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High-Speed Ground Transportation: Planning and Design Issues

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60.1 Introduction

Purpose

High-speed ground transportation (HSGT) refers to rail services that use appropriate technology that allows trains to operate at speeds over 200 kph (125 mph) in revenue service. This technology consists of trains, track, and other necessary equipment. There are two major types of technology used to achieve such speeds:

- Trains that operate using steel-wheel-on-steel-rail technology and are powered by either electric or diesel locomotives. These are called high-speed rail (HSR) trains.
- Trains that are suspended (levitated) and propelled with the use of magnetic fields (magnetic levitated (MAGLEV) trains).

FIGURE 60.1 The first Japanese bullet train, Shinkansen 0. (From Fosset, D.A.J., 1998.)

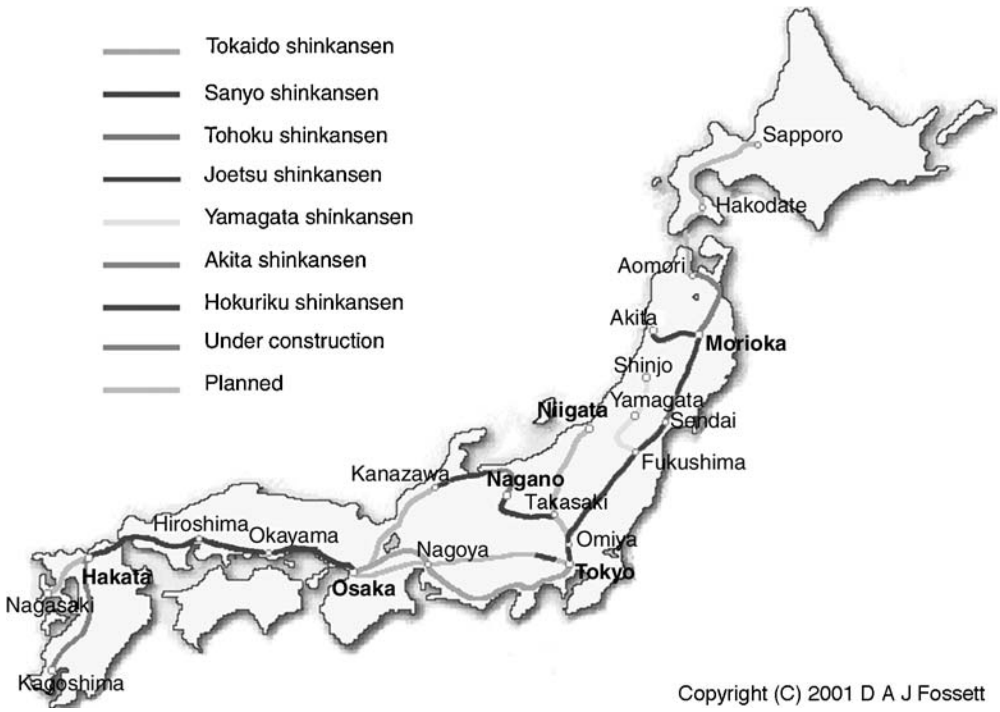

FIGURE 60.2 The Japanese HSGT network. (From Fosset, D.A.J., 2001.)

The technology available allows HSR trains to operate at 300 to 400 kph (186 to 250 mph). Such trains have been successful in revenue service in France (the Train Grande Vittese (TGV)), Germany (the Intercity Express (ICE)), Japan (the bullet trains — Shinkansen), and other countries for several years. For example, Japanese HSR trains have been operating since 1965 and French TGVs since 1981. On the other hand, MAGLEV trains have been a promising still-experimental technology for many years and are expected to be operating in the near future. There are two major MAGLEV types — Transrapid of German origin and MLU of Japanese origin — operating experimentally and accommodating small routes. MAGLEV technology is implemented at the moment to connect the Shanghai airport with the city of Shanghai in China. There are also plans of using such technology to connect Shanghai with Beijing [1].

Further, the United States is still remaining skeptical in applying or developing such technology, either HSR or MAGLEV, so a great part of this chapter will be devoted to the planning and systems issues associated with implementing this technology in the United States. Despite that fact, agencies such as the Federal Railroad Administration (FRA), Transportation Research Board (TRB), and U.S. Department of Transportation (DOT) propose, examine, and fund studies and projects for the implementation of HSGT in the United States [2–11].

It should be noted also that since HSR and MAGLEV technologies are complex and have many facets, details and advanced information on them are beyond the scope of this chapter.

HSGT has many important civil engineering planning and design considerations. It is calculated that between 65 and 80% of the investment cost is for civil engineering–type facilities (track, right-of-way (ROW), stations, catenaries, bridges, etc.). System requirements that pertain to its introduction to the United States are under scrutiny as government and industry still attempt to identify pertinent issues and problems. Of special concern are those areas of operation, like safety and noise, that are considered in a different manner by the foreign manufacturers and operators whose history in passenger rail is not parallel to that in the United States.

Scope

A brief history background sets the stage. Section 60.2 discusses pertinent systems issues such as market demand, corridor development, cost estimating, scheduling, safety, noise, ride quality, and the like. Section 60.3 presents specifications that pertain to the most well-known types of train sets (TGV and ICE), while Section 60.4 discusses the infrastructure. Section 60.5 identifies several track–train interactions. Section 60.6 discusses several HSR examples worldwide, and Section 60.7 is devoted to MAGLEV technology. A long list of up-to-date references is also provided to help the reader develop a better understanding on HSGT, enhance his or her knowledge, and gather extensive information regarding the subject.

It should be noted that HSR is often used to refer to the French TGV train [12,14], while Germans have developed a similar operating train fully competitive to the TGV: the ICE [12,13]. Both types have been competitors for implementation in the United States in the past years (for example, in Texas for the Dallas–Fort Worth–Houston and Dallas–Fort Worth–San Antonio corridors [14–16] and in Florida for the Miami–Orlando–Tampa corridor [12,17,18]).

Brief History

High-speed trains were introduced in the early 19th century when British engineers developed the steam railroad locomotives. These locomotives were the beginning of a long era in which varying technologies were pursued in order to achieve higher speeds coupled with operating and fuel efficiencies. Steam propulsion gave maximum speeds of about 160 kph (100 mph) in the early 20th century. Test speeds of 209 kph (130 mph) were attained by using diesel-electric and electric propulsion in the 1930s and 1940s. This change in technology provided slightly improved performance and fuel efficiency, but it was not until the 1960s that breakthroughs in suspension, train–track dynamics, and other factors permitted an increase in train speeds by a factor of 2 or more.

On November 1, 1965, the Japanese introduced, as part of the regular train schedule, a standard-gauge railway service that reached the maximum speed of 209 kph (130 mph). The average speed of the train was 166 kph (103 mph). Although the speed of the train was not a major breakthrough in terms of what had been previously achieved, the uniqueness was in the dedication of the right-of-way to this system.

The ensuing decade brought much activity in the area of high-speed rail. The Pennsylvania railroad developed the “metro-liners” by placing traction motors on each axle. That train achieved the maximum

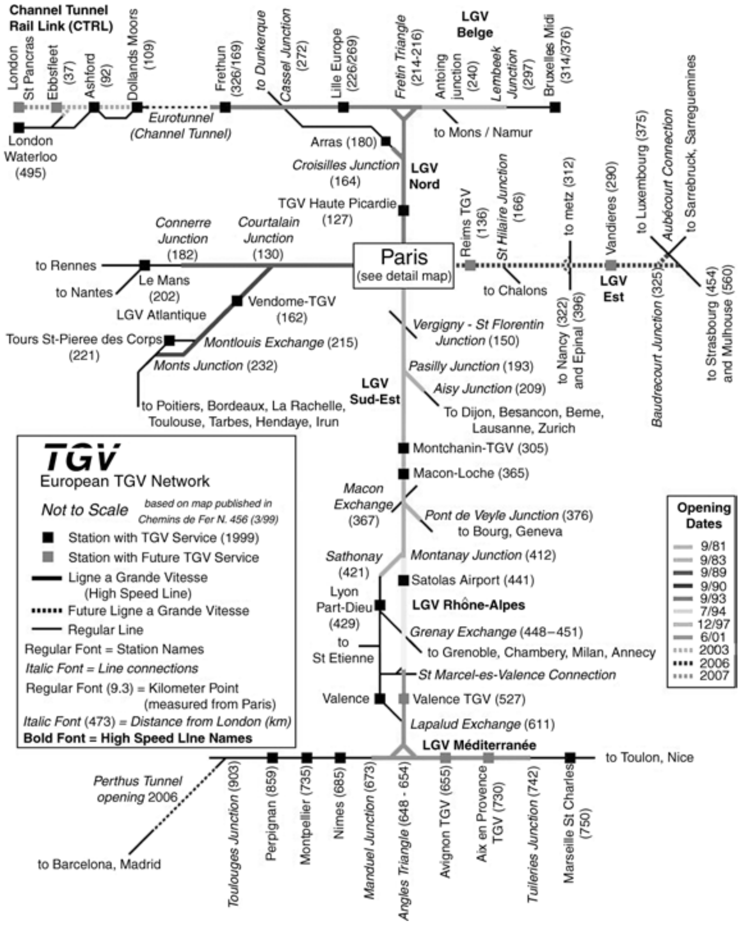

FIGURE 60.3 The TGV HSGT network around Europe. (From French TGV web information (TGVWeb), mercurio.iet.unipi.it/tgv, Italy, 2001.)

speed of 251 kph (156 mph) in Princeton, New Jersey, in May 1967. Only a decade ago, "metro-liner-like" coaches pulled by AEM-7 locomotives operating at speeds of up to 201 kph (125 mph) in revenue service were the only relatively high-speed rail systems in the United States.

At present, high-speed rail trains regularly operate in Japan, France, Germany, and other countries worldwide in revenue service, at speeds between 240 and 300 kph (150 and 187 mph). The Japanese have been operating their Shinkansen (bullet train) between Osaka and Tokyo for more than 30 years [12,19]. The French initiated high-speed revenue service between Paris and Lyon with the TGV in 1981 [12,14]. The latest French TGV trains operate in revenue service on several lines (about 25% of the lines are dedicated to their use [12,14]) connecting Paris with Brussels, London (under the British Channel, called the Eurostar [12,21]), and cities of the Atlantic and Mediterranean coasts [12,14]. The TGV achieves peak speeds of 320 kph (200 mph) and has been tested at a sustained speed of 515 kph (330 mph) [12,21]. Similarly, the Germans operate their own ICE all over the country (using mainly nondedicated lines [12,13]). Meanwhile, a project called Thalis is under development and partial operation for the connection of major western European cities (Paris, Brussels, Cologne, and Amsterdam — PBKA [12,21]).

The United States has been slow and in some cases unwilling to embrace the development of HSGT systems [17,18,22]. This is probably due to the combination of several factors:

FIGURE 60.4 HSGT systems under study in the United States. (From U.S. Government Accounting Office, Report to the Chairman, Committee on Energy and Commerce, High-Speed Ground Transportation: Issues Affecting Development in the United States, House of Representatives, November 1993.)

- The love of Americans for the automobile
- The advances of the airline industry and the economic power of airline companies (which is questionable after the 2001 terrorist acts in the United States)
- The size of the U.S. landmass in conjunction with its population density
- The skepticism of generating enough demand for a profitable venture in any but the highest population corridors
- The lack of a passenger railroad culture

Concerns over gridlock, wing lock, negative environmental impacts, and the failure of airports to expand to fully meet commuter demand, coupled with the successes of HSGT in Europe, have brought about a resurgence of interest in high-speed passenger rail traffic. The HSR is most likely to succeed between cities with stage lengths in the range of 200 km (125 miles) to 400 km (250 miles), where it can be competitive with airline connection [12]. The map in Fig. 60.4 indicates the leading candidates for HSR or MAGLEV consideration in the United States. HSGT systems could free capacity at some of the congested highways, air space, and airports. Moreover, it is a mode of transportation that appears to be reasonably energy efficient when compared with other modes; with electrification for its power source, it is potentially less dependent on petroleum resources [23,24].

60.2 Systems and Planning Issues

Because of its years of revenue service in Europe and Japan and because it has continued to achieve growth and implementation worldwide, HSR should be considered a mature technology that might be expected to find its way quickly and easily into operation in the United States. In fact, an Amtrak-operated HSR train, called ACELA, has served the Northeastern U.S. corridor (NEC) since 1999 [12], connecting Boston, New York, Washington, D.C., and Philadelphia — getting around 45% of the passenger market between Boston and New York and cutting the travel time of 4 h 30 min to about 3 h [12]. In California and 20 other states, plans are made to implement HSR along corridors [25]. On the contrary, in Texas

FIGURE 60.5 Photo of the ACELA Express. (From French TGV web information (TGVWeb), mercurio.iet.unipi.it/tgv, Italy, 2001.)

FIGURE 60.6 The proposed California HSGT network — environmental progress. (From CalHSR.)

and Florida such plans proposed in the past years were either abandoned or cancelled [12,17,18]. The initial notion, though, still requires exploration in three major areas:

1. When, how, and who will provide leadership to back high front-end costs in the face of widespread skepticism and competitive pressure? For example, the proposed HSRs to serve major corridors in Texas and Florida were abandoned [12,17,18]. Pointed opposition of local airlines (Texas) [12], difficulties in raising funds [17], negative public opinion [18], and studies that questioned the effectiveness of HSR (for example, the Wendell Cox Consultancy Report regarding the HSR implementation in Florida, issued by the James Madison Institute (JMI) in 1997) were major reasons for not continuing projects of implementing HSR trains in the United States. On the contrary, in other cases (Northeastern corridor, California, etc.) plans and implementation of HSR are being developed, having obtained necessary funds and support [25].
2. Can potential projects in the United States secure right-of-way with adequate space to meet HSR requirements of track geometry and provisions for electric power supply and catenary? The answer to that question is mainly related to the special characteristics of the studied corridor. An example of the meeting of the above requirements by an HSR in the United States is ACELA, operating in the Northeastern U.S. corridor. NEC was electrified up to Boston by 1999, while tilting technology (which will be discussed later) was used to operate HSR in existing tracks without passenger discomfort [12,14]. Despite some technical glitches, ACELA began operating in December 2000 [14].
3. Will all the safety concerns, many of which reflect the difference between American philosophy and that of Europe and Japan, be met without significantly reducing the speed of the trains? The American philosophy toward safety is less flexible in most cases, so additional measures are to be taken in the train sets, signaling, and control systems to ensure maximum safety. The fact that HSGT corridors in Europe and Japan are fenced and thus inaccessible, something that is not happening in existing rail corridors of the United States, is something that also has to be taken into account [12].

The most important characteristic in an HSGT system is usually average speed [26]. Average speed affects travel time that has to be decreased, compared to other competing modes, and capacity that has to be increased. As average speed is critically important, the parameters that affect it should be examined. They are as follows:

- The HSR train's ability to negotiate curves
- The HSR train's ability to accelerate and decelerate quickly
- The number of station stops en route and dwell time at each station

Besides travel speed, there are a number of system considerations and performance characteristics that should be used in evaluating HSGT systems. These include travel demand, corridor development, schedule performance, acceleration and deceleration, ride quality, noise, safety, energy conversion efficiency, system-wide parameters, and air–rail combination possibilities.

Market Demand

The cost of the investment of most HSR systems is high, and the introduction of an HSR system will require a thorough and positive market analysis. Since it impinges on the commuter air market and the automobile–bus vehicle market, its potential entry as a competitor may be difficult to judge. In addition, there will be a latent demand for HRS travel that will become part of the demand picture.

For example, Table 60.1 shows that the French have succeeded in shifting traffic from the air and highway and in generating new demand with the initiation of the TGV operation from Paris to Lyon (with other nearby cities, served by standard rail). Analysis of the growth in the Paris-to-Lyon market of 2.2 million passengers from 1980 (pre-TGV) to 1994 indicates that 40% of the passengers have been diverted from commuter air, 23% from auto, and 37% are new or induced demand [12,14,16].

TABLE 60.1 Passenger and Traffic Demand for the French TGV: Paris-to-Lyon Route

	Travel Demand (thousands of passengers), Paris to				
	Dijon	Geneva	Lyon	Grenoble	Marseilles
1980 train	850	105	1470	435	720
1994 train (TGV)	1045	325	3670	710	1005
% increase	23%	209%	150%	38%	40%
1980 airplane		605	970	515%	1480
1994 airplane (after TGV)		495	525	280	1195
% increase		–18%	–46%	–46%	–24%
	Probable Diversion from				
Plane		165	865	40	165
Road	50	20	500	65	50
Induced traffic	145	35	835	90	70

Source: Texas TGV, Franchise Application, submitted to Texas High-Speed Rail Authority, 1991.

How will the U.S. public respond to the placement of an HSR system in a given area? Will people give up their autos for these trips? Is there an adequate market in these days of electronic mail and teleconferencing? Will the public accept rail with trip times from origin to destination in the same range for commuter air?

These are questions that must be answered. Without adequate answers and without a strong infusion of capital from the federal government to help construct the expensive facilities, HSR or MAGLEV will probably not reach any significant level of implementation in the United States. At the time, there is no actual data regarding HSR influence on market demand. Studies on future market demand have been conducted for California, Florida, and other cases in the States [17,27]. Especially in Florida, two controversial studies have been conducted, one attempting to reject the other.

California HSR Case: Expectations of the Final Plan of HSR Implementation in the State [25,27]

The market for intercity travel in California is projected to grow up to 40% by 2020 (population expected to grow about 36%) [25,27]. Today's 154 million trips will grow to up to 215 million trips by 2020. The forecast for HRS is that it will be serving around 32 million passengers and gain $888 million (assuming 86 HSR trains per day in both directions). This is expected to cover operating costs and produce a surplus of $340 million. These numbers are based on current parameters like cost of travel for each mode and travel times, a scenario considered conservative. Sensitivity analysis showed that by assuming negative changes in these parameters, the revenue for HSR might be doubled, while an additional 10 million passengers will be using the HSR every year. The HSR is expected to gain 45% of its ridership from air transportation and 42% from auto transportation. The rest will be new passengers produced because of the presence of the new mode.

The study compares key elements for mode selection. For example, total travel time is in favor of the HSR (total travel time includes waiting time, time to access mode terminals, etc.). As for fares, the HSR is expected to generate maximum surplus revenue, with fares 20 to 30% lower than airfares. In addition, according to the study, the quality of HSR seems to be more attractive for users compared to auto or air transportation.

It should be noted that the study takes into account uncertainties in the results of projection, especially in the first years of the HSR operation. Therefore, a reduction of 15%, annually reduced, is taken into account (supposing that HSR will start operating in 2017 with an 85% ridership of the projected one).

The above and other facts were drawn from the study. Sensitivity analysis was conducted, taking into account increased airfares, auto growth rates, longer air or auto travel times, and combinations of the above scenarios. The sensitivity analysis showed that increases in airfares have a significant impact in HSR, while travel times have only modest impacts [25,27].

The major conclusion of the study is that, despite that HSR will not be the dominant mode of intercity transportation in most cases, the fact that it will be economically viable makes it applicable to California.

Florida HSR Case: Two Opposing Studies

Since 1991, the Florida DOT (FDOT) has initiated studies of implementing HSR in Florida, with the potential of partial public funding [17,18]. In 1995, FDOT asked for proposals by private companies for financing, operating, and building an HSR system along the Miami–Orlando–Tampa corridor. Five companies offered proposals, from which Florida Overland Express (FOX) had the winning proposal, mainly because of its better financing plans and the fact that the company fulfilled the requirements regarding environment, safety, technology, etc. set by FDOT.

FOX had developed an analysis in 1995 to support its proposal along the Miami–Orlando–Tampa corridor, including ridership, building and operating costs, and financing of the project. The ridership analysis was revised by FOX and FDOT later in 1998, only to find increased projected ridership.

In 1997, a report prepared by Wendell Cox Consultancy [17] and issued by the James Madison Institute questioned the accuracy and results of the FOX market analysis, concluding that HSR would carry fewer passengers than the FOX market analysis expected and would cost more and expose taxpayers because of that. The Cox analysis asserted that the ridership forecast was incorrect (unreliably high for the HSR part), as were the air and HSR fare forecasts. The Cox analysis concluded that the FOX project had an incorrect market analysis (in terms of forecasting) and, thus, its financing plan would not be achievable and would be costly to taxpayers. Comparisons with FRA-forecasted numbers for ridership and fares and the economic condition of HSR companies in Europe were additional facts in the Cox analysis. The result of the confrontation was in favor of the Wendell Cox Consultancy study; in 1998 the governor of Florida cancelled the FOX project.

Chicago–Milwaukee: Twin Cities Corridor Study [28]

For the Twin Cities corridor study, fairly conservative demand models were developed, examining three scenarios (125-, 186-, and 300-mph systems). It was revealed that the 125-mph option offers the best financial return, the fewest environmental costs, and the highest economic benefit per dollar invested, which would be relevant to a public sector capital-constrained investment program. While the net economic benefits are not quite as high as with the 185- and 300-mph options, the level of benefit is substantial. The economic benefits achieved by the 125-mph option are 80% of those achieved by the 185-mph technology and 94% of those achieved by the 300-mph technology. The 185-mph technology (TGV) has a good financial return and the highest net economic benefits, but it suffers from the highest environmental costs because of the severance problems associated with its new right-of-way. The 300-mph technology (MAGLEV) provides good economic benefits but has only marginal financial performance due to its substantial capital costs. What is surprising is that the 300-mph option performs as well as it does, given its huge capital costs.

Corridor Development

The corridor for HSR will require either an upgrade of existing track or new land acquisition coupled with the construction of straighter track, built with the stability in alignment required for these speeds. This may not be so easy, since the corridor will bisect farmers' fields and create dead ends for many rural roads. The corridor would also require rerouting of utility service lines such as gas, water, sewer, telephone, and electricity.

At the speeds of the HSR, grade separation is necessary, so overpasses and underpasses will be required in many areas. For some farms it may be necessary to put an access tunnel under the roadbed in order for the farmer to get from his fields on one side of the track to those on the other. For example, the 458 km between Fort Worth–Dallas and Houston is estimated to require 270 bridges over creeks, rivers, highways, and other railroads, plus about 25,000 m of elevated track, mostly in the urban areas. Also needed would be about 145 culverts (10 ¥ 10 ¥ 150 ft) for drainage and access along the same right-of-way [15].

Small towns also pose problems to an HSR corridor. If the use of the present ROW is suggested, much of that ROW passes through small towns and other lightly populated areas. The choice and the placement of the corridor, the approach to tunnels, and the design of other depressed or elevated ROWs around these towns may significantly increase the cost of the investment. Most of these towns will not have a station, since the train won't be able to stop frequently in order to take advantage of the higher peak speed. Therefore, the economic development aspects, which classically occur around stations, will not take place and the towns may see the HSR only as a nuisance.

Entering large urban areas may be easy or difficult, depending on the existing roadbed. The TGV, operating at reduced speeds, uses existing track for entry and exit of Paris and Lyon [12,21].

The corridor chosen may require some tradeoff between the cost of wetlands remediation (if wetlands are in the path of the HSR corridor) and alternate routes that require less or no mitigation.

There is no doubt that access of ROW for a corridor, whether through procurement, eminent domain, or condemnation, must occur very early in the project — well before any construction is due to begin. With the corridor disruption or "severance" of farms or landscape, the HSR will face the usual uphill battle from those who do not want the railroad. The "Not in My Backyard" (NIMBY) syndrome will in all likelihood be very prevalent.

An example of a corridor study for HSGT implementation is the Chicago–St. Louis High Speed Rail Study, completed in August 2000 by the U.S. DOT, FHWA, FRA, and Illinois DOT [28]. For the corridor study, two major alternatives were examined: (1) the "do-nothing" alternative, where the existing Amtrak service would remain with the regular maintenance and rehabilitation actions on the corridor and (2) an HSR train implementation as a more viable solution, compared to air and auto travel. The HSR would operate at speeds of 110 and 125 mph and would consist of 8 round trips per day, every 2 hours, with a travel time of around 3.5 h. Existing tracks would be used and, in addition, new tracks would be constructed to facilitate the HSR performance. Three different alignments were proposed for the HSR implementation. Also, different types of train sets (electric or diesel) and different operating speeds were examined; 110 mph was chosen as the most cost effective. The evaluation of the different alternatives examined land use and farmland; displacements; and effects on employment around the corridor, on water and natural resources, and on wetlands and floodplains, as well as effects on cultural resources, waste, and grade crossings. Special care was taken for the accommodation of grade crossings and effects when crossing small cities. Also, unresolved problems remained, concerning other agencies as well, for the disposal of waste, the treatment of historical properties, air quality issues, etc.

Cost Estimate

The Transportation Research Board has developed a series of cost estimates based on several HSGT scenarios [30]. The scenarios compare several options against an "as is" railroad. The options for which data are presented in Tables 60.2 and 60.3 are:

TABLE 60.2 Estimates for Six Alternatives of HSGT: 300-Mile Corridor

Alternative	Urban Track, 40 Miles, Cost per Mile	Suburban Track 60 Miles, Cost per Mile	Rural Track, 200 Miles, Cost per Mile	Total System, 300 Miles, Total Cost
1	$915,000	$400,000	$235,000	$108,000,000
2	$1,660,000	$1,000,000	$740,000	$275,000,000
3	$7,645,000	$6,410,000	$5,260,000	$1,742,000,000
4	$7,680,000	$7,370,000	$8,340,000	$2.418,000,000
5	$8,110,000	$14,490,000	$10,495,000	$3,293,000,000
6	$31,115,000	$19,715,000	$14,055,000	$5,239,000,000

Source: Parsons Brinckerhoff Quade & Quade, Inc., High-Speed Surface Transportation Cost Estimate Report, TRB, Washington, D.C., April 1991.

TABLE 60.3 Speeds and Trip Times for the Six Scenarios

Alternative	Urban Track, 40 Miles, Speed (kph)	Suburban Track 60 Miles, Speed (kph)	Rural Track, 200 Miles, Speed (kph)	Total Trip	
				Total Time (h)	Average Speed (kph)
1	50	65	70	4.58	65
2	50	80	90	3.77	80
3	55	90	90	3.39	88
4	55	90	130	2.93	102
5	60	100	150	2.60	115
6	100	170	230	1.62	185

Source: Parsons Brinckenhoff Quade & Quade, Inc., High-Speed Surface Transportation Cost Estimate Report, TRB, Washington, D.C., April 1991.

1. *"As is" railroad* requiring a typical class-3 track to be upgraded with the addition of block signaling and passing sidings to permit 125-kph (79-mph) passenger service.
2. *Low ROW/capital investment strategy* with top speeds of 175 kph (110 mph) and upgrades in track and cab signaling. ROW width sufficient for second track and major rehabilitation at stations.
3. *Intercity/shared ROW* would have top speeds of 200 kph (125 mph) with electric propulsion, a full double track, and concrete ties maintained to FRA class-6 standards. All high-speed crossings would be grade separated.
4. *Intercity/shared ROW/new bypass segment* with one to several bypass segments with track geometry and signaling to permit top speed on the bypasses of 240 kph (150 mph).
5. *The TGV approach* with trains operating mostly on new ROW dedicated to the TGV with top-speed operation in the 290- to 320-kph (180- to 200-mph) range.
6. *New technology using MAGLEV* concepts with a top speed of 500 kph (320 mph).

The TRB presents many assumptions on which the above numbers are based. However, for the purpose of planning, these numbers should be sufficient for preliminary estimation. The costs include land, ROW preparation, utilities relocation, track construction, realignments, grade separations and enclosures, fencing, electrification, signaling, undergrade bridges, overhead bridges, tunnels, terminals, beltway stations, O&M, central control administration, and train sets. The assumptions are given in sufficient detail so that a quick estimate can be made. The costs for a 500-km (300-mile) system with 67 km (40 miles) of urban land, 100 km (60 miles) of suburban land, and 333 km (200 miles) of rural land are presented. The average cost for the TGV (option 5) is about $6.84 million per kilometer ($11 million per mile) [30,31].

Schedule Performance

Providing that the ride quality is acceptable, the demand for the HSGT will depend on the perception that the consumers have as to its schedule performance and reliability. When comparing the HSGT with competing modes, the actual travel time for the user between origin and destination is critical. The line-haul speed, typical average speed, and time of trip are given in Table 60.3 for the six alternatives shown in Table 60.2.

Somewhat higher speeds than those quoted for alternatives 3 and 4 may be obtained if an active tilt train such as the Swedish X2000 or EGR 460 is used. [12,32–34]. The speed of the train on curves will depend on the radius of the curve, the superelevation of the track (bank angle), and the allowable deficiency in the cant angle — the limits for which come from ride comfort (lateral forces on passengers). A train, such as those in alternatives 2 to 4, that must regularly slow down for curves and then accelerate again will have a slower overall line-haul speed than one that can negotiate the curves at or close to its regular speed. Improved acceleration and braking are aided by lower train set weight achieved through the use of lightweight materials and appropriate construction techniques.

The number of stations and the dwell time in each station will also affect the overall time of travel between two points. Analysis of the TGV on one 400-km (250-mile) route with a maximum line-haul train speed of 300 kph (186 mph) and stops at four intermediate stations, each with a dwell time of 3 min, had 118 min of elapsed time from doors closing at the origin to opening at the final destination. The average speed was 204 kph (127 mph).

Safety

The potential severity of higher-speed accidents can be offset by such factors as dedicated right-of-way, fully fenced corridors, automatic train control, and ROW maintenance — all geared to reduce the overall risk. A large part of the research regarding HSGT systems has focused on safety issues [35–38]. Many of these issues deal with crash tests and car designs that will minimize bodily injuries in case of a crash. The existing HSGT systems in Europe are operating at a level of safety that is better than that of conventional rail technology. The excellent system maintenance, highly automated train control, dedicated ROW, and fencing around the tracks have led to an amazingly safe accident record. For example, the Japanese Shinkansen line has had no fatal accidents in the past 18 years while having transported approximately 2 billion passengers [24,43]. The same applies to the TGV: while operating at high speeds, no fatal accidents have happened since it began service in 1981. In fact, within the last 20 years of TGV service, only 11 incidents have occurred, the most important of which occurred in the conventional lines, where the speeds were lower and any conventional train had the same chances of facing such an incident. Table 60.4 shows the incidents and the dates they occurred. The most serious accident concerning an HSR train within the last 20 years of HSGT operation in Europe happened in 1998, when a German ICE 1 HSR-type train derailed on a highway bridge abutment at a speed of 200 kph and caused the bridge to collapse, as well. The accident caused the death of 88 passengers and injury of at least another 100 and forced the German government to operate its ICE trains at lower speeds for a long period [12,13]. The cause of the crash was the cracking of a defective wheel [12,13].

Higher-speed operations on existing lines pose an especially difficult problem. The track, ballast, and geometry are all designed to accommodate lower speeds. There will certainly be increased risk associated with the use of this track in high-speed operation. In fact, the use of an existing ROW such as in the Northeast corridor is what happened in the United States. With the large amounts of capital needed, it is clear that until the federal government decides to fund dedicated ROWs, the upgrading and increased use of existing ROWs will be the direction higher-speed rail takes in the United States (Next Generation Rail, Accelerail, Incremental Rail, or whatever one wants to call it). With this use comes the need to assess how ROW and equipment design, signal systems, onboard and wayside detectors of various sorts, grade crossings, ROW security, etc. contribute to enhancing the overall safety risk, given the accident severity potential that inherently increases with speed. Such progress is achieved by using other system elements to control risk to the same or lower levels than is currently accepted by the riding public [44,45]. The TRB IDEA program suggests several areas of study regarding the safety of HSGT [5], focused mainly on upgrading the existing ROWs.

This leads to a careful design of an onboard monitoring system that will automatically slow a train that is starting to hunt. The elements with automation will include accelerometers to detect the onset of truck hunting, bearing temperature monitors, brake system sensors, various wayside detectors, etc. [5,7].

As speeds increase above 200 kph (125 mph), dynamic force control is a key factor in maintaining safety of operation. New inspection methodologies to move from the currently accepted static geometry (even if loaded) measurements to more dynamic real-time monitoring of equipment forces (wheel) and the track response and interaction (rail) are needed for the HSR. The whole issue of maintaining track for ride comfort versus minimum track geometry standards must be addressed [47,48].

Lighter weight but stronger materials will be required (one key to the success of TGV and ICE), while it will be appropriate to maintain or reduce, not increase, axle loads. Thus, given the United States' need to design for different collision scenarios (mixed freight and passenger operations), the challenge to be innovative will be even greater. (Even though the TGV and ICE trains in some cases do operate on existing

TABLE 60.4 Incidents since TGV Started Service

Date	Cause	Train Set Involved	Service	Location	Injuries
05 January 2001	Derailment	Atlantique, unknown	Train 8720, Brest to Paris	Standard line near Laval (Mayenne)	None
05 June 2000	High-speed derailment	Eurostar 3101/3102	Train 9047, Paris to London	LGV Nord Europe, near Croisilles (10 km south of Arras)	14, slight
28 November 1998	Grade-crossing accident	Atlantique, unknown	Unknown, Brest to Paris	Grade crossing 303, near Guipavas (29)	None
9 May 1998	Grade-crossing accident	4345 (Thalys PBKA)	Train 9344, Amsterdam to Paris	Hoeven, southern Netherlands	6, slight
19 November 1997	Grade-crossing accident	Atlantique, unknown	Brest to Paris, unknown	D140 road at Neau, near Laval	6, slight
11 October 1997	Fire	PSE, 15 (or 45?)	Train 644, Lyon to Paris	Near Montchanin, LGV Sud-Est high-speed line	None
25 September 1997	Grade-crossing accident	502 (Réseau)	Train 7119, Paris to Dunkerque	Bierne (10 km south of Dunkerque)	7, slight
10 August 1995	Grade-crossing accident	394 (Atlantique)	Train 8737, Paris to Brest	Near Vitré, kilometer post 342, PN 172 grade crossing with road D34	2, slight
21 December 1993	High-speed derailment	511 (Réseau)	Train 7150, Valenciennes to Paris	TGV Haute Picardie station, kilometer post 110.5, LGV Nord (Paris-Lille) high-speed line	1, slight
14 December 1992	High-speed derailment	PSE, unknown	Train 920, Annecy to Paris	Mâcon-Loché TGV station, kilometer post 334, LGV Sud-Est high-speed line	27, slight
23 September 1988	Grade-crossing accident	70 (PSE)	Train 736, Grenoble to Paris	PN 74, Voiron	2 dead, 60 injured
31 December 1983	Terrorist bombing	PSE, unknown	Unknown, Marseille to Paris	Near Tain-l'Hermitage, south of Lyon in the Rhône Valley	

Source: Chemins de Fer, La Vie du Rail, TF1 television, Dernieres Nouvelles d'Alsace, U.S. Federal Railroad Administration, etc.

or shared ROWs, as well as on dedicated lines, the type of freight equipment and thus accident scenarios are different from those in the United States). Given some of the accidents France and Germany have had between "regular" passenger trains and freight trains and their resultant severity, one could argue that such risks would not be acceptable to the U.S. riding public.

Studies have also been made for the fire safety [49], emergency preparedness [50], control, communication [51,52], the human factor, and automation as they apply to train control [53].

Finally, there is considerable concern over the effects on health of electromagnetic field (EMF) radiation. The FRA, through the Volpe National Transportation Systems Centre and the Environmental Protection Agency, has done considerable testing and analysis of this potential, both for the TGV-type train and the MAGLEV train. A series of 17 reports [54] is available on the subject.

Noise

Since HSGT is to be powered by electricity, air pollution is not a factor, leaving the major environmental considerations: severance of land, wetland mitigation, and noise. The National Environmental Policy Act of 1969 requires that any project with federal government involvement be accompanied by an environmental impact statement. Certainly the choice of a corridor is critical, as it may require wetland mitigation and the HSR noise can have an effect on the land use along the corridor. Fortunately, the HSR noise seems to be less than the noise associated with conventional rail operations [55–57].

Given that noise increases with speed, due to the high aerodynamic component, the need for either passive barriers or active noise canceling systems becomes apparent [46].

The major noise sources in diesel operations are the engine and the interaction of the steel wheel on steel rail. The noise levels from pre-1987 diesel locomotives vary from 67 dBA at idle to 89 dBA at full throttle when standing 100 ft from the locomotive [55]. The wheel–rail noise levels vary dramatically according to the type of wheel and track structure. Most irritating is the track squeal resulting from lateral sliding of the wheels. Wheel–rail noise is usually computed as a function of the speed of the train.

Likewise, the noise experienced by rapid rail transit is attributed to the electric engine, which is much quieter than its diesel-driven counterpart and the rail–wheel interaction. The noise level for the San Francisco Bay Area Rapid Transit System (BART) at 60 mph is approximately 83 dBA 50 ft from the train; the corresponding diesel noise is 97 dBA [55].

The Japanese Shinkansen has been in operation since 1964 and has provided much noise data. The noise level measured at 15 ft from the train varies from 62 dBA at 118 mph to 76 dBA at 124 mph. The French TGV showed noise somewhat higher when operating on its Paris–Lyon route. However, 72 dBA was exceeded at only three homes along the route, and the maximum noise measure 82 ft from the train was 97 dBA. The German ICE reported noise levels of 86 dBA at 11.5 ft from the train travelling 124 mph and 93 dBA at 186 mph.

Care in design will keep the noise at these relatively low levels. With noise barriers provided by either trees and shrubs, constructed walls or depressed track, the noise of the HSGT should be well below any sound levels that would pose an annoyance to neighbors.

Ride Quality

In addition to the stress on performance, the consumers will ride the HSGT only if, as passengers, they perceive it to be comfortable. Thus, ride quality as experienced in the seat design and in the amenities is quite important. Although ride quality is subjective in nature, the train set appearance, both interior and exterior, lighting, sound levels, airflow, and temperature determine the appeal. Most of the European trains also provide places for small meetings, phone and fax service, special workspaces including computer hookups, and real-time trip-related status information.

Physical ride quality is determined by track design and alignment, car body motion, and the design of the passenger seats. The track input comes from the track itself: is the rail continuous and is it aligned? Most of the high-speed lines maintain track to achieve lateral and vertical forces and acceleration levels low enough to assure good ride quality. At present International Standards Organization (ISO) standards for ride quality do exist. From a vehicle point of view, dynamically balanced wheel sets, wheel profile, and low unsprung mass are considered the strongest influences for best ride quality [58]. Low unsprung mass is essential for truck stability, while the suspension must be designed to minimize lateral and vertical movements of the car body. Wheel profile is important in maintaining safe levels of wheel–rail interaction forces to ensure a smooth and comfortable ride. In summary, ride comfort is very subjective, and each railway authority develops its own criteria.

So important is riding quality that sensors and a computer are employed on many trains to give a real-time measure of ride quality and to make adjustments or signal the engineer as necessary. Furthermore, these data may be used to indicate portions of the track for special maintenance. Such a maintenance philosophy dramatically reduces the likelihood of encountering unsafe levels. The TGV uses truck-mounted accelerometers to detect truck hunting and requires immediate reduction in speed if such hunting is detected.

Energy Conversion Efficiency

Energy use by the train is important, and one of the goals of the HGST systems is to conserve energy to minimize operating cost. Energy efficiency is a function of the propulsion system, gearing, and train set design. The Federal Railroad Administration, through the Improved Passenger Equipment Evaluation

Program (IPEEP), found that increased train weight leads to increased energy consumption, in the range of 0.06 to 0.08 watt hours/seat-km ton [59].

The friction involved in steel-wheel-on-steel-rail technology is extremely low. The concern for the HSGT is that at very high speeds significant additional energy losses will occur in bearing friction and from aerodynamics. Equation (60.1) is the generalized equation for the horsepower required to pull a train. Aerodynamic design is extremely important, since the power to overcome aerodynamic effects increases by the cube of the increase in speed. Thus, increasing speed from 60 to 180 mph requires 27 times the power and from 120 to 180 mph requires 3.4 times the power [60]. From the outset of the first TGV, significant effort has gone into reducing aerodynamic drag [46]:

$$HP = C_0 V \times \left(C_1 + C_2/W + C_3 V + C_4 V^2/W\right) \tag{60.1}$$

where HP = horsepower
W = the weight of the train set
V = the speed
C_0 = the efficiency of the drive system
C_1 and C_2 = the friction between the rail and wheel
C_3 = the rolling and bearing resistance
C_4 = the aerodynamic coefficient

HSGT is not particularly energy efficient except in energy expended per passenger kilometer, when compared to other modes. In addition, regenerative braking can be used if the power source is receptive to it. Energy input enables the train to accelerate in order to reach its line-haul speed. When it decelerates, some of the energy that would otherwise be dissipated as heat can be returned to the power source, thus reducing the energy needed to accelerate again.

System-Wide Parameters

The HSGT vehicle performance can be seriously affected by certain other system parameters. For example, the location of the corridors is a critical factor in construction cost. Hilly or mountainous terrain, wet marshy land, and large numbers of river, creek, drainage ditch, and road crossings all add to the alignment of the track system. The elimination of grade crossings is a must, and the communications and signaling systems must be designed to handle the high speed. Most HSGT lines are double track. The catenary will require more supports as the track crosses mountains.

Automation is an important design requirement at these high speeds. The manner in which train operators (engineers, dispatchers, etc.) are trained, how the design of their workstation enhances their performance, and how emergencies are to be handled are all dependent on the extent and nature of automation. In all likelihood it will be different from all current intercity rail systems in the United States or abroad. Some lessons are available by examining BART, the Washington Metropolitan Area Transit Authority (WMATA), the Port Authority Transit Corporation (PATCO), etc. and definitely from the international front, where different uses of automation can be seen when comparing TGV to ICE operations. The similarity of these issues to those confronting the aviation industry increases as the use of automation increases [50]. Two obvious options for automation application are:

- A highly automated system with a human in-the-loop, both heavily observed and managing a fully automated system
- A system with a human out-of-the-loop, where the human operator is an observer of automatic systems with virtually no override capability, except to stop the train

Each system has its individual safety and design implications [50].

The basic principles of operation of the signaling, communication, and control mechanisms, the extent and type of automatic train operation or control to be used, and the provisions for driver vigilance monitoring and override are important but beyond the scope of this handbook. It also should be noted that there is a recent effort in Europe to keep the same standards and types in automation technology over all European HSGT lines so that HSGT train sets from different origins can operate everywhere in Europe.

Air–Rail Combination Capabilities

It is a fact that there should be intermodality between air and rail so that passenger traffic in short distances can be diverted from air to rail transportation, freeing up airline capacity [61]. The fact that most airports in Europe are connected with HSR supports the above. "Sharing traffic with other modes, sharing efficiency with industries and parties, and sharing wealth with the community around the airport" are the goals to be achieved, as proposed by a European organization director [61]. As an example, ICE trains have replaced air connection between Frankfurt and Stuttgart, Germany, being designated as a flight sector with a Lufthansa flight number [14].

60.3 Train Set Specifications

There are several configurations that are often chosen for the train set; however, as shown in Fig. 60.7 for a TGV, a train set typically consists of the power car (engine), 6 to 12 coaches, and another power car. Table 60.5 gives the typical physical characteristics of the TGV Paris Sud-Est (PSE) and TGV Atlantique.

Maximum speed in revenue service is between 290 and 340 kph (180 and 210 mph); however, test runs on the TGV Atlantique, which the French built to more stringent specifications, have posted test speeds in excess of 510 kph (322 mph) [12,37,46].

60.4 Infrastructure Specifications and Design

The infrastructure that supports the HSR includes the track structure from the subbase, subballast, ballast section, ties, fasteners, rail, switches, turnouts and crossovers, rail anchors and tie pads, catenary and its supports, power substations, bridges, and tunnels. The specifications for the infrastructure of the TGV Sud-Est and Atlantique routes are given in Table 60.6 [37,46].

The gauge of the track and the distance between the centers of the dual tracks are included as specifications. The amount of ballast determines the stiffness of the track, ballast, and subgrade, taken as a combined subsystem under load. The ballast shoulder width is also important in maintaining adequate lateral track stability. Most roadbeds have a minimum width of 14 m (46 ft) [15,46].

Geometric Design

Geometric design for the HSR is little different than good practice for the geometric design of ROWs was years ago, except that with the higher speeds, more care is taken in design and the curves have much larger radii. The critical elements in the design are the superelevation and the length of the transition spiral. As long as a safe speed is maintained, the performance on curves is dictated by ride comfort, which in turn is determined by the centrifugal force the passenger feels. Figure 60.8 shows how the centrifugal force acting on a passenger is developed. A curve that is banked properly (has the right superelevation) will have those forces canceled out.

Going from a tangent track to curved track requires a spiral as the radius of the horizontal curve goes from infinity to a specific number. The spiral is not flat but must begin the run-in of the superelevation to meet that required for the curve. Likewise, as the track returns to a tangent track, there is a spiral and superelevation run-out, as well [36,38].

Equation (60.2) indicates how superelevation height difference, which is about 18 cm (7.1 inches), is determined:

$$E = 0.0007 \times V^2 \times D \qquad (60.2)$$

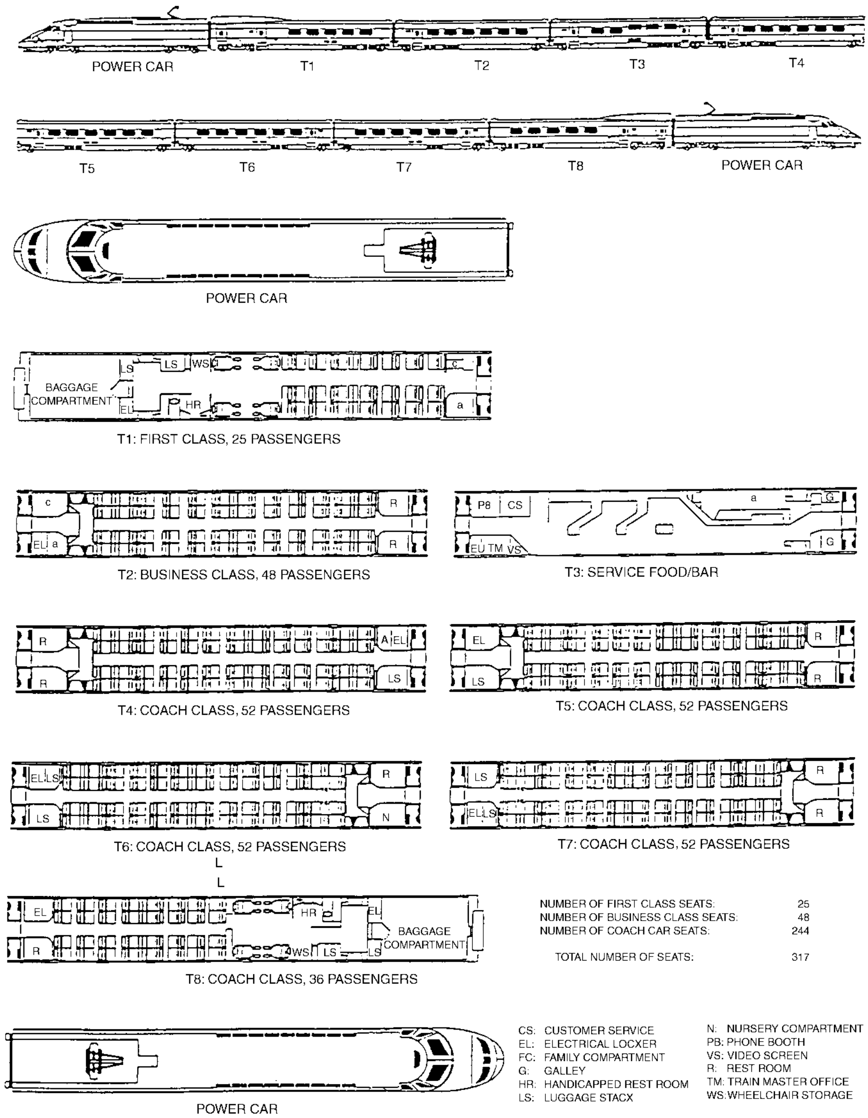

FIGURE 60.7 Typical TGV 1-8-1 train set. (From Federal Railroad Administration.)

where E = the superelevation distance in inches
V = the design speed of the vehicle in the curve in mph
D = the degree of the curve

However, since the speed with which a train would actually traverse the curve is seldom the exact speed used in design, it is necessary to specify the deficiency in cant angle, which in turn indicates the degradation of ride quality.

In the United States the design of the spiral is dictated by the following quote from the American Railway Association Design Manual:

> The desirable length of the spiral for tracks … should be such that when the passenger cars of average roll tendency are to be operated the rate of change of the unbalanced lateral acceleration acting on a passenger will not exceed 0.03 g's per second. Also the desirable length needed to limit possible racking

TABLE 60.5 TGV Rolling Stock Characteristics for Southeastern and Atlantique Routes

Characteristic	Atlantique	PSE
Configuration	1-8-1	1-10-1
Seating capacity	260 coach, 108 first	369 coach, 116 first
Fleet size	95 passenger, 2 mail	105
Dimensions:		
Length	200 m	237.6 m
Width	2.8 m	2.8 m
Height	4.1 m	4.1 m
Total weight	416 tonnes	490 tonnes
Operating speed	270 kph	300 kph
Total axles	26	30
Maximum axle load	16.25 tonnes	17.00 tonnes
Total powered axles	12	8
Unsprung mass	2.2 tonnes	2.2 tonnes
Transmission type	Sliding cardan shaft	Sliding cardan shaft
Traction:		
Location	Body mounted	Body mounted
Type	DC THO 676	AC synch, 3-phase
Motor power	525 kW	1100 kW
Total power	6300 kW	8800 kW
Full-power speed range	109–175 mph	80–186 mph
Start-up tractive effort	212 KN	212 KN
Adhesion:		
At start	0.12	0.16
At full speed	0.05	0.08
Brake system	Rheostatic; disc brakes on unpowered axles; tread brakes on all wheels	Rheostatic and tread breaks on powered axles; 4 discs on unpowered axles
Stop distance from maximum speed	3.6 km	3.6 km
Suspension:		
Primary	Coil spring	Coil spring
Secondary	Coil spring	SR10 airbag
Articulation	Annular ring	Annular ring
Current collection	MADE pantograph	GPU pantograph
Truck	Y230 motorized; Y231 trailer	Y230A powered; Y237 A and B trailers
Wheel size	36 in. (920 mm)	36 in. (920 mm)
Pressure sealed	No	No

Source: Canadian Institute of Guided Ground Transport, GEC-Alsthom/SCNF TGV Baseline, draft report, Queen's University, 1992.

and torsional forces produced should be such that the longitudinal slope of the outer rail with respect to the inner rail will not exceed 1/744 (based on an 85 foot car). [62]

The formulae given to achieve these results are expressed in Eqs. (60.3) and (60.4) [62]:

$$L = 1.63 ¥ E_u ¥ V \tag{60.3}$$

$$L = 62 ¥ E_a \tag{60.4}$$

where L = the desirable minimum length of the spiral in feet
V = the maximum train speed in mph
E_a = the actual elevation in inches
E_u = the unbalanced elevation in inches

HSR track has to be able to provide accurate vehicle guidance at very high speeds and under various weather conditions, to resist static forces, to withstand extensive dynamic loading, and to minimize the

TABLE 60.6 TGV Infrastructure Characteristics for Southeastern and Atlantique Routes

Characteristic	PSE	Atlantique
Line length	258 miles	193 miles
Line configuration	Full double track	Full double track
Design operating speed	168 mph	186 mph
	Track Geometry	
Horizontal curvature:		
Minimum	10.660 ft	13.130 ft
Design	13.120 ft	20.000 ft
Vertical curvature:		
Crest:		
Minimum	39,370 ft	52,490 ft
Design	82,020 ft	82,020 ft
Trough:		
Minimum	45,930 ft	45,930 ft
Design	82,020 ft	82,020 ft
Maximum gradient	3.5%	2.5%
	Parabolic Transitions	
Maximum superelevation	7.09°	7.09°
Unbalanced elevation:		
Normal limit	0.25°31'	0.22°31'
Exceptional	0.31°31'	0.27°31'
Exceptional at 100 mph	0.48°31'	0.48°31'
Rate of variation in unbalanced elevation on transition curves:		
Normal	1.19°246'	1.19°271'
Exceptional	1.97°246'	1.97°246'
Minimum spiral length	780 ft	987 ft
Minimum separation between transitions	500 ft	500 ft
Track gauge	4 ft 8 in.	4 ft 8 in.
Distance between track centers	4.2 m	4.2 m
	Track Structure	
Rail	UIC 60 (121 lb/yd) CWR	UIC 60 (121 lb/yd) CWR
Fasteners	Nabla double-curvature steel spring, 11 KN force with deflection of 0.32 in.; 0.36-in. rubber pad with 1780 KN/in. stiffness	Nabla double-curvature steel spring, 11 KN force with deflection of 0.32 in.; 0.36-in. rubber pad with 1780 KN/in. stiffness
Ties	U41 twin block, 550-lb concrete on 26-in. centers	U41 twin block, 550-lb concrete on 26-in. centers
Ballast	Minimum ballast depth, 12 in.; clean crushed rock, with top 4 in. of hard material	Minimum ballast depth, 14 in.; clean crushed rock, with top layer of hard material
Crossovers	160-kph maximum at 25-km intervals	160-kph maximum at 25-km intervals
Turnouts	230 kph on deviated track, 270 kph on main line	230 kph on deviated track, 300 kph on main line
Signaling	Full CTC with in-cab signaling; current-coded track circuits; TVM automatic train operation system with override train braking capacity	Full CTC with in-cab signaling; current-coded track circuits; TVM automatic train operation system with override train braking capacity
Catenary	Power 2 ¥ 25 kV/50 Hz; feeder/overhead system in phase opposition; OCS has 107-mm² reinforced contact wire at 16 ft 9 in. height	Power 2 ¥ 25 kV/50 Hz; feeder/overhead system in phase opposition; OCS has 150-mm² reinforced contact wire at 16 ft 9 in. height

TABLE 60.6 (continued) TGV Infrastructure Characteristics for Southeastern and Atlantique Routes

Characteristic	PSE	Atlantique
Substations	8 single phase, 200-kV supply feed	5 single phase, 220-kV supply feed
Bridges/flyovers	540 total, longest is 10 spans covering 419 m; all bridges covering TGV line are ballast deck	328 major bridges; ballast deck as for PSE; 488 culverts
Tunnels	None	Five bored tunnels, total length 6.3 miles; tunnel cross sections: double truck: 125 mph, 441 ft^2; 168 mph, 764 ft^2; single truck: 168 mph, 495 ft^2

Note: UIC = Union Internationale de Chemins de Fer.

Source: Canadian Institute of Guided Ground Transport, GEC-Alstrom/SCNF TGV Baseline, draft report, Queen's University, 1992.

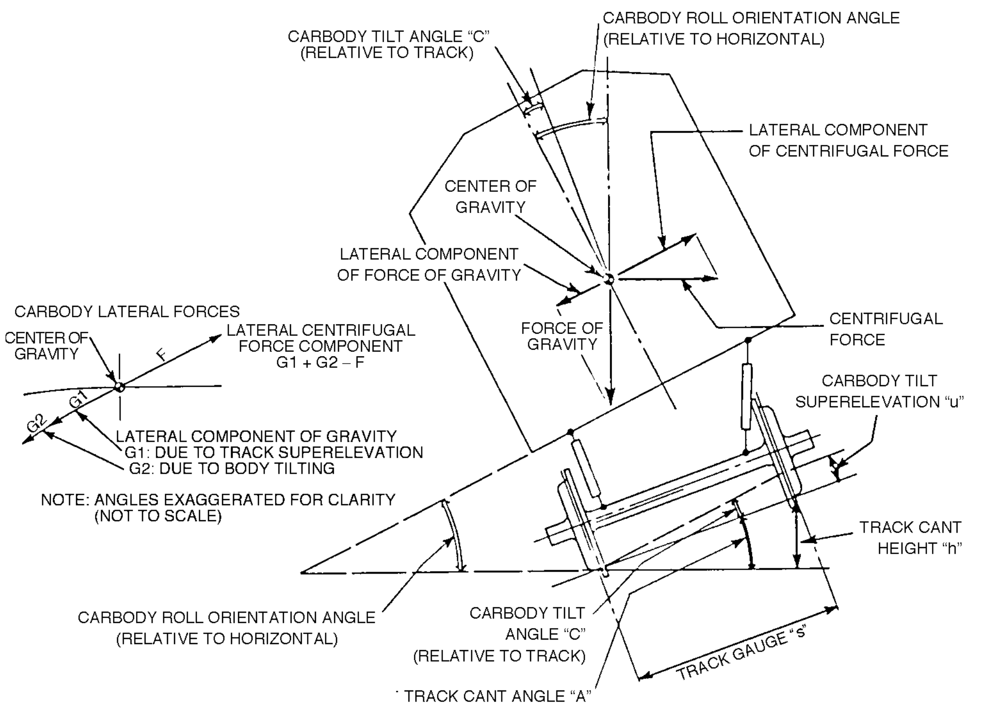

FIGURE 60.8 Effect of deliberate body tilting on forces acting on passengers. (From Federal Railroad Administration.)

transmission of vibrations and noise [63]. A typical cross section of track used for the TGV train is shown in Fig. 60.9 [16].

Track and Ties

Rail stresses associated with energy absorption depend on the elastic properties of the track as a whole [64]. In the early stages of HSGT systems, heavy rail was anticipated and a 142-pound-per-yard rail was developed. However, the development of this type of rail was proven to be unwarranted. Heavy rail may even cause problems to the elastic balance of the track due to its excessive stiffness.

In an effort to maintain the strict design requirements, the Japanese have utilized a "slab-track" design on their newer lines. This design incorporates the direct fastening, through elastometric rail fasteners, of the rail to a concrete slab. This approach is rather costly but provides some performance advantages.

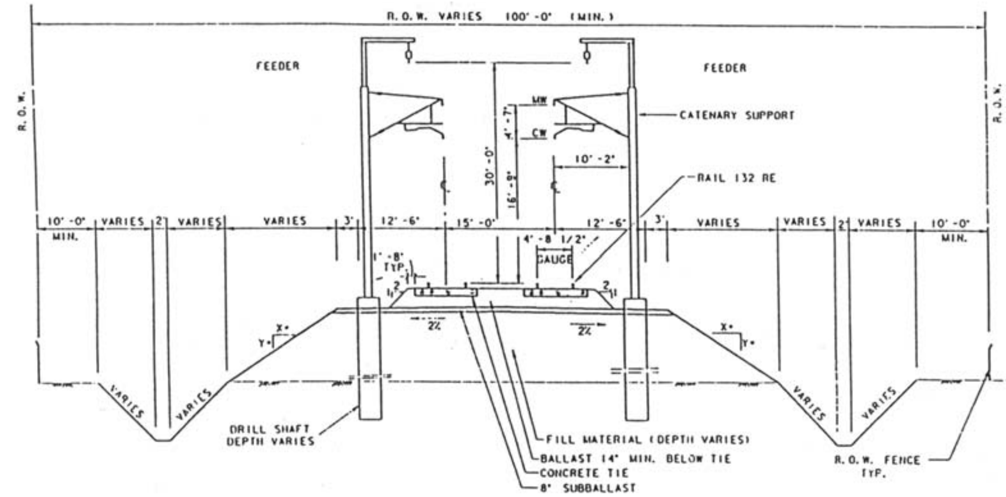

FIGURE 60.9 Cross section of track with ballast and grading. (From Texas TGV, Franchise Application, submitted to Texas High-Speed Rail Authority, 1992.)

The French maintain excellent track alignment using dual-block concrete ties and spring-clip fasteners in their conventional tie-and-ballast approach.

Both the French and the Japanese use the lightweight rail tracks (121 pounds per yard) and ties spaced 23 to 26 inches apart. The French TGV track is maintained at a level of tolerance (±0.8 inches) that is four times more stringent than presently required in the United States under FRA class 6 (110 mph) track standards [43]. The track geometry and lining are checked statistically through laser positioning systems in both countries. The French use the onboard dynamic force measurements to align their tracks over the short term and the track geometry measurements for the long term.

High-speed rail also requires the use of improved fasteners that are able to both absorb lateral stress and account for the longitudinal continuity of the rail. Elastic fasteners, which allow for the rotation of the rail around the rail base edge and which are supported by the rigid shoulder of the base plate, reflect common practice.

The weight of the ties is needed to stabilize the track, and for this reason lightweight concrete, steel, or wood ties cannot be used in high-speed rail. In France, concrete two-block ties weighing 250 kg (550 pounds), which rely on more resultant lateral area and resisted tie sides (leading to lower weight), are preferred. Unprestressed concrete blocks can lead to very economical results [43].

Ballast–Subgrade

An integral part of the system, the subgrade constitutes a significant factor to the overall track performance [16]:

- The subgrade should be constructed of materials that have an acceptable potential for shrink–swell.
- Active soils should be stabilized to reduce the potential for shrink–swell to an acceptable level.
- The shrink–swell potential should be controlled so that seasonal changes are minimized and the long-term changes are adjusted using routine track releveling procedures.

One of the main advantages of supporting the rails on the ties and rock ballast–subballast system is that grade adjustments caused by active soils can be corrected by routine releveling techniques. This is, of course, not the case for slab-track design, where periodic releveling would be extremely expensive. Further, the slab itself can increase and magnify the amount of moisture that will migrate with time beneath the slab. Where clay soils are prevalent, the subgrade will be better designed by removing the clay and replacing it with a compacted granular soil or by using in-place stabilization with materials such as liquid lime or fly ash slurry.

For the Atlantique the minimum ballast section is 35 cm of crushed rock laid in two stages beneath the ties. The ballast grading provides material 1# to 2# size. The bottom layer of normal stone is compacted and the track placed on it. The top layer of harder material is then stabilized by vibration after the track has been lifted by tampers. A sub-ballast layer separates the ballast and the subgrade materials. Prior to the record setting run in May 1990, ballast cleaning was undertaken to ensure that there were no fine materials that could be blown up by the slipstream. [46]

Catenary

The catenary system is basically state of the art, with special attention given to providing [16]

- Ample tension on the contact wire to reduce uplift, thereby improving the collection capacity of the pantograph
- A more rigid suspension system to prevent swaying in lateral winds
- Use of flattened contact wire to reduce wear on both the contact wire and the current collector
- The spacing of support poles from 30 to 70 m, depending on the mechanical requirements of the system at any given location

60.5 Track–Train Interactions

Using Existing ROW

With the difficulty in procuring large portions of new rights-of-way, in raising the new capital from private sources, and in building new infrastructure, it becomes imperative that engineers find ways of better using the existing track. The principal problems are:

- The tightness of curves built for slower trains will cause a loss of average speed and energy because of constantly accelerating and decelerating.
- The ride quality will suffer because the superelevation is designed for much slower trains.
- The track, ballast, and subgrade may not have the width to provide the lateral stability needed.
- Grade separation does not exist and will require special provision for safety.
- The change to electrification of the line will have to be accommodated.
- Access to the ROW will have to be restricted.

In any event, the roadbed will almost always require some rehabilitation and upgrading. Signaling will have to be upgraded in order to account for the higher speed. The potential of mixed freight and HSR operations may call for more siding and more frequent inspection and realignment. One solution is to depend more on the train set. The result is trains with active tilting capability.

Tilt Trains [12,32–35]

The radii for curves that will accommodate the high speeds of a TGV or ICE train are extremely high, so the use of existing track, built with tighter curves and lower superelevation for slower trains, would require excessive slowing and accelerating of a typical high-speed train. To maintain the speed on tight curves, Asea Brown Boveri (ABB), in cooperation with the Swedish State Railroads (SJ), developed a train using an active tilt mechanism. The train, known as X2000, is similar in its use of technology to FIATs, ETR 450, and 460 trains [12,35]. They are all active tilt trains. The purpose of developing this technology was to significantly reduce trip times while using conventional track.

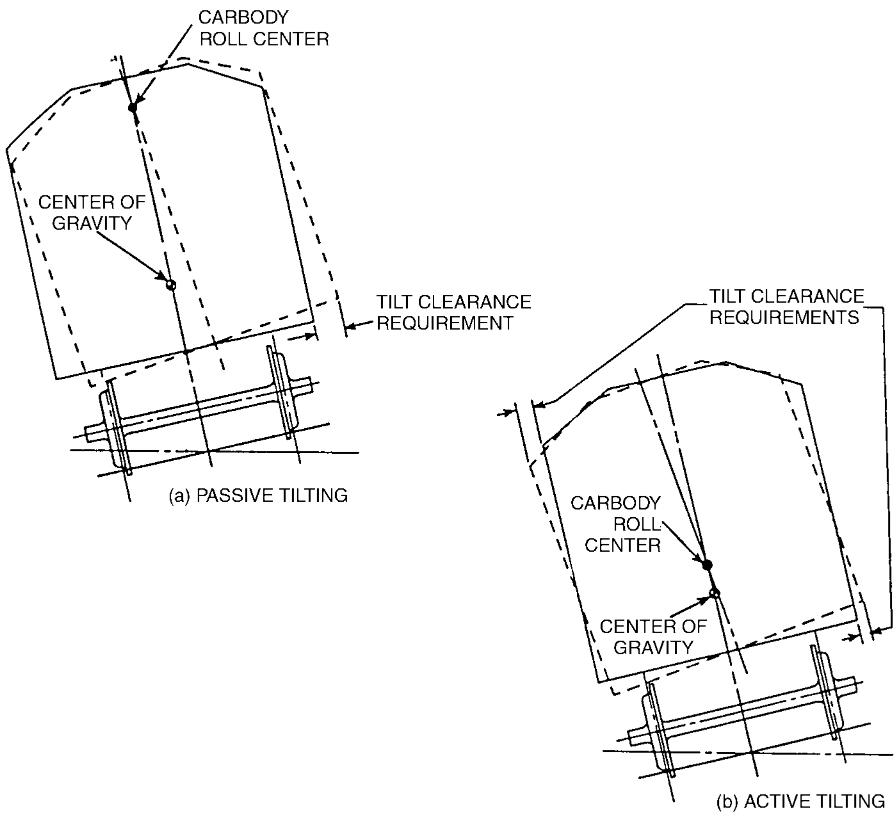

FIGURE 60.10 Location of car body roll center and center of gravity for passive and active body tilting. (From Federal Railroad Administration.)

The X2000 features a self-steering radial truck that consists of a rigid frame in which two wheel sets are mounted in parallel. As the stiff truck travels through curves, the axles remain parallel to each other, exerting forces on the rails [32]. The higher the speed for a given curve radius, the greater the tendency of the wheels in the normal truck assembly to try to overturn the rail (rollover) or to climb over the rail (climbing). The solution given by ABB was the self-steering radial truck. A soft chevron primary suspension system allows each truck to assume its natural radial position in each curve [33]. The result is a redistribution of forces exerted by the wheel sets. For example, the X2000 exerts no more force rounding a curve at 125 mph than does a regular train at 80 mph. The result of this capability is that it allows for significantly higher average speed.

The active car body tilting system, shown in Fig. 60.10, was developed mainly for passenger comfort. Along with the increase of train speeds in the curves come associated lateral forces experienced by the passengers. By anticipating each curve and causing the car bodies to tilt inward at the appropriate angles, centrifugal forces are compensated and passenger comfort is maintained. The X2000 is designed for speeds of 201 kph (125 mph) in Sweden, and it has been tested at 250 kph (156 mph) in Germany [32]. The X2000 operated in revenue service in the Northeast corridor for several months. Tilt technology is being used in several HSR trains around the world. Figures 60.11 and 60.12 show the Swedish X2000's tilt technology and operation.

Train–Track Dynamics

The design of track components, special track work, ballast, subballast, and subgrade and the acceptance of soils are controlled by the dynamic loading associated with track irregularities. Figure 60.15 shows the

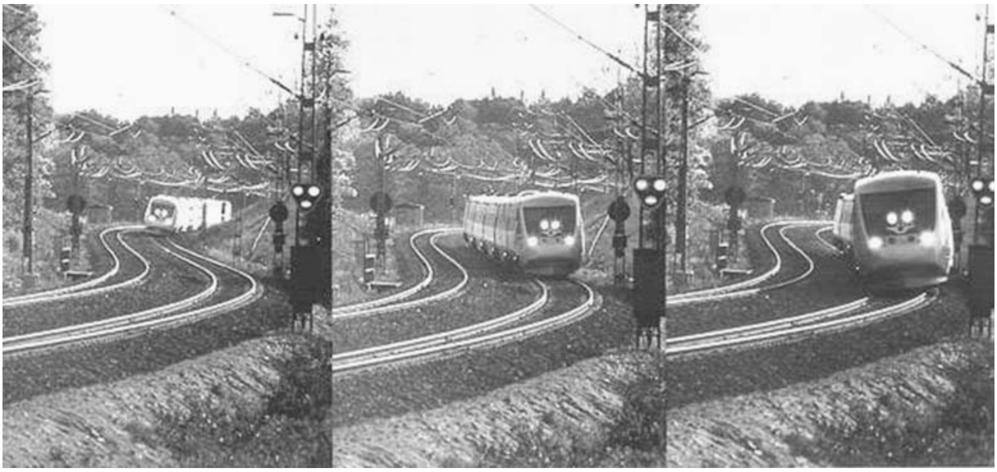

FIGURE 60.11 Swedish X2000 tilt technology. (From Railway Technology website, www.railway-technology.com.)

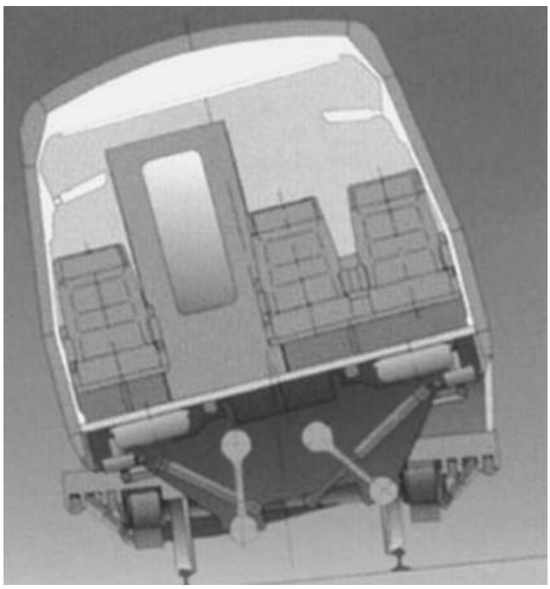

FIGURE 60.12 Swedish X2000 tilt operation. (From Railway Technology website, www.railway-technology.com.)

track–vehicle system for dynamic analysis of forces. The approach used to analyze the total vertical dynamic effects has been expressed as a function of the static loading. The total vertical dynamic impact is expressed by the coefficient I_t, as indicated in Eq. (60.5). The value of the coefficient is given with respect to the impact of the vehicle design and the impact of the track design [43]:

$$I_t = f(I_v, I_s) \tag{60.5}$$

where I_t = the dynamic impact loading factor
I_s = the factor for track stiffness
I_v = the impact factor for the vehicle design

In the early days of railroads, the vehicle component dominated the combined dynamic impacts, forcing designers to focus more on improving vehicle design rather than track irregularities. The relatively

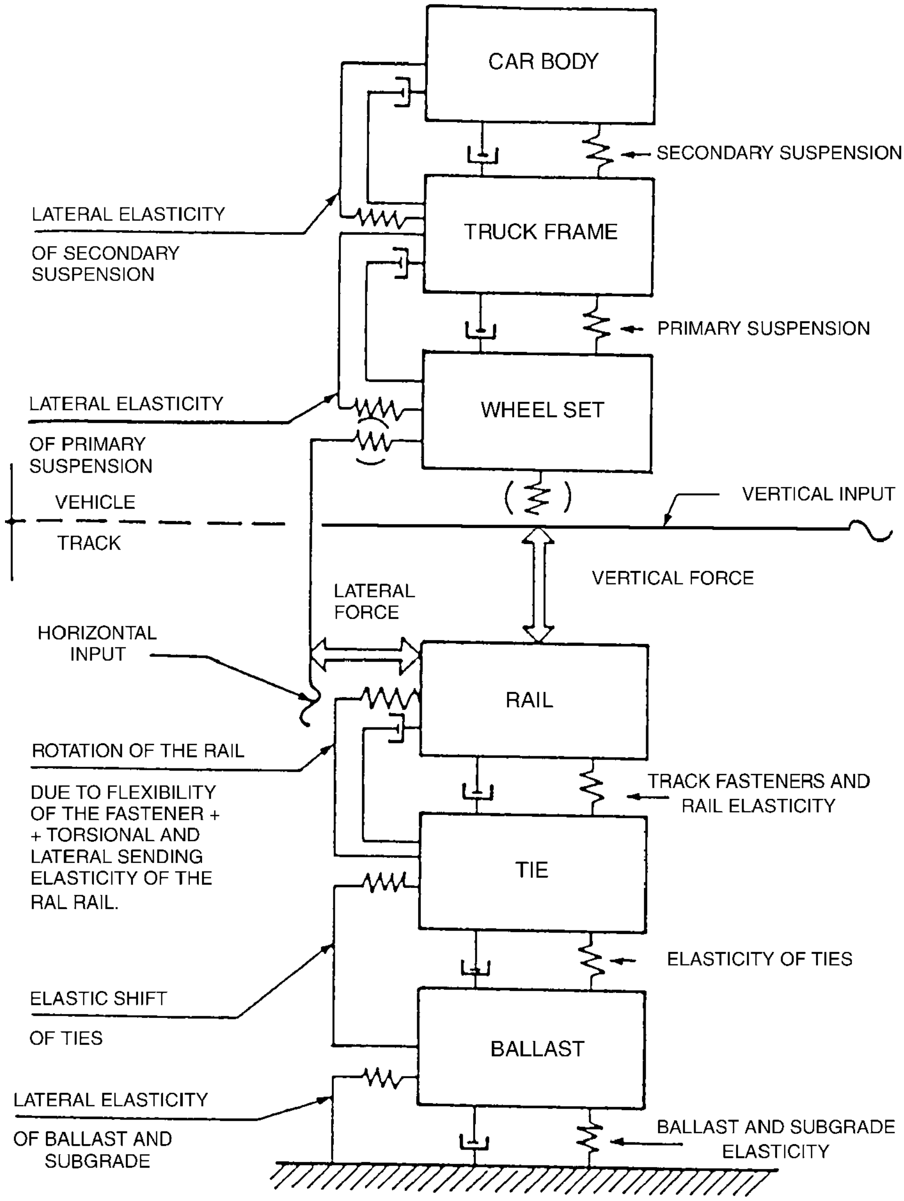

FIGURE 60.13 Track–train system for dynamic analysis of forces. (From U.S. Government Accounting Office, Report to the Chairman, Committee on Energy and Commerce, High-Speed Ground Transportation: Issues Affecting Development in the United States, House of Representatives, November 1993.)

one-sided improvement effort for vehicle design over track design through the years has shifted the effects of the two coefficients on the total dynamic loading impact. At present, the dynamic impact loading factor (I_t) is affected almost entirely by track irregularities and stiffness (I_s) of the rail, ballast, and subgrade; thus, the track tolerances are specified as tightly as possible within financially feasible limits [47]. Controlling the impact of dynamic loading is essential in HSR systems and mainly requires uniformity of subgrade.

It is clear from published track force and acceleration data derived from high speed test runs and from instrumented trainsets in commercial service that the TGV trucks are stable even at very high speed,

FIGURE 60.14 Picture of ACELA Express. (From Railway Technology website, www.railway-technology.com.)

FIGURE 60.15 The original TGV. (From Dechamps, F.)

and that the dynamic force and acceleration levels are well within limits established by SNCF. … For the December 1989 test run at 482 kph, the measured maximum vertical accelerations were 3 g to 4 g at the tie and 1 g to 1.5 g in the ballast, about the same as those measured for a conventional locomotive-hauled passenger train at 200 kph and well within established limits. Measured lateral force reached a maximum of 48 kN. In fact, the lateral resistance of the TGV track, which uses concrete ties and dynamic stabilization, is more than double the Prud'homme limit [126 kN vs. 57 kN]. [12,14].

60.6 HSR Examples Worldwide

Introduction

Unlike in the United States, where HRS implementation is still in the planning phases (except for the ACELA HSR, which started operating in 2000), in other places of the world (Europe and Asia), HSR trains are either operating or in the phase of near future implementation. Such systems will be discussed in the following paragraphs.

United States: The ACELA Express [12,20]

ACELA is the first HSR train to be used in the United States. It was because of Amtrak's efforts since 1996 to improve its operations in the Northeastern corridor from Washington, D.C., to Boston, where the company holds about 45% of the passenger market, that it was decided to put an HSR train into service. It was also decided that existing tracks would be used and that with some upgrades tilt technology would be implemented. Also, the whole corridor would be electrified (completed in late 1999). The service started operating in December 2000. The ACELA managed to cut the time from Boston to New York from 4 h 30 min to a little more than 3 h.

The ACELA train set is based on the TGV, but it is largely constructed in the United States. It was unveiled in March 1999 after a number of controversies that delayed its appearance. It should be noted that TGV technology was finally selected after examining the German ICE technology and the Swedish X2000 tilt technology. (Both train sets were demonstrated in the United States in 1993). The building of the ACELA train set started in 1998, along with the NEC modifications. As for the ACELA train set technology, it was based on used and proven technologies. The ACELA can achieve speeds of 150 mph and has a length of 202 m and a weight of 566 tonnes. Its configuration is that of 1 power car, 6 cars, and another power car, giving it the ability to carry 304 passengers. The six cars consist of one first-class car, four business-class cars, and a dining car.

The ACELA uses the third-generation TGV traction technology and tilt technology in its suspensions (up to 6.5 degrees), and it complies with the FRA's standards on possible crushes, which are the toughest around the world. For that reason, the ACELA is significantly heavier than other HSR trains worldwide (45% heavier than the TGV). The signaling and safety systems, as well as the monitoring system, are also technologically advanced, to ensure maximum safety on the existing corridor.

France: The TGV [12,14]

The TGV (Train Grande Vitesse) is the French HSR train. Since there are significant differences among the 350 train sets based on the TGV, a more appropriate term would be "a system which comprises train, track and signaling technologies that when combined, allow the train to achieve high speeds (300 kph)" [14].

TGV is owned by Societe Nationale de Chemins de Fer Francais (SNCF), the French national railways, and it is an integral part of French rail travel.

When developing the TGV, SNCF wanted a train to be able to use existing tracks on high speeds, especially in main cities, where new tracks would be difficult to construct and expensive. The first prototype of the TGV train set began testing in the early 1970s. The first line to be operated by the TGV was completed and started operation in 1981, connecting Paris with Lyon. Its success gutted the Paris–Lyon airline connection and freed the expressway connecting the two cities. The TGV became one of the few parts of SNCF that gained profit, and within ten years of its initiation, it had completely paid for itself. Since 1981, new lines have been built in France and neighboring countries. TGV Atlantique was initiated in 1989, connecting Paris with western points of France. Today there are three major lines, with Paris at their center. The most recent line connects Paris to Lille, Belgium, the Netherlands, Germany, and Britain (through the Channel tunnel). TGV technology is also applied in other countries.

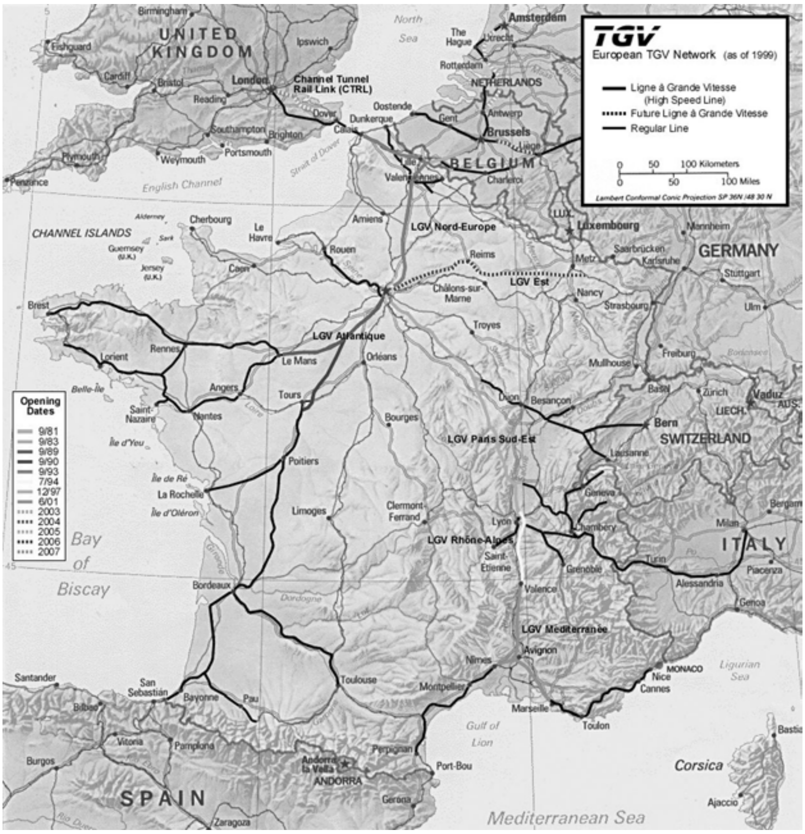

FIGURE 60.16 The TGV network map. (From French TGV web information (TGVWeb), mercurio.iet.unipi.it/tgv, Italy, 2001.)

TGV is a lightweight train. Its special placement of articulation (a truck between trailers instead of two tracks in each trailer) reduces noise, provides more space and a higher plane for the suspension, and improves aerodynamics. Some of its technological advantages are the special pantograph and the onboard signaling information (since it is impossible to watch signs next to the track when traveling at speeds of 300 kph). TGV-dedicated lines are of no special construction, just heavier ballast to hold the track and higher radii combined with appropriate superelevation. The TGV holds the record for the fastest train in the world, achieving a speed of 515.7 kph in 1990. There have been no accidents within its 20 years of operation, only the incidents mentioned earlier.

An important project linked to the TGV technology is Thalis (PBKA), a European high-speed service connecting Paris (France), Brussels (Belgium), Amsterdam (the Netherlands), Koln (Germany), and other European destinations. It is a semiprivatized commercial operation and an effort of the several railway agencies of European countries to cooperate. The project began in 1996. Trains are based on TGV technology, achieve maximum speeds of 300 kph (186 mph), and can carry up to 377 passengers. Their configuration consists of two power cars and eight trailers. Advanced technology was applied to ensure compatibility between the systems used by different countries.

Germany: The ICE [12,13]

Germany was behind other European countries in HSR up to 1992, but with the development of the ICE (Intercity Express), it managed to make up for the lost time. The first lines connected Hanover and Wurzburg, and Mannheim and Stuttgart, in 1992. Other ICE services connected Hamburg, Hanover, Fulda, Frankfurt, Mannheim, Stuttgart, and Munich in the following years. The operating speed of the

FIGURE 60.17 ICE type 1. (From Kroczek, O., 1998.)

FIGURE 60.18 ICE type 3. (From Kølher, T., 1998.)

ICE trains in these lines is 250 kph (280 kph if late). To service these lines, 60 ICE-type (ICE1) train sets were built. The train set design was updated into ICE2, ICE3, and ICE-T tilting trains. Along with the train set development, the network expanded, including East Germany lines in 1997 and destinations in the Netherlands, Switzerland, and Austria, as well as many more destinations in Germany.

ICE aimed for long-distance passengers (75 km more than the trip of an average passenger). Within its first two years of operation, the ICE brought an additional 1.3 million passengers per year. Lufthansa, the German airline, bought part of the ICE company and canceled flights within Germany, rerouting passengers to rail transportation. The ICE types 1, 2, and 3 are able to achieve speeds up to about 415 kph. They use nondedicated lines. They have electrical as well as diesel capabilities and use technology advanced over the scope of this chapter. ICE trains are serving in other places worldwide.

Japan: The Shinkansen (Bullet Train) [12,19,65]

High-speed railways were born in Japan. The Japan network has been developed over the past 37 years and covers all main routes. At the moment, the network has Tokyo as the center and lines extend to the north and west of the country. The first line to operate (Tokaido Shinkansen) was the Tokyo–Osaka line in 1964, at a speed of 200 kph, later increased with improvements in the infrastructure, signaling, and

FIGURE 60.19 Shinkansen type 100. (From Fossett, D.A.J.)

FIGURE 60.20 Shinkansen type 700. (From Fossett, D.A.J.)

maintenance. In 1972, the second generation of bullet trains was introduced, connecting Shin-Osaka and Okayama, to be extended 3 years afterward to Hakata. The north of the country operated its first Shinkansen in 1982, to Morioka (Tohoku Shinkansen) and Niigata (Joetsu Shinkansen). Further expansions northbound were made in the following years. In 1987, the Japanese National Railways were privatized and separated into two companies, JR West and JR Central. At the moment, Japan has more than 1500 miles of HSR-dedicated lines. The Japanese HSR serves around 400,000 passengers daily and has an on-time arrival record of 99% [24].

There have been several models of the Shinkansen in the 37 years of its service (0, 100, 300, 500, and variations). Trains use dedicated lines in high speeds (operating at around 300 kph). The Shinkansen trains have shown higher levels of safety than any other transportation mode. Of the train sets, the more advanced is the 500 series Nozomi that, according to its builders, achieves an excellent balance of train performance, passenger comfort, and environmental friendliness. The Nozomi is capable of operating at a speed of 300 kph and carrying approximately 1320 passengers, more than two times the passenger-carrying capability of a Boeing 747-400 airplane.

As for the Shinkansen's market success in Japan, the first line between Tokyo and Osaka (320 miles) is a bright example. The Shinkansen has captured around 80% of the market of trips between the two cities. The line was built on a complete grade-separated line and exclusive ROW. Sixty-six tunnels and more than 3100 bridges were built to facilitate the ROW.

Other Examples

Based upon the TGV, ICE, and Shinkansen models, other countries have or are developing at the moment HSR networks worldwide:

- Spain uses the AVE HSR network [12], which during the 1990s linked key cities of the country. The first link connected the 417-km distance between Madrid and Seville (since Seville was hosting the World Expo in 1992 and was also a popular destination for French visitors). Soon, links to Barcelona and the French border were constructed, stretching to other cities, as well. The Spanish HSR trains are close relatives of the TGV, offering high-quality services to their passengers to withstand the intense competition with airlines on the same routes. In addition to the AVE, Spanish Railways (RENFE) introduced in 1999 tilting trains (which have a different gauge than the AVE) in the existing and busy route between Madrid and Valencia. ETR 460 Italian-type trains are used, with a configuration of two power cars and a single trailer, being able to carry 160 passengers. These trains have a maximum speed of 220 kph and travel the distance of 489 km between Madrid and Valencia in 3 h 15 min.
- The Eurostar Italia is the HSR's latest generation of Italy's rail [12]. It is serviced by the ETR 500 nontilting high-speed train. Three routes have been upgraded: the Bologna–Firenze route, the Rome–Naples route, and the Milan–Bologna route, allowing ETR 500 train sets to achieve speeds of 300 kph. The train sets are operating around routes that connect Italy's fastest-growing cities, like Rome, Naples, Florence, Bologna, Genoa, and Venice, where more than 50% of the country's population lives. The ETR 500 is a 13-vehicle unit that can accommodate 590 passengers and can achieve a maximum speed of 300 kph. There are 60 train sets programmed to service the routes, more than half of which were built in 2000. The ETR 500 has automatic control and protection systems and provides and offers extended services to its passengers.

FIGURE 60.21 AVE picture. (From AVE web page, http://mercurio.iet.unipi.it/ave.)

- In China the largest engineering project at this time is the HSR connection between the two largest cities of the country, Beijing and Shanghai [12]. The distance between the two cities is 1307 km, and the separate corridor is expected to boost growth to the rest of the country. The corridor will be operating at 350 kph. Two-thirds of the corridor will be on embankments, while the rest will be mostly bridges. Chinese construction train sets will be used for the project.
- VIA rail, Canada's national rail corporation, found that high-speed rail is technically feasible, is financially attractive, and can result in significant user benefits. Three corridors (Quebec City–Windsor, Montreal–Ottawa–Toronto, and Toronto–Windsor) were examined regarding their HSGT system potential, but only the Quebec City–Windsor corridor seemed promising. This corridor is about 700 miles long and contains a population of 15 million, which is approximately half of Canada's population. In this study VIA indicated that high-speed rail can succeed in capturing sufficient ridership in the medium distance (250 to 350 miles) if it offers door-to-door times that are comparable to that of air transport.
- Other projects like TGV Korea plan to connect Seoul with Pusan with HSR TGV technology [12,14]. The Taiwan HSR project will link the two ends of the island with trains traveling at 300 kph, using hybrids of both TGV and ICE technologies [12] on a corridor of 345 km, almost completely through tunnels and viaducts. The Swedish network is based on the X2000 tilting trains that operate at 200 kph and the Arlanda Express, which operates at the same speeds. The Australian HSR (Speedrail) project, connecting Sydney and Canberra with TGV technology trains moving at 320 kph, is expected to be completed in late 2004 [12] and later expanded to other cities of the country [12].

60.7 Magnetic Levitation Technology

Using magnetic levitation for suspension and propelling by means of electric fields is one technology that has been considered as a replacement for the conventional steel-wheel-on-steel-rail technology. The technology is referred to as MAGLEV [1,66–70]. Without the friction, higher speeds are possible, but the system requires a specially designed guideway, often elevated. The "father of electromagnetic levitation," Herman Kemper, began his research on the subject in 1922, with a basic patent granted in 1934 [1]. The patent was proof of magnetic levitation and resulted in a model that could carry a load of 450 pounds. The research on magnetic levitation and its application to passenger transport have come a long way since, with the German government initiating an in-depth examination of the feasibility, safety, and planning issues of such a system in the 1970s [66,69,70]. At about the same time, the Japanese National Railways started conducting their own research at RTRI.

The German study pointed out that MAGLEV technology could be very successful, in terms of passenger traffic, for medium- and long-distance routes [1]. Planners have calculated that the construction cost of a MAGLEV system would be about 30% higher than that of the steel-wheel-on-steel-rail system. Germany took a careful look at the prospect of initiating a MAGLEV line at the Hamburg–Berlin route to accommodate the considerable increase in passenger traffic due to the 1991 unification of Germany. It is worth noting that the interest from the industry in MAGLEV technology was such that private capital would be incorporated into the public infrastructure through the construction of the MAGLEV line. The name of the train set, which was further developed in the following years, was Transrapid [1]. The project was expected to be completed in 2006. After quite a few drawbacks and problems in the financial viability of the project and lack in political will to implement it (despite the continuous technological advancement of the MAGLEV train set), the project was canceled in February 2000, only 6 months before its construction was supposed to begin. The alignment would have consisted of a 292-km double track (55% at grade, 45% elevated), 5 stations, and 11 propulsion system substations. At the time, within Germany, five new projects are being examined and feasibility studies are being conducted. The final decision will be taken in late 2002. Meanwhile, the eighth generation of Transrapid carried around 50,000 paying passengers to visit the World Expo 2000 Exhibition in Hanover. Transrapid

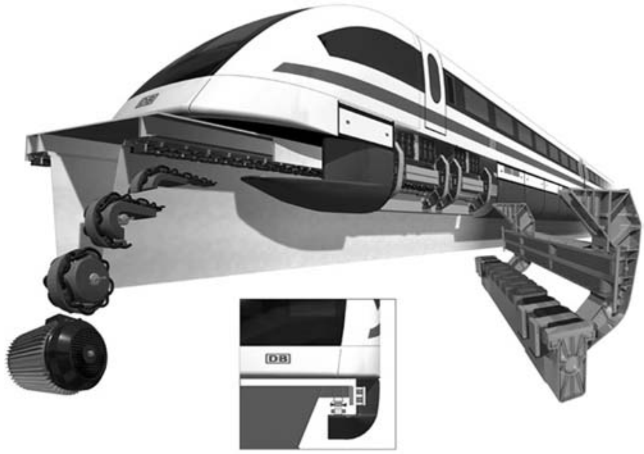

FIGURE 60.22 Transrapid figure and technology. (From Transrapid website, www.transrapid-international.de/en, Germany, 2001.)

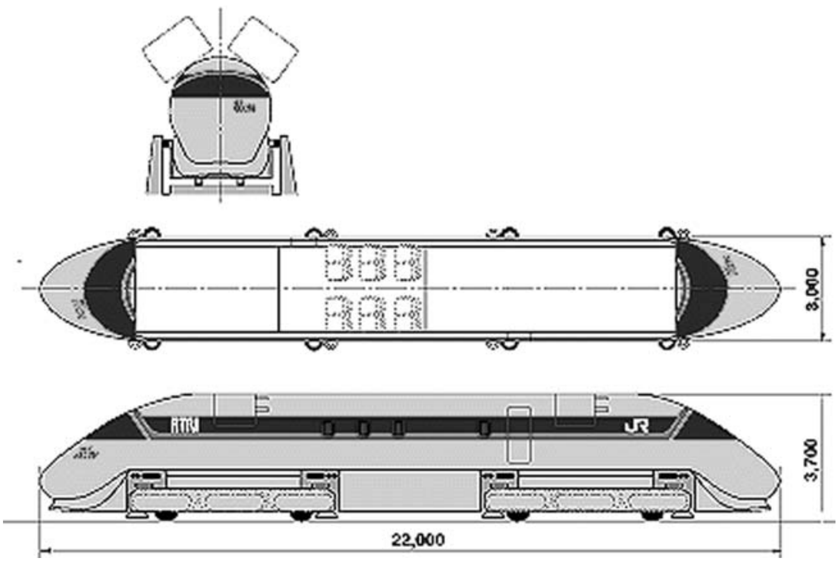

FIGURE 60.23 MLU design. (From RTRI.)

feasibility and implementation studies are also being conducted around the world. The first project to be completed in a few years is the connection of the Shanghai Airport with Shanghai, China. The Chinese are also considering construction of MAGLEV lines from Shanghai to Beijing (1307 km) instead of applying an HSR corridor of the conventional type. In the United States, TEA 21 will be funding feasibility and implementation studies of the Transrapid in the California–Nevada (Las Vegas–Barstow–Ontario County, California North–South), Florida (Orlando–Port Canaveral), Pennsylvania, and Baltimore–Washington, D.C., corridors.

As for Japanese MAGLEV trains, called MLU [74], the Japanese have been testing them and developing their technology from time to time. The only track existing in Japan is a 7-km test track. The latest MLU vehicle (five cars) managed to achieve a speed of 552 kph (manned vehicle) in the test track in April 1999 [67].

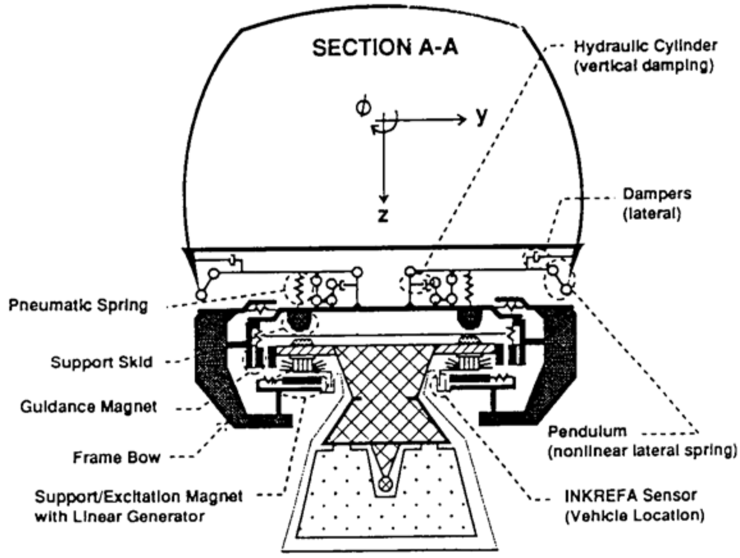

FIGURE 60.24 Transrapid TR-07 MAGLEV train. (From Galanski, R.A., Safety of High Speed Guided Ground Transportation Systems: Collision Avoidance and Accident Survivability, DOT/FRA/ORD-93/2.III, March 1993.)

FIGURE 60.25 Transrapid track. (From Transrapid website, www.transrapid-international.de/en, Germany, 2001.)

MAGLEV technology differs significantly from that of steel-wheel-on-steel-rail. The Transrapid (the name of the German MAGLEV system) vehicles are magnetically levitated and guided within a guideway, as shown in Fig. 60.26. They are propelled by synchronous linear motors along a guideway. Levitation forces are generated by magnets on the undercarriage, or levitation frame, below the guideway beam. Guidance magnets are also mounted on the undercarriage but face the outer edges of the guideway, thus keeping the vehicle aligned with the guideway. Each car has a series of levitation frames, which align magnets and carry the levitation and guidance forces to the car body through pneumatic springs and links. When the levitation magnets are energized, the vehicle is lifted toward the guideway [67]. The

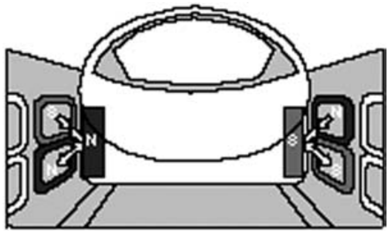

FIGURE 60.26 MLU track. (From RTRI.)

magnets are energized with power provided by onboard batteries. The batteries are charged when the vehicle is moving at speeds greater than 75 mph.

Guideway shape is the main difference between German Transrapid and Japanese MLU. While Transrapid wraps around a T-shape beam (making it almost impossible to derail), MLU fits into a U-shape beam, moving along this U-shape channel [1,74]. Figures 60.25 and 60.26 show the two different guideways.

Guideway structures are made of steel or prestressed concrete beams. They can be elevated on piers up to 65 ft, or they can be elevated up to 130 ft with the use of special structures. A ground-level guideway is used in tunnels or in areas where an elevated guideway is undesirable. The switches, used to divert vehicles to different branch lines, are steel bending beams aligned elastically by a series of electromechanical or hydraulic actuators. This type of construction allows for a smooth ride during the switch, while switches with radii of 7500 ft allow for speeds of 125 mph in the branching position.

The accuracy of the guideway in the high speeds that the MAGLEV vehicles reach is extremely important. Accuracy and stability are achieved with the use of automated production techniques and construction of the piers and the foundations to appropriate specifications. The system is operated automatically, and its monitoring is achieved with the use of fiberoptic wave transmission between the vehicle and a central control center.

The MAGLEV system is not directly damaging to the environment, since it is electrically propelled and emits no pollutants. Any pollution caused by MAGLEV technology is the indirect effect of the power stations supplying the electric energy necessary for the system. The electromagnetic system necessary for the vehicles' propulsion, with magnets located beneath the guideway, results in minor magnetic fields in the vehicles or in the vicinity of the vehicles (10 to 30 milligauss at sea level) [67,68].

The MAGLEV vehicles reach speeds of 250 to 300 mph, making safety a critical consideration. MAGLEV vehicles "wrap" around the guideway, essentially eliminating the danger of derailment. The automated operation and control minimize possible "driver error." Furthermore, the fully separated guideway provides a natural barrier, preventing most types of conflict. The vehicles' interior is designed to meet the fire protection standards set by the 1988 Air Transport Standards Act [70–73]. Noise has been studied, and since the MAGLEV trains are elevated and there are no outside connections with the guideway, they are very quiet [73].

Several sites in the United States have been examined for the possible implementation of a MAGLEV system, yet only the successful operation of a revenue system would prompt further development. On June 12, 1991, Florida certified the Orlando-based MAGLEV Transit, Inc., to construct and operate the first commercial system, based on MAGLEV technology, in the United States. The 14-mile track is to provide access from the airport to the Orlando tourist district. It is anticipated that the system will carry approximately 8 million passengers per year, at a top speed of 250 mph. It is also planned that arriving baggage will be checked through to the terminal at the tourist district [66].

In 1998, Congress passed the Transportation Equity Act for the 21st Century [75]. Section 1218 of this act is about creating a magnetic levitation transportation technology deployment program. The Transportation Equity Act provides federal funding of $55 million for planning studies and another $950 million for construction. According to the act, each state or company that starts such a project should finance the project with one-third to two-thirds of federal money. The proposed projects should be able to show that they will be economically viable for a period of 40 years to be eligible for federal funding. Rules and technical details were later issued to guide potential projects.

MAGLEV systems are convenient and attractive for development in that they offer a comfortable, environmentally safe, and very fast mode of transport. On the other hand, both the supporting structures and the equipment needed for electromagnetic levitation and propulsion are very expensive. This, along with the continuing concerns for safety, makes the use of such technology problematic.

60.8 Conclusions

Plans to introduce HSGT systems have been proposed for several corridors in the United States and are shown in Fig. 60.4. Two key issues that must be addressed before any project moves ahead are the adequacy of the cost-benefit analyses and identifying mechanisms to adequately fund the high-speed systems.

Questions often asked in terms of the adequacy of the cost-benefit analyses are:

- Is the HSGT system feasible from both the engineering and socioeconomic perspectives?
- Where will the market share for HSGT systems come from? Will travelers shift from existing modes of travel — automobile, mass transit, and aviation? How much? How often? What will be the impacts of this shift in mode of travel?
- Will the new system provide benefits that cannot be obtained from the existing infrastructure? Will the attracted ridership optimize revenue generation adequately so that operating expenses can be covered in the short run and ultimately provide for system profitability?
- Can the system obtain the necessary approvals and permits from the regulatory and other agencies in a timely manner? Table 60.7 summarizes the major approval requirements before the HSR system can begin construction. A portion of the process for new corridors will involve solving the severance problem.

The primary issue that must be resolved before HSGT systems can be developed in the United States is project funding [5–12]. The past policy has relied heavily on the private sector or user fees to develop many of the transportation systems in the United States, yet little private investment is likely for HGST without substantial federal government support. Private investors may fear that passenger demand will be overestimated and the fares collected will not cover costs (as happened in the Florida case). There is also the concern that other emerging technologies, such as tilt-rotor aircraft and videoconferencing, may

TABLE 60.7 Major Approval Requirements for HSGT Systems in the U.S.

Level of Government Approvals	Conceptual Approvals	Detailed
Federal	Environmental assessment section 4(f): Recreation impact statement Environmental impact statement	Joint use of highways Dredge and fill/(404) wetland permits Coast guard permit(s) Other federal permit(s)
State	Franchise certification Environmental certification Financing project	Dredge and fill Storm water discharge Water quality certification Historic and archaeological Other permit(s) Financing package refinement
Local	Local government comprehensive plans Environmental or community impact statements	Noise ordinances Zoning Other local approvals

Source: Mudd, C.B., Local, State, and Federal Approvals in Developing High-Speed Rail Systems, paper presented at First International Conference on High-Speed Ground Transportation Systems I, 1992, p. 648.

compete successfully with other forms of intercity travel, including HSR. The failure of the Texas High-Speed Rail Authority to raise the necessary funds to continue the Dallas–Houston–San Antonio work is testimony to the critical nature of funding.

It is also a fact that, unlike in the United States, in Europe and Asia the public sector is willing to finance such projects, despite the fact that they may not be cost effective, since serving the passengers is considered more important than obtaining surplus from the service. This is a strong reason why HSR funding is easier in Europe than in the United States, where it is likely that the private sector with little incentive on its own will assume a major share of the risks associated with financing the HSGT development. For the HSGT systems to be developed in the United States, the federal government will have to assume a substantial portion of the risk, making the private investment through some sort of partnership arrangement possible.

With over 30 years of experience in France, Japan, and Germany, HSGT is a mature useful technology that could meet a number of U.S. needs. There is a substantial interest in HSGT systems because they provide a cost-effective means of intercity travel endorsed and widely accepted by the passengers (as proven in the many countries where HSGT systems have been operating for many years), because they are an environmentally safe alternative, and because they can be a safe alternative to the capacity limitation, winglock, and gridlock surrounding the nation's busiest airports.

The vast area of the United States makes it unlikely that the HSGT systems will have similar success to the ones developed in Europe and Japan, unless a major and lasting oil crisis increases the price of gasoline to such a magnitude that the extensive use of the automobile is shaken. However, HSGT systems can efficiently and successfully serve corridors between markets that are located 200 to 500 km apart. These cities reflect long travel time for automobiles and are too close for anything more than commuter air travel. Further, the business is often in the city center, making an additional, often tedious trip from the airport on the outskirts of the city. In addition, after the tragic terrorism incidents of September 2001 in New York and Washington, D.C., where domestic airplanes were used as bombs, and the serious crisis affecting major U.S. airlines afterwards, the HSR seems a fine alternative because of the capability of minimizing risks in case of terrorism acts (only the HSR train can be harmed, not its surrounding environment) and of the safety feeling it creates (after all, it is moving on the ground).

The HSGT will succeed only when the United States embraces the technology developed and used by other countries and is willing to spend the money for the sizable investment in the infrastructure. It is one viable transportation mode that fits squarely into the unique market of intercity travel.

Terminology

Many abbreviations are in common use for railroad organizations and high-speed rail systems and their components. Note that some abbreviations, particularly those used for different control systems (ATC, ATCS, ATP, etc.) may not have the same meaning for all users. The commonly accepted meanings are given.

AAR	Association of American Railroads.
ASTREE	Automatization du Suivi en Temps (French onboard train control system).
ATC	Automatic train control. Systems that provide automatic initiation of braking or other control functions. ATP and ATO are subsystems of ATC.
ATCS	Advanced train control systems. A specific project of the AAR to develop train control systems with enhanced capabilities.
ATO	Automatic train operation. A system of automatic control of train movements from start to stop. Customarily applied to rail rapid transit operations.
ATP	Automatic train protection. Usually a comprehensive system of automatic supervision of train operator actions. Will initiate braking if speed limits or signal indications are not obeyed. All ATP systems are also ATC systems.

AWS	Automatic warning system. A simple cab signaling and ATC system used on British Rail.
BART	Bay Area Rapid Transit (San Francisco).
BN	Burlington Northern Railroad.
BR	British Rail.
CalHSR	California High Speed Rail.
CFR	Code of Federal Regulations.
CPU	Central processing unit (core unit of a microprocessor).
DB	Deutsche Bundesbahn — German Federal Railways.
DIN	Deutsche Institut for Normung — German National Standards Institute.
DLR	Docklands Light Railway, London, United Kingdom.
EMI	Electromagnetic interference. Usually used in connection with the interference with control circuits caused by high-power electric traction systems.
FCC	Federal Communications Commission (United States).
FRA	Federal Railroad Administration of the U.S. Department of Transportation.
FTA	Federal Transit Administration.
HSGT	High-speed ground transportation.
HSR	High-speed rail.
HST	High-speed train — British Rail high-speed diesel–electric train set.
ICE	Intercity Express — German high-speed train set.
ISO	International Standards Organization.
Intermittent	A term used in connection with ATC and ATO systems to describe a system that transmits instructions from track to train at discrete points rather than continuously.
JNR	Japan National Railways. Organization formerly responsible for rail services in Japan. Reorganized as the Japan Railways (JR) Group on April 1, 1987, comprising several regional railways, a freight business, and a Shinkansen holding company.
JR	Japan Railways.
LCX	Leakage coaxial cables. LCX cables laid along a guideway can provide high-quality radio transmittion between the vehicle and wayside. LCX is more reliable than airwave radio and can be used where airwaves cannot, for example, in tunnels.
LGV	Ligne a Grand Vitesse — French high-speed lines. See also TGV.
LRC	Light, rapid, and comfortable. A high-speed tilt-body diesel–electric train set developed in Canada.
LZB	Linienzugbeeinflussung. Comprehensive system of train control and automatic train protection developed by German Federal Railways.
MAGLEV	Magnetic levitated train system.
MARTA	Metropolitan Atlanta Rapid Authority.
MLU	Japanese experimental MAGLEV technology train system.
MU	Multiple unit. A train on which all or most passenger cars are individually powered and there no separate locomotives used.
NBS	Neubaustrecken — German Federal Railways high-speed lines.
NTSB	National Transportation Safety Board (United States).
PATCO	Port Authority Transit Corporation (Lindenwold line).
PSE	Paris Sud-Est. The high-speed line from Paris to Lyon of French National Railways.
RENFE	Rede Nacional de los Ferrocarriles Espanoles — Spanish National Railways.
SBB	Schweizerische Bundesbahnen — Swiss Federal Railways.
SELTRAC	Moving-block signaling system developed in Alcatel, Canada.
SJ	Statens Jarnvagar — Swedish State Railways.
SNCF	Societe Nationale de Chemins de Fer Francais — French National Railways.
SSI	Solid-state interlocking.

TGV	Train Grande Vitesse — French high-speed train. Also used to refer to French high-speed rail system.
TRANSRAPID	Japanese experimental MAGLEV technology train system.
UIC	Union Internationale de Chemins de Fer.
UMTA	Urban Mass Transportation Administration of the U.S. Department of Transportation. The name of this agency has been changed to the Federal Transit Administration (FTA).
VNTSC	Volte National Transportation Systems Center.
WMATA	Washington Metropolitan Area Transit Authority.

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