility of traveling on elevated guideways means fewer land occupations. Also, maglev guideway has lower dead loading. These vehicles can travel at steeper gradients and are capable of traveling at higher speeds with increased accelerations and braking, and lower staff and maintenance costs. Maglev vehicles have lower static and dynamic loading, higher passenger capacity and increased passenger comfort and convenience. Such vehicles can travel along routes with lower curve radiuses. They are reliable, reasonably safe and convenient. Other benefits of maglev systems include travel time, health, flexibility, frequency, operational and schedule reliability (weather and equipment delays), accessibility, safety and security, system availability (origin and destination). Among the most important aspects of using maglev vehicles is the possibility of traveling at 10% grades while for high-speed trains such as German ICE this grade angle reduces to 4%. This important aspect considerably reduces the total length of the routes for maglev vehicles. As a further bonus, the cost of constructing and establishing maglev routes at grades and hilly areas reduces (Zakeri & Yaghoubi 2008). Maglev is obviously the most attractive and powerful transportation system. On the other hand, it is particularly suitable for long-distance transportation of passengers. Maglev is very competitive with air transportation at long distances and against passenger cars at distances starting of 100 kilometers. In contrast to maglev, HSR is only conditionally able to compete with passenger road and air traffic at shorter distances between approx. 150 and 350 kilometers (Naumann et al. 2006).

4.1 Geometrical Requirements

Although the guideway has the different procedure with the manufacturing and examination, its geometrical requirements and criteria can be compared with railway tracks. The engineering rules of guideway geometry specification define the requests at the function planes of the guideway and their permissible deviations from the nominal values. These tolerances are valid for a guideway girder, finished equipping and under load of dead weight of the girder. The geometrical examination occurs to the outfit of the girders with the functional components in the manufacturing plant. On the basis of the defined space curve geometry, the deviations to that can be represented graphically. A comparable criterion of the wheel-on-rail system is the internal, shortwave geometry. This is with 2 mm related to 5 m length indicated in each case for layout (y-direction) and height (z-direction). Standardized onto a consideration length of 1 meter the comparative value turns out 1.5 mm/m at the maglev and 0.4 mm/m at the wheel-on-rail-system. It results from that this tolerance request is significantly higher at the wheel-on-rail system. The tolerance requests at the geometry are approximately identical with both systems. The comparison of the geometrical requests between the maglev and wheel-on-rail shows that similar tolerance requests are made. During the change of the inclination at the wheel-on-rail track system is approximately 4-times higher as the maglev guideway (Suding & Jeschull 2006).

4.2 Performance

Based on little wear and tear, the maintenance of the maglev system is less than that of the HSR systems. Due to high operating speed and acceleration abilities and the low maintenance expenses' maglev can reach very high operation performances (Köncke 2002). Maglev generally has an advantage over HSR in terms of travel speed. The operating speed of maglev is about 45% higher than that of the HSR trains (Liu & Deng 2004). The limited speed of HSR is always the main concern of railway professionals. Resistance increases as the speed increases, which limits the increase of speed of HSR. On the contrary, high-speed potential is an inherent characteristic of the maglev technology.

If the speed of each mode plays a key role in the travel time comparison, acceleration and deceleration rate is an even more important factor in terms of safety spacing and average travel speed over certain distances. The maglev vehicle accelerates quickly to higher speeds. A maglev vehicle with acceleration/deceleration rate of 1 m/s2 can obtain the maximum speed in much less time and space than HSR trains. For example, the distance required for the maglev vehicle to accelerate to 300 km/h from a standing start is just about 4-5 kilometers, while HSR trains require about 20-23 kilometers and over twice the time to reach the same speed. Therefore, this advantage of the maglev system results in much less loss of the time for the station stops. The German TR08 maglev vehicle takes 265 s and 19.3 km for the acceleration to achieve the speed of 500 km/h, which are less and shorter than the corresponding values 370 s and 20.9 km for ICE03 train to achieve 300 km/h. The deceleration time and distance via maglev are both shorter so it can maintain ideal speed much longer. The eventual travel time via HSR doubles that of maglev even though the analysis only presented about 50% difference (Liu & Deng 2004, Witt & Herzberg 2004, Baohua et al. 2008)

Acceleration and braking capabilities of the maglev system result in minimal loss of time for station stops. The vehicles reach high operating speeds in a quarter of the time and less than one quarter of the distance of HSR systems (AMG 2002).

The maglev vehicles can easily overcome uphill gradients and slopes with inclinations up to 10 % comparing to a maximum 3.5 % - 4 % for the HSR trains. In general, the maglev vehicle can climb grades from 2.5 to 8 times steeper than HSR trains with no loss of speed. Embankments and incisions are necessary for the compensation of the small ability of climbing and the constructive design of the guideway. This can lead to a considerable land use. The maglev vehicles can negotiate 50-percent tighter curves (horizontal and vertical) at the same speeds as HSR trains. They can travel through a curve of the same radius at much higher speeds than HSR trains. For example, the maglev vehicle can cant up to 16°. The minimum curve radius of the maglev guideway under the speed of 300 km/h is also 1590–2360 m, which is smaller than 3350 m of HSR tracks (AMG 2002, Liu & Deng 2004, Dai 2005, Jehle et al. 2006, Stephan & Fritz 2006, Baohua et al. 2008)

Resulting from the greater propulsion performance the maglev systems offer not only a higher travel speed but also a higher acceleration and deceleration level. The maglev accelerates very well and almost constantly with 0.9 m/s². Its maximum speed of 450 km/h is reached within 3 min. The ICE train requires nearly 5 min until it reaches its maximum speed of 300 km/h. Moreover the maglev vehicle may run approaches to the stop stations in urban surrounding with a speed of 250 km/h due to its low noise emissions and vibrations. The pure running time difference of both systems regarding a line length of approximately 300 km from Berlin to Prague amounts of 29 minutes (50 % more) (Stephan & Fritz 2006, Fengler & Platzer 2006).

Table 1 shows the results of comparison between a maglev train and a HSR train from operational viewpoint (Schach & Naumann 2007, Liu & Deng 2004, Witt & Herzberg 2004, Köncke 2002, Baohua et al. 2008).

Tabale 1. Comparison between two German trains of ICE-03 HSR and TR-08 maglev.

Parameter	Unit	InterCityExpress (ICE) 3 ICE-03 the type series 403		Transrapid Shanghai Maglev TR-08 SMT the type series TR 08		
Operational maximum speed	km/h	until 300		until 450		
Sections per vehicle		8		5 (from 2 to 10 possible)		
Seats (on average)		415		446		
Length (total)		200		128.3		
Capacity		8: 850		10: 1192		
Maximum engine performance	kW	8.000		approx. 25.000		
Power Requirement at Constant Speed of	MW	-		Train Sections		
				2	6	10
200	km/h			0.9	2.2	3.6
300	km/h			2.2	5.0	7.9
400	km/h			4.4	10.3	16.1
500	km/h			8.2	18.7	-
Net weight vehicle	ton	409		247		
Weight / Seat	kg	Approx. 930		Approx. 550		
Maximum longitudinal gradient	%	3.5		10		
Acceleration	m/s^2	maximum 1,0		constant 1,5		
Acceleration	m/s^2	Distance (m)	Time (s)	Distance (m)	Time (s)	
0- 100	km/h			424	31	
0- 200	km/h	4400	140	1700	61	
0- 300	km/h	20900	370	4200	97	
0- 400	km/h			9100	148	
0- 500	km/h			22700	256	

Train Configuration		Driving Trailer/ End Car	Trailer Car	End Section		Middle Section		
Train Size		2	6	2		0-8		
Section Length	m	25.68	24.78	26.99		24.77		
Section Width	m	2.95	2.95	3.70		3.70		
Section Height	m	3.84	3.84	4.16		4.16		
Payload / Section	ton	-		10.3		13.9		
Seats / Section		-		62-92		84-126		
Floor Space / Section	m	-		70		77		
Weight / Seat	kg	Approx. 920 to 1000		500 – 700		400 – 600		
Number of Sections		8		2	4	6	8	10
Seats (high density)		408 to 418		184	436	688	940	1192
Seats (low density)		-		124	292	460	628	796
Passengers	ton	-		20.6	48.4	76.2	104	131.8
Curve Radii	m							
Minimum	km/h	300		350				
200	km/h	1400		705				
250	km/h	2250		1100				
300	km/h	3200		1590				
350	km/h	-		2160				
400	km/h	-		2825				
450	km/h	-		3580				
500	km/h	-		4415				

4.3 Reliability, Availability, Maintainability and Safety

An important issue in the proper operation of rapid transit systems is the reliability, availability, maintainability and safety (RAMS). RAMS is the item that needs to be considered in any new rapid transit system establishment. This item is the factor that affects the passenger's mode choice decisions and is important for project evaluation (Behbahani & Yaghoubi 2010). Maglev is one of the safest means of transportation in the world. The use of a dedicated and separated guideway without intersections with other transportation modes such as roads and highways ensures no safety conflicts and allows uninterrupted maglev operations (AMG 2002). The maglev technology has essentially eliminated the safety risks associated with the operation of rapid transit systems. Compared to the operating experiences of HSR, the maglev technology has a scarce record. On the other hand, the German Transrapid Test Track in Elmsland has been operating for more than 20 years and close to a million passengers have ridden around the 40-kilometer closed loop (Liu & Deng 2004). The maglev vehicle wraps around the guideway beam so it is virtually impossible to derail. Redundancies achieved through the duplication of components as well as the automated radio-controlled system ensure that operational safety will not be jeopardized. The principle of synchronized propulsion on the guideway makes collisions between vehicles virtually impossible. In general, no other obstacles can be in the way. If two or more vehicles were ever placed simultaneously in the same guideway segment, they would be forced by the motor in the guideway to travel at the same speed in the same direction. The vehicles are also designed to withstand collisions with small objects on the guideway. Energizing only the section of the guideway on which the train is traveling enhances operational safety and efficiency. The maglev vehicle is absolutely weatherproof and masters wind and adverse weather easily. Regarding the aspect of fire protection the maglev vehicle meets the highest requirements of the relevant standards. No fuels or combustible materials are on board. All used materials within the vehicles are PVC-free, highly inflammable, poor conductors of heat, burn-through-proof and heat-proof. The fire proof doors can be optionally used in order to separate the vehicle sections. The system is controlled in all the directions of the movement to ensure ride comfort throughout all the phases of the operation. The seat belts are not required, and passengers are free to move about the cabin at all speeds (AMG 2002, Köncke 2002, Liu & Deng 2004, Dai 2005, Behbahani & Yaghoubi 2010).

4.4 Energy Consumption and Space Requirement

With non-contact technology, there is no energy loss due to the wheel-guideway friction. The vehicle weight is lower due to the absence of wheels, axles and engine (low mass of approx. 0.5 t per seat). In terms of energy consumption, the maglev vehicles are better than HSR trains. The maglev consumes less energy per seat-mile than HSR trains due to the utilization of lightweight materials and improvement in the advanced technology. The energy consumption of the maglev system with its non-contact levitation and propulsion technology, highly efficient linear motor and low aerodynamic resistance is very economical when compared to other transportation modes. The high-speed maglev system consumes 20 to 30 percent less energy per passenger than the very modest railroad. With the same energy input, the performance of the maglev system is substantially higher than HSR systems (Liu & Deng 2004, Köncke 2002).

As consumers of energy, the transportation sectors are vulnerable to environmental and global warming concerns and the increasing volatile oil market. Reducing dependency on foreign oil is also an important criterion. The system of the external power supply over the contact rail causes higher investment and operational costs. The energy costs of the maglev vehicle despite higher design speed, is lower than that of ICE3 train (Witt & Herzberg 2004). The maglev vehicles running at 400 km/h has lower environmental impact indicators, such as system energy consumption, waste gas discharges, site area and the like, then the ICE trains running at 300 km/h (Baohua et al. 2008). They also have low running resistance of approx. 0.2 kN per seat at 400 km/h (Köncke 2002).

Maglev is one of the first transportation systems to be specially developed to protect the environment. The system can be co-located with existing transportation corridors and needs a minimum amount of land for the support of the guideway beams. Use of the elevated guideway minimizes the disturbance to the existing land, water and wildlife, while flexible alignment parameters allow the guideway to adapt to the landscape. Compared to roads or railway tracks, especially the elevated guideway does not affect wildlife movement. Even the ground-level guideway allows small animals to pass underneath due to the clearance planned under the guideway. Compared to all other land-bound transport systems, the maglev requires the least amount of the space and the land. The land area required for a ground-level double-track by either maglev or HSR systems is about similar so it is 14 m2/m and 12 m2/m, respectively. But for an elevated double-track guideway, approx. 2 m2 of land is needed for each meter of guideway (Schwindt 2006). Considering the densely populated and limited land resources, an elevated structure is a preferred choice. The traffic effects on the land-use have been always considered by urban planner and transportation engineers. In the center of metropolitan areas with large economic activities, such as Mashhad, the increase of traffic volume has indirectly cost. It includes wasting time and damages such as environmental pollution (Behbahani et al. 2002).

4.5 Pollution

As maglev is electrically powered, there is no direct air pollution as with airplanes and automobiles. The maglev causes lower CO2 emissions. It is also easier and more effective to control emissions at the source of electric power generation rather than at many points of consumption. Maglev is the quietest high-speed ground transportation system available today. Due to its non-contact technology, there is neither rolling nor gearing or engine noise. The frictionless operation of the maglev vehicle reduces vibration and maintenance resulting from wear. Comparing the noise levels at different speeds, the maglev vehicle is much quieter than the HSR trains. For example, The German TR07 maglev vehicle can travel about 25 percent faster than existing HSR trains before reaching the peak noise restrictions of 80 to 90 dBa. Such an advantage in speed will yield reduced the trip times along the noise-limited routes, which is most urban areas. At the speeds up to 200 km/h, the noise level compared to other noises from the surroundings can hardly be heard. At 250 km/h, the pass-by noise level is 71 dB(A), and from 250 km/h upwards, the aerodynamic noises begin to dominate the noise level. The result is that, at the speed of 300 km/h, the system is no louder than a light rail vehicle, and at 400 km/h, the noise level can be compared to a conventional train traveling at around 300 km/h. Even when at respective high speeds, data also indicates that maglev vehicle is 5 to 7 dBa quieter than the HSR train (Liu & Deng 2004, Dai 2005, Schwindt 2006).

The American JetTrain HSR train is almost twice as noisy as the maglev vehicle at the similar operational speeds (AMG 2002). The results of the noise measurements of the TR08 Maglev System may be compared with similar data, documented by the Federal Railroad Administration (FRA 1998), for other high-speed ground transportation systems (FRA 2002a).

A field experiment was conducted, to investigate the possible differences in perceived annoyance of noise caused by high-speed trains, both HSR and maglev. These results were evaluated for the TGV train at speeds of 140 km/h & 300 km/h and for the maglev vehicle at speeds of 200 km/h, 300 km/h and 400 km/h. The L_{Aeq}-annoyance relationships determined for the HSR and for the maglev train did not differ significantly. Figures 4, 5 show the A-weighted sound exposure level in 1/3-octave bands for some of the experimental traffic sounds, as recorded in the free field. Figure 6 gives an overview of the annoyance functions for the 10-minute menus as a function of $L_{Aeq,10min}$. In the conventional listening experiment, the sounds were presented as short 45-second fragments. Figure 7 shows the results of these master scaled annoyance values as a function of time averaged A-weighted façade exposure, $L_{Aeq,45s}$. If Zwicker loudness is a good first estimate of perceptual loudness, the difference between trains noise would be seen in a Zwicker loudness versus L_{Aeq} plot (see Figure 8). This study has shown that the noise annoyance caused by different types of trains at the same average outdoor façade exposure level is not significantly different. In particular, the magnetic levitation systems are not more annoying than the HSR trains, which is in agreement with earlier research (Coensel et al. 2007).

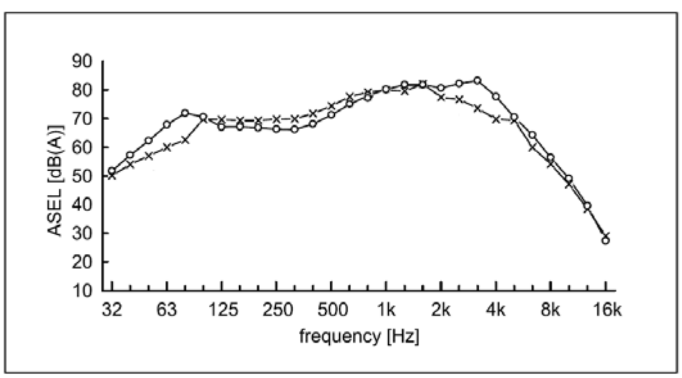

Figure 4. Sound exposure level (ASEL) in 1/3-octave bands of the traffic sounds, all recorded during 45 seconds in free field at a distance of 50 m to the track: (×) a passage of a maglev train traveling at 400 km/h, (○) a passage of a TGV train traveling at 300 km/h.

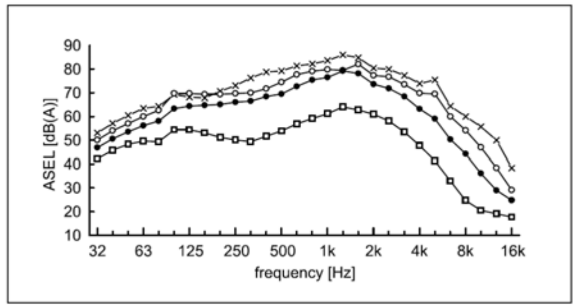

Figure 5. Sound exposure level (ASEL) in 1/3-octave bands of a maglev train traveling at 400 km/h, recorded during 45 seconds in free field at various distances to the track: (×) 25 m, (○) 50 m, (●) 100 m and (□) 200 m.

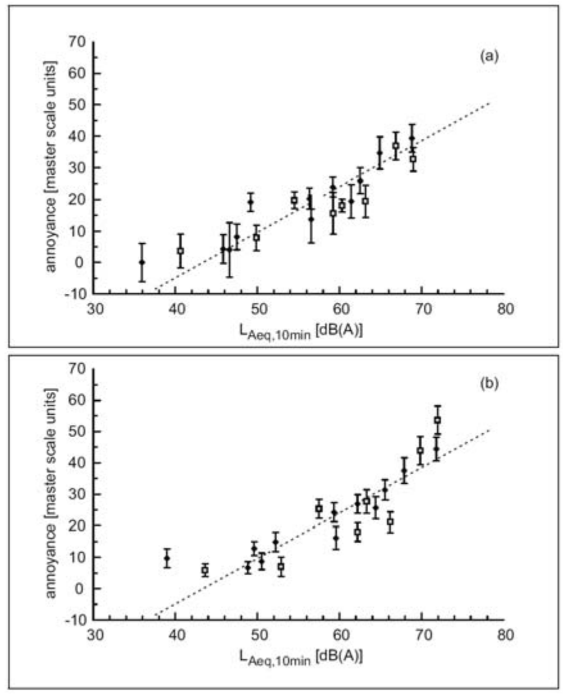

Figure 6. Average master scaled annoyance of the menus versus $L_{Aeq,10min}$ (a) for two events per 10-minute menu and (b) for four events per 10-minute menu, for the HSR and maglev trains sounds: (◘) TGV and (◆) maglev train. Standard error on means is indicated, as well as the master function (dashed line).

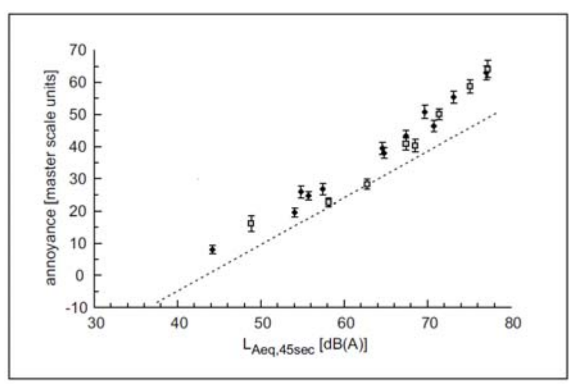

Figure 7. Average master scaled annoyance versus $L_{Aeq,45s}$ for the conventional listening test, for different types of trains sounds: (◘) TGV and (◆) maglev train. Standard error on means is indicated, as well as the master function (dashed line).

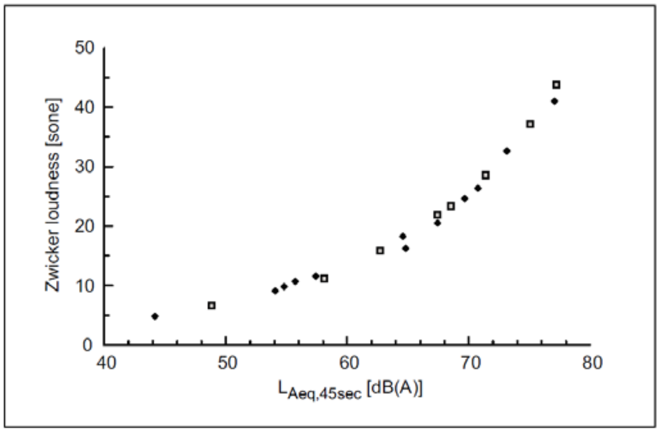

Figure 8. Zwicker loudness versus $L_{Aeq,45s}$ for the HSR and maglev trains sounds: (■) TGV, (◆) maglev train.

Whatever the kind of transport system, a passing maglev vehicle always creates ground vibrations due to dynamic loading of the track. Depending on the speed, load transfer, load dispersion and the nature of the ground, these vibrations are transmitted through the ground to different degrees and may thus be felt as shocks in neighboring buildings. For especially sensitive areas, technical solutions are currently being investigated, which minimize the dynamic loads that are transferred from the vehicle to the guideway and then to the bearings in the supports and foundations (Schwindt 2006).

TR08 vibration levels for both the concrete elevated and concrete at-grade (AG) guideways are compared with those of the TGV, the Italian Pendolino, the Swedish X2000, and the Acela at 240 km/h. The vibration levels for the TR08 traversing the at-grade guideway structures are comparable to those from HSR trains measured in Italy (Pendolino) and France (TGV), whereas the levels for the elevated structure are considerably lower for the distances measured. Vibration levels measured at 15 m for the TR08 traversing the at-grade guideway at 400 km/h are less than those previously measured at 15 m for the Acela traveling 240 km/h. These comparisons, however, are representative of data collected at various sites and are generally typical of local geological conditions. In general, ground-borne vibration levels from trains on elevated structures tend to be lower than those from at-grade operations (FRA 2002b). The curves for European HSR trains are taken from the FRA high-speed ground transportation guidance manual (FRA 1998), and for the Acela from measurements conducted by HMMH (FRA 2000).

4.6 Loading

In this part of research, maglev guideways and road and railroad bridges are compared from loading and design aspects. The optimal design of all bridges, including road, railroads and maglev elevated guideways is really vital. Majority of the existing maglev guideways are elevated and completely built on the bridge. In fact, a maglev elevated guideway is one kind of bridges. Therefore, it can be compared with any bridge like railroad or road. An Iranian maglev guideway proposed for the M-T maglev system was compared with the typical railroad and road bridges in the M-T route. In the case-study, the bridges nearly have the same geometrically and technically characteristics.

According to the AREMA regulations and the UIC leaflets, the live loading models for the rail tracks, is a combination of the concentrated and distributed loads. However, the live loading models for the maglev trains, in the absence of wheels and pursuant to uniformity in the intensity of magnetic forces due to the magnets, are uniformly distributed on the guideways. The lateral magnetic force in maglev is less than the lateral force in the rail tracks. The low level of this force in maglev is due to the absence of the rails and wheels, lower weight of the vehicle and the presence of lateral restoring and equilibration magnetic force.

In general, vertical loadings (dead and live) in the spans of maglev guideways are much lower than those of the railroad bridges. The intensity of the uniform distributed load in live loading of the railroad bridges is almost four times that in maglev. In the UIC model of the loading of the rail tracks, the intensity of the uniform distribution in the live loading equals 8×103kg/m while in the live loading of the existing maglev trains it is somewhere between 1.78×103kg/m to 2.5×103kg/m. The moment due to only live load in the mid-span of a railway bridge with a span of 18 m, according to the loading regulation of the UIC, is estimated to be about 505×103kg/m. In comparison, the maximum moment due to only the live load in the mid-span for a guideway with the same span and vehicle length is less than 100×103kg/m. One reason for this difference is the lower weight of the maglev vehicle due to the absence of wheels, axles and transmission parts plus the overall short length of the vehicle.

The amount of the earthquake lateral force on the M-T guideway is also calculated. In order to evaluate its earthquake-resistant design, the result is compared with the earthquake force on a road bridge deck on the same route. The very significant outcome is that the amount of the earthquake lateral force on the maglev guideway is less than one third of its value for the road bridge.

The bending moments and shear forces at various sections of the M-T guideway were calculated. The envelope diagrams of the shear force and bending moment for the non-factor loads of the considered railroad bridge and maglev guideway were compared. The obtained results are presented in Figures 9, 10. As illustrated in these figures, the diagrams have overlapping indicating that in the case-study of this research, loading of the guideway is almost equal to the loading of each one of the four girders of the railroad bridge. In other words, taking into account the fact that the bridge consists of four girders, comparison of the results indicates that the load on the railroad bridge deck is four times greater than the load on the maglev guideway. This means that the guideway by itself can play the role of each one of the girders of the railroad bridge (Yaghoubi & Ziari 2011, Yaghoubi, & Rezvani 2011).

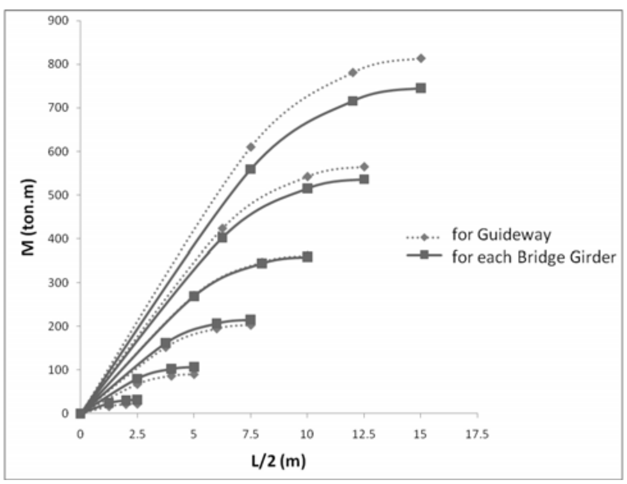

Figure 9. Envelope diagrams of the bending moments for the non-factor loads.

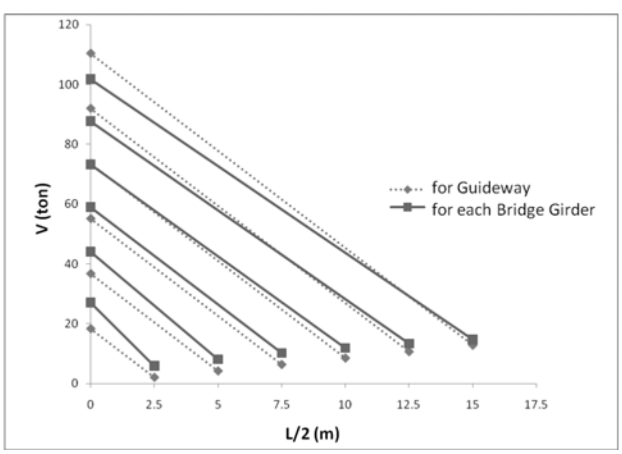

Figure 10. Envelope diagrams of the shear forces for the non-factor loads

5 CONCLUSIONS

HSR and maglev are guided ground transportation modes with very large capacity, and both use electric power from the utility grid for propulsion. They also exhibit some fundamental differences that distinguish them as very separable transportation modes. Maglev systems offer the unique combination of technical attributes. These include light weight vehicles, centralized and fully automated control of propulsion systems, non-reliance on

In this research, an entire technical comparison of the high-speed transportation systems including HSR and maglev was made. It included and considered the different views and aim criterions, and a lot of aspects were discussed. The results show that the maglev system comes off clearly better and surpasses the HSR systems in almost most fields. These include the pollution, noise emission, vibration level, environmental issues, land occupations, loading, speed, acceleration and deceleration, braking, maintenance costs, passenger comfort, safety, travel time, etc. However, further studies should be conducted before the particular technology is selected for a corridor.

With the maglev guideway it is also possible to reach to the minimal radiuses for the horizontal and vertical curves. A maglev vehicle can as well travel at the steeper gradients compared with the HSR systems. This considerably reduces the total length of track for the maglev routes compared to the HSR systems. The possibility of traveling with the higher grade angles also reduces the number of tunnels that are required to travel through the mountainous areas. This can also shorten the total length for the maglev route. Therefore, construction of the maglev routes in the hilly areas, in addition to many other advantageous of these systems, can be considered as an attractive choice for the transportation industries.

The lower energy consumption of the maglev vehicles in comparison with the HSR systems is also among major characteristics of the magnetically levitated trains. This can be easily associated with the absence of the wheels and the resulting situation of no physical contact between the maglev vehicle and its guideway. Therefore, the energy loss due to the unwanted friction is out of the equations. Furthermore, the vehicle weight is lower due to the absence of wheels, axles and engine. By establishing the maglev vehicle services, the travel time between Tehran and Mashhad reduces from 11 hours to two hours. On the other hand, reduction in the travel time considerably reduces the energy consumption. The limited energy resources that are currently available to the nation have highlighted the fact that every individual has to be the energy conscious. The government had to take steps, and it started by setting the preventative rules and the tightening access to the cheap energy resources. Rationalizing petrol is an example of such actions that started since 2007. Clearly, the widespread application of the magnetically levitated trains for the public transport, in short and long distances, can provide the nation with huge saving in the energy consumption. This is not a fact that can be easily ignored nor can it be bypassed.

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