Chapter 1
Introduction

With the official operation of the world's first High-speed Rail (HSR) in Japan on October 1, 1964, HSR opened a new era of transportation development. "There is not a fastest vehicle, but only faster vehicle", speed and capacity are eternal pursuit of mankind. No matter what kind of transportation (trains, cars, airplanes, ships, etc.), the requirements of human beings for it not only depend on speed but also on transport capacity.

Although the aircraft operates at a high speed, its transport capacity is limited. While the train has a large transport capacity, but it runs at a low speed. Therefore, the pace of human's pursuit of transport never ceased, and HSR is the crystallization of human wisdom in transportation. The French Wheel High-speed Rail TGV (train à grande vitesse, TGV) is as shown in Fig. 1.1.

HSR is an abbreviation for high-speed rail. It is a large system composed of dedicated lines, high-speed trains, and dedicated control systems. Therefore, HSR is a system concept but not an individual concept. The "high-speed" in the high-speed rail refers to the quality, while the "rail" is the property. In addition to Wheel High-speed Rail (WHSR), HSR also includes Magnetic High-speed Rail (MHSR) and Super-speed Rail (SSR). Therefore, the narrow concept of HSR refers to the WHSR transport system. The broad concept of HSR includes not only the WHSR transport system, but also the MHSR, which is using the magnetic levitation technology, and the SSR transport system in the vacuum track. Figure 1.2 is a diagram of high-speed rail train.

HSR has become a hot issue in the world. This is because HSR has some technological advantages that are incomparable to other modes of transportation. The first advantage is the high speed. The French WHSR TGV set a world record with the speed of 574.8 km/h. Japan's MHSR set a world record with the speed of 603 km/h. The America's SSR set a world record with the speed of 1000 km/h, and it faster than the normal speed of the airplane. The normal speed is 800 km/h. The second advantage is the large volume. The interval of HSR trains can be as short as 4 min and twelve trains can be operated per hour in one direction, which is incomparable to

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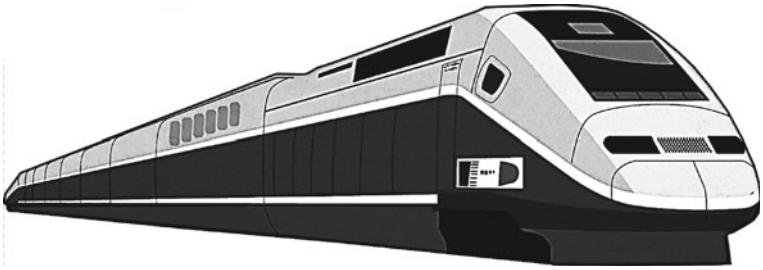


Fig. 1.1 French WHSR: TGV

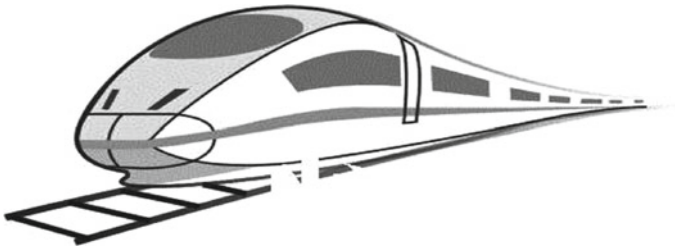


Fig. 1.2 HSR train

highways and aviation. The third advantage is the high safety. The quality and precision of HSR line facilities are high. The train operation control system uses mature electronic technology and intelligent software which ensures the safety distance between the two trains. Therefore, there are few accidents in HSR around the world. Fourthly, HSR can operate throughout the day because it cannot be affected by rain, snow, fog, wind. Fifthly, HSR also has the features of low energy consumption, land conservation, light pollution and high comfort. Therefore, HSR has been welcomed by most countries in the world since its birth.

1.1 Emerging Conditions of HSR

(1) The production of vehicle requires certain conditions. No matter which kind of transportation, human beings appraise it from three aspects. The vehicle that can meet these requirements is good, but not vice versa. First is the functionality such as speed, capacity, and safety. Second is the economics such as cost, energy, and efficiency. The final one is the ecology such as noise, radiation, and environmental protection. As a means of transportation, HSR also takes the load into account while pursuing high speed. Noting that high speed and heavy loads are the eternal pursuit of mankind, HSR exactly meets human needs. Figure 1.3 shows Wheel High-speed Rail system.

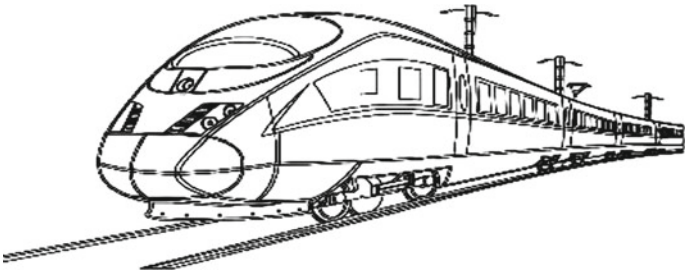


Fig. 1.3 WHSR system

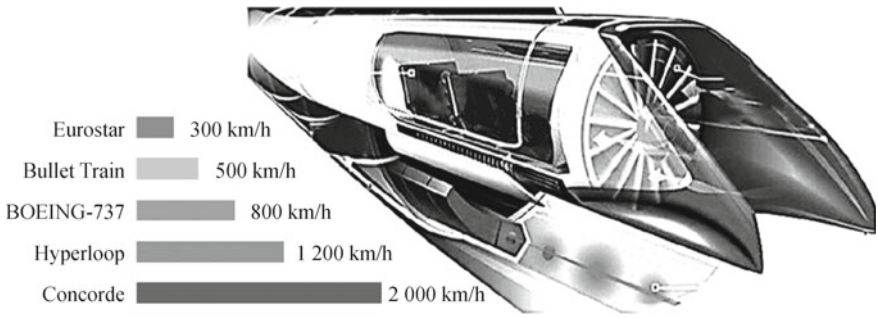
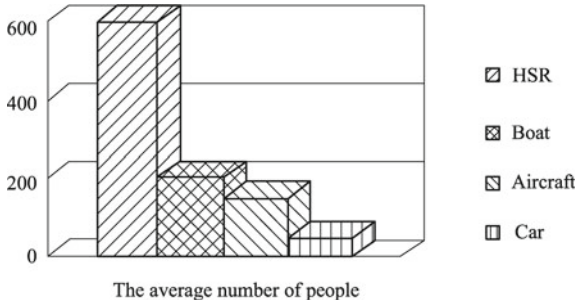


Fig. 1.4 The operating speed of different vehicles

(2) The speed of HSR. Speed is the basic requirement for transportation. It is exactly the rapidity and high efficiency that make the HSR popular with humans and developed greatly. A comparison of speed between HSR and other vehicles is shown in Fig. 1.4.

(3) The load of HSR. In order to meet the basic demand for transportation, people expect vehicles to carry as much weight as possible. The comparison of the loading capacity between HSR and existing vehicles (cars, airplanes, ships, traditional trains, etc.) is shown in Fig. 1.5, from which we can obtain that the HSR is the vehicle with the largest load.

Fig. 1.5 Comparison of the loading capacity between HSR and other vehicles



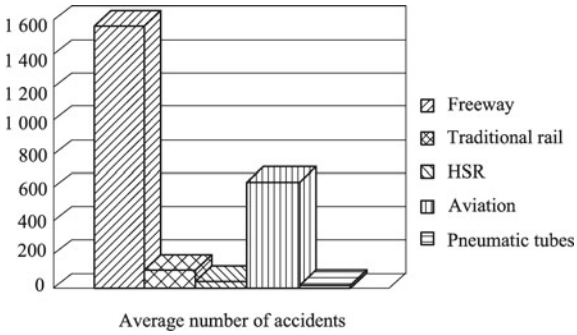


Fig. 1.6 Comparison of safety between HSR and other various vehicles

(4) The safety of HSR. Since HSR is operating automatically in a fully enclosed environment and has a series of comprehensive safety protection systems, its safety is unmatched by any other means of transportation. Several major HSR countries have to operate thousands of HSR trains every day. While the accident rate and casualty rate are far lower than other modern modes of transportation. Therefore, HSR is considered as the safest transportation. The comparison of safety between HSR and other various vehicles is shown in Fig. 1.6.

1.2 Three Leaps of HSR

In order to satisfy the demands for both speed and capacity, the HSR experienced three qualitative changes, namely three leaps. From WHSR to MHSR to SSR, from the operating speed of 200 to 500 to 1200 km/h, this is also the three leaps in human demand for transportation.

1.2.1 The First Leap: Improve the Speed of Operation and the Birth of WHSR

The first category: Wheel High-speed Rail (WHSR). To improve the speed of the train brings the first leap. So the first type of HSR, the WHSR was born. The traditional train and WHSR train are shown in Fig. 1.7.

In terms of capacity, the traditional train is the king of all modes of transportation. However, traditional trains usually run at a speed below 200 km/h, which cannot satisfy human's needs for fast travel. By strengthening the study of track and vehicle type, especially the improvement of vehicle type, people reduce the frictional resistance and air resistance of high-speed train running to increase the running speed. In Japan, the speed of HSR (Shinkansen) train reached 200 km/h in 1964. The train is called HSR when the operating speed is over 200 km/h. However, the WHSR can only operate between 200 km/h and 400 km/h due to air resistance and frictional

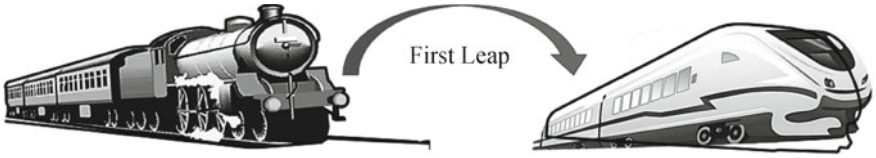


Fig. 1.7 Traditional train and WHSR train

resistance. The operating speed of 400 km/h is the warning threshold of WHSR. When the WHSR train exceed this speed, it is extremely easy to derail and cause traffic accidents. WHSR train is as shown in Fig. 1.8.

Wheel High-speed Rail is mainly a transportation system running on the track, which is generally shortened for WHSR and can also be called conventional HSR. The main features are as follows:

① The operating speed of the WHSR is about 200–400 km/h.
② The warning threshold of WHSR is 400 km/h.
③ The resistances of WHSR are frictional resistance and air resistance.

WHSR belongs to the wheel-rail type of HSR. According to the definition of the International Railway Union, HSR refers to the railway system that has an operating speed of more than 200 km/h by transforming the traditional line (straight line, gauge standardization), or has an operating speed of more than 250 km/h by building a new line. This book divides WHSR into three types. See Table 1.1 for details.

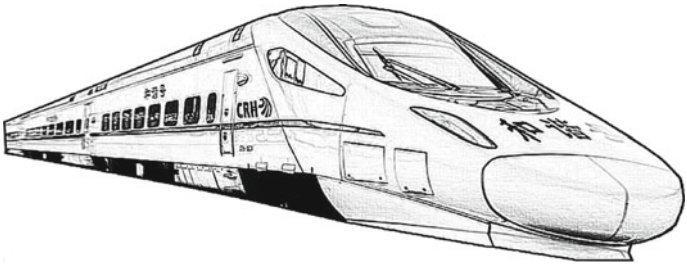


Fig. 1.8 WHSR train

Table 1.1 Types of WHSR

Number	Types	Speed/(km/h)	Name	Main countries	Remarks
1.	First	200–300	Low-speed WHSR	Japan, Germany	The warning threshold of WHSR is 400 km/h
2.	Second	300–350	Normal-speed WHSR	France, China	
3.	Third	350–400	High-speed WHSR	China	

1.2.2 The Second Leap: The Removal of Frictional Resistance Brings the Birth of MHSR

The second category: Magnetic High-speed Rail (MHSR). In order to reduce the friction between the wheels and the rails, the second leap was made. As a result, MHSR, the second type of HSR, was born. The WHSR and MHSR trains are as shown in Fig. 1.9.

In order to reduce the frictional resistance and improve the running speed and meet the fast travel requirements of human beings, MHSR was born with the running speed of more than 400 km/h based on the principle of "same-magnet repelling and opposite-magnet attraction". During the operation of the MHSR, the magnet train does not directly contact the track, but floats on the track so that there is no frictional resistance and then the running speed is improved. In 2015, the speed of MHSR in Japan has reached 600 km/h and more. Although MHSR is not affected by the frictional resistance, it can only operate at the speed of 400–1000 km/h due to the limitation of air resistance. The operating speed of 1000 km/h is the warning threshold of the MHSR. When this speed is exceeded, the operating cost will be too high. Among them, Japan's MHSR train is as shown in Fig. 1.10.

MHSR is the magnetic suspension type of HSR, which is mainly suspended on rails to run. It is also called superconducting high-speed rail. The main features are as follows:

① The operating speed of MHSR is from 400 km/h to 1000 km/h.
② The warning threshold of MHSR is 1000 km/h.
③ MHSR has air resistance but no frictional resistance.

Fig. 1.9 WHSR and MHSR trains

Fig. 1.10 Japan's MHSR train

Table 1.2 Types of MHSR

Number	Types	Speed/(km/h)	Name	Main countries	Remarks (0 K = −273.15 °C)
1.	First	400–600	Low-temperature MHSR	Japan, Germany	4.2 K—Liquid helium (rare, expensive)
2.	Second	600–800	Normal-temperature MHSR	Japan	15 K—Liquid helium (minor, reasonable)
3.	Third	800–1000	High-temperature MHSR	Japan	77 K—Liquid helium (much, cheap)

MHSR belongs to the magnetic suspension of HSR. As a new type of ground transportation, magnetic train has moved from the experimental stage to commercial operation and overcome the problems of traditional train such as the adhesion limit, mechanical noise and wear, etc. Besides that, MHSR has the features of high speed, strong climbing ability and low energy consumption, high noise, high safety, high comfort, no fuel, and little electromagnetic pollution. It has become the ideal vehicle for people.

The MHSR train can be divided into two types based on the principle of suspension: Electromagnetic Suspension (EMS) and Electrodynamic Suspension (EDS). The speed of MHSR train can reach 500 km/h, which is absolutely impossible for traditional train. If the superconducting magnet is installed in the train and an aluminum ring is laid on the ground track, the relative movement between them will generate an induced current in the aluminum ring. Then the magnetic repulsion will occur, lifting the train about 10 cm from the ground, allowing the train to float on the rail and operate at a high speed. This book divides the MHSR into three types as Table 1.2.

The MHSR train uses a superconducting magnet to float the vehicle and obtain propulsion power by periodically changing the direction of the magnetic pole. In addition to its high speed, the MHSR train has the characteristics of no noise, no vibration and energy saving. It is expected to become the main means of transportation in the twenty-first century.

1.2.3 The Third Leap: Reducing Air Resistance Brings the Birth of SSR

The third type of HSR: Super-speed Rail (SSR). When the train runs in vacuum, there is no limit to the operating speed. In order to reduce the air resistance, the third leap has been made. SSR, the third type of HSR, is the suspension of HSR in the vacuum pipeline. MHSR trains and SSR trains are as shown in Fig. 1.11.

Fig. 1.11 MHSR and SSR trains

The SSR was produced to satisfy human beings requirements for fast travel, based on the concept of vacuum pipeline by reducing air resistance. The SSR runs in the vacuum pipeline without air and frictional resistance, and the running speed can reach more than 1200 km/h. In fact, there is no air resistance and frictional resistance in vacuum pipeline, so the SSR train can operate "arbitrarily" and speed up to 10,000 km/h. The SSR system is as shown in Fig. 1.12.

SSR is a vacuum pipeline suspended HSR. It is mainly a HSR transportation system suspended in a vacuum pipeline. So SSR also can be called vacuum high-speed rail. The main features are as follows:

① The operation speed of SSR is 1200 km/h (acoustic velocity is 340 m/s).
② SSR has no limit of warning threshold due to no restrictions.
③ SSR has no friction resistance and no air resistance.

The SSR is a vacuum pipeline type of HSR. SSR is a kind of transportation system designed with the principle of "vacuum steel pipe transportation" as the core of the theory. It has the characteristics of ultra-speed, high safety, low energy consumption, low noise and low pollution. The super train may be a new generation of transportation

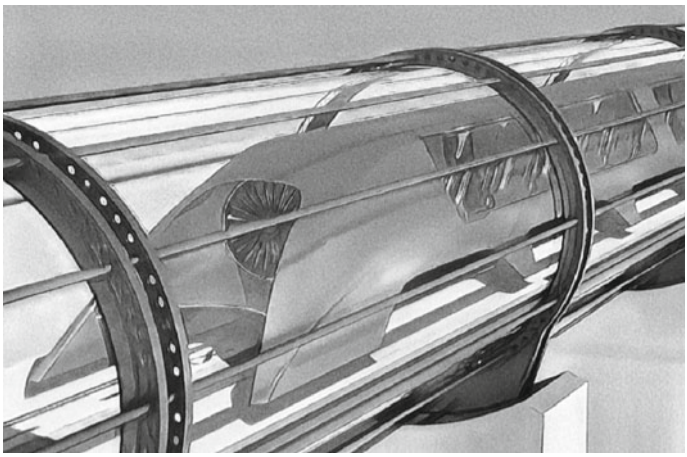


Fig. 1.12 SSR system

Table 1.3 Types of SSR

Number	Types	Speed/(km/h)	Name	Main countries	Remarks
1.	First	1000–1200	Low-sonic velocity SSR	USA	Sonic velocity: 340 m/s, 1224 km/h
2.	Second	1200–10,000	Normal-sonic velocity SSR	NA	
3.	Third	>10,000	High-sonic velocity SSR	NA	

vehicles after the car, ship, train and aircraft as the fifth type of transportation. This book divides the SSR into the following three types as shown in Table 1.3.

Vacuum piping is an unavoidable choice to reduce air resistance. Ultra speed is the demand for high-speed ground transportation in the twenty-first century. This is determined by two factors. On the one way, from the perspective of environment protection Perspective, SSR is more environmentally friendly than other surface traffic. The carbon dioxide emissions are much lower than those of automobile 100 g/(person·km), aircraft 140 g/(person·km), rail 20 g/(person·km). On the one way, from fast perspective, SSR can achieve the speed of social expectation. And vacuum (or low-pressure) pipeline is the only way to reach an ultra-speed. Therefore, in the future, SSR will be an unavoidable choice.

1.3 Different Types of HSR

In addition to WHSR, HSR also includes MHSR using magnetic levitation technology and SSR operating in a vacuum track. The early warning threshold of HSR of operating speed is mainly based on the energy consumption of HSR trains and the degree of damage to the environment. From the perspective of speed and economy, the warning threshold of WHSR is 400 km/h and the warning threshold of MHSR is 1000 km/h. According to the operating principle and early warning threshold, the book divides HSR into three types:

(1) The first type of HSR is WHSR. WHSR transportation system is mainly running on the track. It is also called the conventional high-speed rail. The operating speed of WHSR is 200–400 km/h. WHSR has frictional resistance and air resistance. WHSR train is as shown in Fig. 1.13.

(2) The second type of HSR is MHSR. MHSR is the magnetic suspension type HSR which is mainly suspended on rails to run. MHSR is also called a superconducting high-speed rail. The operating speed of MHSR is 400–1000 km/h. MHSR has air resistance but no frictional resistance. Among them, German MHSR train is as shown in Fig. 1.14.

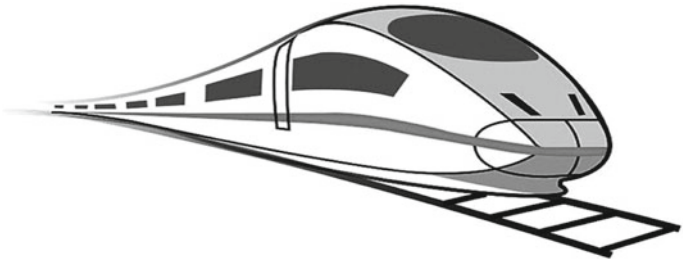


Fig. 1.13 WHSR train

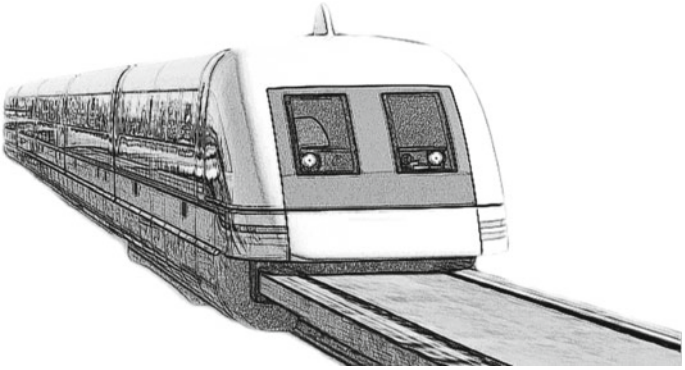


Fig. 1.14 German MHSR train

(3) The third type of HSR is SSR. SSR is a MHSR transportation system suspended in a vacuum pipeline. SSR is also called a vacuum high-speed rail. The operating speed of SSR is more than 1200 km/h (Sonic velocity is 340 m/s) without friction resistance and air resistance. SSR train is as shown in Fig. 1.15.

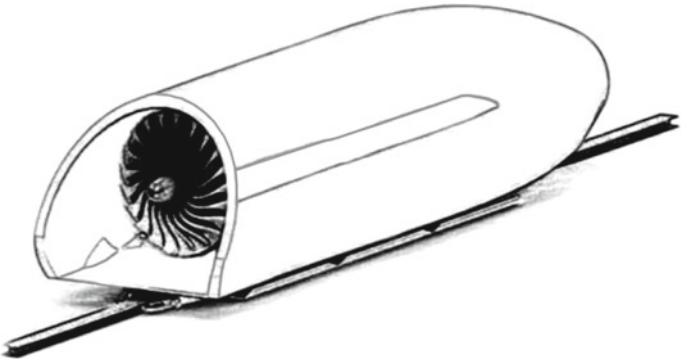


Fig. 1.15 SSR train

1.4 Characteristics of HSR

The rapid development of HSR is determined by its own characteristics, especially its unique technological advantages, which are not available in other modes of transportation (cars, airplanes, traditional trains, etc.). Japan's WHSR train is as shown in Fig. 1.16.

(1) High speed. The test speed of high-speed rail has exceeded 603 km/h and the maximum operating speed is above 350 km/h. Especially, the speed of SSR not only surpasses the sonic velocity (340 m/s), but it will rewrite human history. Compared with other modes of transportation (Fig. 1.17), the advantages of high-speed rail are obvious.

(2) Large volume. HSR is currently mainly used for passenger transportation. At present, no other kind of transportation can surpass HSR in passenger volume. For example, the maximum number of passengers per year on a highway will not exceed 10 million. But according to Japan's statistics, a HSR line has carried 150 million passengers per year. The passenger volume of HSR is as shown in Fig. 1.18.

(3) High safety. In all types of transportation, HSR is the safest. According to statistics, the number of deaths per billion people per kilometer is 1.971 for railways, 18.929 for cars and 16.006 for airplanes. There are about 50,000

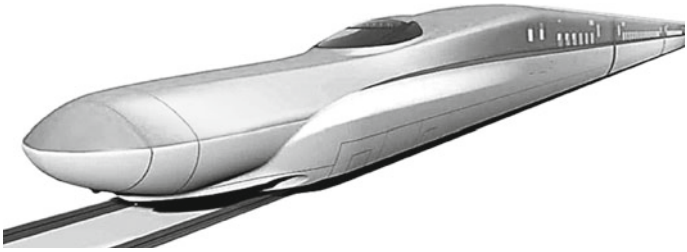


Fig. 1.16 Japan's WHSR train

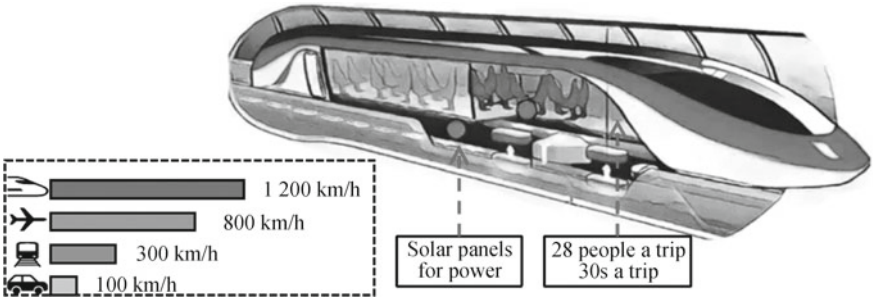


Fig. 1.17 The speed of different vehicles (picture from the network)

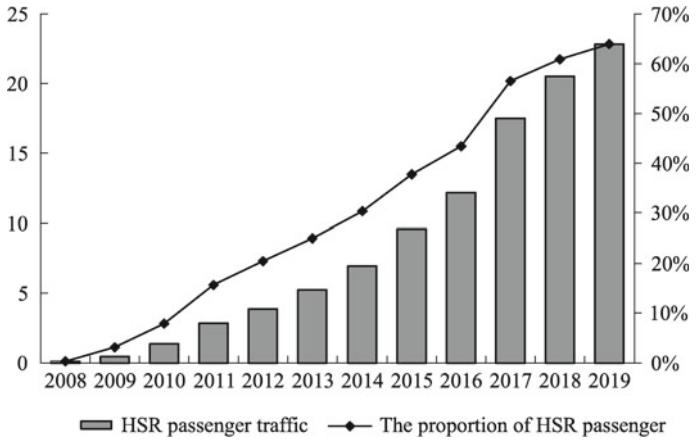


Fig. 1.18 Number of HSR passengers

deaths and 1.7 million injuries per year due to road traffic accidents in Europe, 125 times more than that of traditional railway. And in the United States, there are about 50,000 deaths in highway accidents,while there are less than 100 deaths in railways. In terms of safety, HSR is better than cars and airplanes as shown in Table 1.4.

(4) High punctuality rate. HSR operation is controlled by computer, and only receives signals from the vehicle during operation. Hence, the bad weather like big wind, fog has almost no impact on it unless an earthquake occurs. Airplane airports and highways must be closed down in severe weather conditions such as dense fog, heavy rain and snow. The SSR runs inside the pipeline, so the bad weather such as wind, rain, fog has no influence on it. The high punctuality

Table 1.4 List of global accidents of HSR

Number	Time (Year)	Country	Deaths/Person	Injuries/Person	Reasons
1.	1998.06.03	Germany	101	88	Tyre fracture
2.	2002.11.16	France	12	10	Line short
3.	2005.04.25	Japan	107	562	Overspeed derailment
4.	2011.07.23	China	41	38	Signal failure
5.	2013.07.24	Spain	80	170	Overspeed
6.	2015.11.14	France	11	32	Overspeed
7.	2018.10.21	Taiwan, China	18	207	Overspeed derailment

Table 1.5 The impact degree of different environments on vehicles

Factors		HSR train	Airplane	Car	Traditional train
Natural factors	Wind	Little	Little	Huge	Huge
	Rain	Little	Little	Huge	Huge
	Lightning	Some	Some	No	Some
	Temperature	Little	No	Little	Huge
	Debris flow	Some	No	Some	Some
	Earthquake	Some	No	Some	Some
Human factors	Throwing foreign objects	Some	No	Some	Some

rate (Table 1.5) is also one of the reasons why the HSR is popular among passengers.

(5) Less pollution. The electrified HSR has no dust, soot and other exhaust gas pollution. Although construction of power plants will cause pollution, the amount of pollution is less than that of freeways and air transportation. The ratio is about 1:3:4. In addition, the noise of HSR is 5–10 dB (decibel) smaller than that of freeways. Environmental pollution degrees of different vehicles are as shown in Table 1.6.

(6) Land conservation. Compared with the four-lane freeway, the area of HSR is only half of that of the freeway, and most HSR lines are built on dedicated bridges, which will not obstruct the ground transportation. A freeway with 8 lanes can realize the volume of one HSR. While the rail covers an area of 13.8 m wide, the six-lane highway covers an area of 37.5 m wide, as shown in Fig. 1.19.

(7) Low energy consumption. HSR takes the least energy consumption among all types of transportation. The energy consumption per person per kilometer is only 3.6 kW·h, which is equivalent to 10% of the energy consumption of the aircraft. Energy consumption ratio of various modes of transportation is shown in Fig. 1.20.

Table 1.6 Environmental pollution degrees of different vehicles

Name		Road transportation	Air transportation	HSR transportation
Emission substance	CO	1.26	0.51	0.003
	NO_x	0.25	0.7	0.1
	CO_2	111	158	28
	SO_2	0.03	0.05	0.01
Noise (internal)	dB	76	81	68

Unit: g/(person·km)

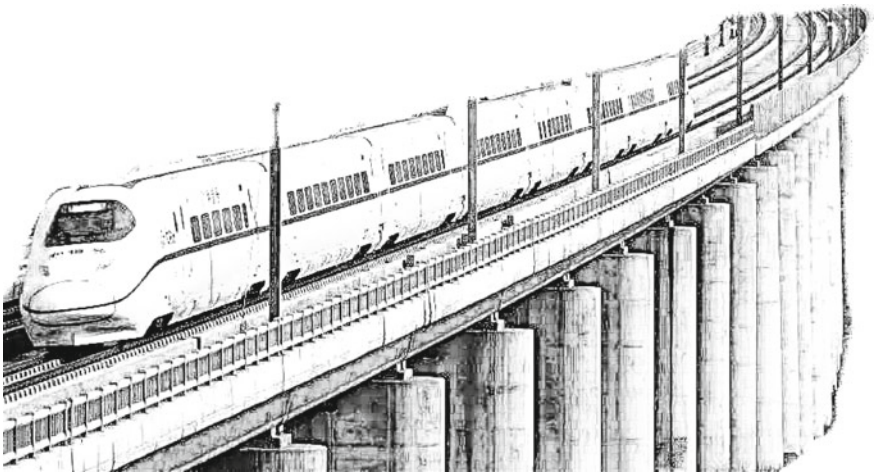


Fig. 1.19 Special bridge for HSR

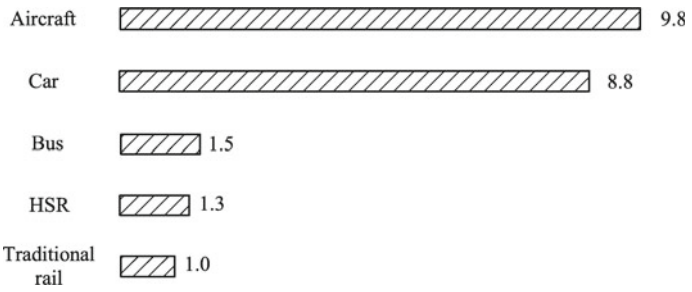


Fig. 1.20 Energy consumption percentage of various modes of transportation

(8) High comfort. The HSR train is luxuriously arranged with complete working and living facilities, spacious and comfortable seats, good running performance, large activity space and stable operation. The train is very quiet because of shock absorption and sound insulation. Travelers are comfortable, convenient and enjoyable when travel on a high-speed track. No matter they are lying or walking, it is more comfortable than stay in other modes of transportation. Business seats of the HSR train are shown in Fig. 1.21. Advantages of HSR are shown in Table 1.7.

HSR has many advantages. In addition to the above advantages, it also has its social, economic, environmental and external boundary benefits.

Fig. 1.21 Business seats of HSR train

Table 1.7 Advantages of HSR

Advantages	Details	
Large transportation capacity	A long train can transport more than 1000 people	Operating interval is 3 min
Strong adaptability to the natural environment	All-weather running	Rarely affected by rain, snow and fog
Short departure interval	Take the "bus" model	Travelers can set off at any time
Energy saving and environmental protection	Green transportation	Energy conservation

1.5 Summary

Since Japan built the world's first High-speed Rail (HSR) in 1964, HSR has developed rapidly. The word will enter the "era of high-speed rail" by 2020. Therefore, "A Brief History of High-Speed Rail" introduces the emerging concept of "high-speed rail" systematically to readers. It includes the terminology, structure function and development trend of high-speed rail system. It is designed to allow readers to fully understand the past, present and future of HSR.