Chapter 2

HIGH-SPEED RAIL TECHNOLOGIES AND FOREIGN EXPERIENCE

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HIGH-SPEED RAIL TECHNOLOGIES AND FOREIGN EXPERIENCE

In this assessment, a high-speed passenger rail system is defined as one that can attain speeds of 125 mph or more. With the exception of the Northeast Corridor (NEC) in the United States where trains now achieve speeds of 120 mph on some parts of its right-of-way, all development and use of these systems has occurred abroad. This chapter examines the high-speed rail operations of foreign countries and, on the basis of that analysis, describes the technology options for high-speed rail service, and the various conditions that may make one option more attractive than the others.

SUMMARY

The technological options for high-speed rail service include combinations of equipment, track, and power systems. Two of the equipment and track options—conventional equipment on upgraded track, and state-of-the-art equipment on new track or on partly new track—are now employed in the regular high-speed passenger rail service offered by Great Britain, Japan, and France. Advanced technology (tilt-body equipment) on existing track is being actively pursued by Britain and Canada, but is not yet fully developed or implemented. The final equipment, track, and power option—the ultra-high-speed mode, magnetic levitation (maglev)—is still in the developmental stage in West Germany and Japan. Of the propulsion system options, either diesel or electric are used on all state-of-the-art trains. A brief discussion of each of these technology options is presented below.

Equipment and Track Options

Improved Conventional Equipment Run On Upgraded Existing Track (Great Britain, United States, Canada)

This least-cost option uses conventional equipment at a maximum speed of 125 mph on existing track shared with freight and/or commuter trains. Foreign experience, particularly in Great Britain, shows that such equipment can run comfortably and safely at speeds of 125 mph. Grade crossings usually are eliminated on high-speed sections. Stringent safety precautions are required where freight shares the high-speed route with the passenger trains. Frequencies of service are contingent on coordination with freight and commuter services and are adversely affected when the speeds of each service differ widely.

New technology applied to vehicles and signal and control systems make faster trips possible on existing track. At speeds of more than 125 mph, however, automatic speed controls are desirable as are technologies that reduce weight and pressure on the track. Where speeds are limited by curves, the use of tilt-body vehicles (if further developed) might improve trip times. Above 125 mph, complete grade separation is essential, and, on the high-speed sections, tracks cannot be shared with other types of trains.

State-of-the-Art Equipment, Partly or Totally New Track (France, Japan)

Where speeds substantially above 125 mph are desired, dedicated track becomes essential. The equipment must be designed to new and more stringent specifications to keep the ride quality and the forces exerted on the track within the proper limits. Lightweight materials, new and sophisticated signaling, and train control systems are required, and radii of curves must be increased. For relatively small changes in elevation en route, heavier gradients can be used to reduce the need for expensive viaducts and cuts.

This option technically allows for design speeds up to 200 mph on new track between cities, though lower speeds typically are used in revenue service. The French avoided the major capital expenditure of new track into city centers at the cost of lower speeds (125 mph maximum) at each end of the trip. The Japanese, because of overcapacity on existing lines and unsuitable track gage, constructed totally new track for their bullet train.

Very High-Speed New Modes—Maglev (Developmental: West Germany, Japan)

Maglev is the only new surface mode for high-speed intercity transport still in the development stages. Speeds in excess of 250 mph are possible using such systems. The Japanese have tested an experimental vehicle at 320 mph. The West Germans are beginning final testing of their maglev vehicles this year. Theoretical operating costs for a maglev system have been projected to be lower than those of a conventional new high-speed railway corridor, however, verification of operating costs under conditions that fairly reflect revenue service await test results.

Maglev would be competitive with air travel from station to station on routes characterized by high population densities at one or both ends, "travel affinity" between the cities, and long distances between stops.

Propulsion System Options

Diesel Power

The diesel power unit carries its own primary power supply (the diesel engine) with fuel for 1,000 miles or more. It uses an onboard generator to provide electric power to motors that drive the axles of the power car and to provide heating, cooling, ventilation, and lighting. Although limited in size and weight, the diesel-powered train is very flexible and can be moved around the system as traffic needs dictate. Nevertheless, a design speed much higher than 125 mph is regarded as impractical by engineers because of power constraints inherent in diesel traction.

Electric Power

Electric locomotives basically are simpler, lighter in weight per horsepower, and cheaper to maintain than diesel locomotives. They make it possible to use at least twice as much power continuously as a diesel locomotive, with a significantly higher short-term power output and acceleration rate, as well as improved braking. However, the necessary overhead power supply installations and substations are very expensive, and existing signaling systems usually require renewal to prevent magnetic interference from the traction system. Replacement of signaling systems also is required to accommodate safe train spacing at higher speeds. To transfer the amount of power needed, high voltage systems are a necessity, usually by means of an overhead power supply. Whatever traction is used, as speed increases, unsprung axle load* must be kept to lower values to avoid too great an impact on the track and vehicle. Unsprung axle load can be reduced by suspending heavy electric motors on the truck above the primary springs or on the vehicle body itself with flexible drive. Total weight on each axle also is important and must be reduced as speed increases to ensure good ride quality.

Gas Turbine Power

While gas turbine power units offer the advantages of rapid power buildup and are very lightweight, the escalating fuel costs in the 1970's and the engine's lower efficiency except at full power led to the virtual abandonment of this technology. ** Turbotrains, which use gas turbine engines, are run routinely from Buffalo to New York.

Linear Motors

To date, electric propulsion has used rotary motors carried on the train. With linear motors, the magnetic parts of the conventional rotating motor are replaced by a passive element on the vehicle and an active element in the track that interact to accelerate, maintain speed, or decelerate the train. Problems of power transmission and wheel to rail adhesion may be reduced by linear induction motors (LIMs). The first commercial installations of LIMs (noncontact propulsion) for

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● Unsprung axle load is the weight not supported by springs, and therefore in immediate contact with track structure. This type of contact will result in higher impact loads for the same weight because of the absence of a cushioning effect of the springs.

● *However, the French National Railways (SNCF) still operates a few trains at 100 mph maximum speed.

revenue operation are under construction now as *low-speed* transit lines in Toronto, Vancouver, and Detroit.

Maglev vehicles use linear motors for noncontacting propulsion. A variety of such motor types have been developed and tested with maglev vehicles; however, only the *linear synchronous motor (LSM) currently is being developed for high-speed applications.* While the principle of linear motors is simple, maglev requires a sophisticated power conditioning and distribution system to control the proper amount and frequency of electrical power for propulsion.

Comparison of various propulsion system options, indicates that diesel power is flexible and does not require a large capital expenditure for fixed installations for power supply. However, it limits train size and speed. Electric propulsion depends on expensive fixed installations but offers much higher power to weight ratio and thus larger and faster trains. For frequent service, it is simpler and cheaper to operate than the diesel and does not necessarily depend directly on oil as fuel. Gas turbine power has been discarded because of high fuel consumption and maintenance cost. LSMS for maglev systems theoretically offer very high speed at reduced costs but require new guideway construction, and sophisticated power conditioning systems.

Foreign Experience

France, Great Britain, and Japan now operate rail services at 125 mph and above. However, each country tailored its system to its own unique demographic and transport needs and to its geography. Consequently, significant differences exist among these three high-speed passenger rail systems.

France uses existing track into and out of Paris and Lyon and new track between the population centers and state-of-the-art vehicles that were developed jointly by French National Railways (SNCF) and French manufacturers. The equipment is being used on other routes as well. The French system, TGV (Train a Grand Vitesse), has exceeded 200 mph in test runs. In actual service, its top speed initially was restricted to 160 mph, though it was recently increased to approximately 170 mph.

Great Britain uses conventional equipment (diesel- and electric-powered lightweight trains) on *existing track* at maximum speeds of 125 mph. The British decided not to build new track because of projected high costs and probable opposition on environmental grounds. Great Britain and Canada also are developing separate versions of tilt-body equipment, designed to improve train speeds on curves through the use of tilt mechanisms. Viable commercial application of tilt-body equipment is still in question.

Japan's Shinkansen bullet train system uses *state-of-the-art equipment on completely new track.* The trains are designed for speeds of 160 mph, although they currently are operated at 131 mph. The original Tokyo-Osaka bullet train was built to alleviate the overload on the existing rail route and to meet new traffic demand. During the first 5 years of operation, ridership increased substantially. Later, additional extensions and routes were built. Because population densities are lower in the areas served by the newest routes, the ridership is less, and train numbers and sizes are smaller. Economic success is likely to be more difficult to achieve with the recent lines.

The French, British, and Japanese vehicles all could be adapted for suitable existing track in the United States, although the TGV and Shinkansen vehicles cannot operate at full design speed without new track and signaling equipment. The Japanese built entirely new track, in part, because they could not interrupt service on their existing lines. With the new right-of-way, they also reduced the number and degree of curves and built a wider (standard) gage, rather than the narrow gage used by the rest of the system. The French and British trains are designed for electric and diesel traction respectively, but could be redesigned for the alternative. Every car in the Japanese trains is electric-powered.

Electric power requires expensive wayside facilities to enable the trains to pick up current for traction and train use. Thus, the lowest capital requirement is for diesel-powered trains. High ridership is required before the benefits or revenues of electric traction can overcome the additional fixed capital cost. However, the use of existing track avoids the very high capital expenditure required by new track, with either diesel or electric traction. The costs of building new track, although always higher than upgrading existing track, can vary greatly with topography. The construction cost of the French line, for example, is reported at $4 million per mile, in part owing to the relatively open country. The two latest sections of the Shinkansen are estimated to have cost about $35 million to $40 million per mile, due to the high percentage of tunnels and viaducts that had to be constructed. Earlier Shinkansen lines cost approximately $20 million per mile in 1979 dollars.

DISCUSSION

In recent years, several foreign railways have operated conventional equipment at speeds in excess of 100 mph, the previously accepted maximum speed of operation. The Japanese National Railways (JNR) opened its Shinkansen (131 mph maximum) in 1964, which from the outset was a phenomenal success. The first sector was followed by a second completed in 1975, and two more sectors recently have been added.[1] In 1975, British Railways (BR) inaugurated the first daytime high-speed passenger train line on tracks shared with other trains. It has since opened five other such lines. In France, a new high-speed line from suburban Paris to suburban Lyon used by TGV has been built. It permits operation at speeds up to 170 mph (with potential of 186 mph) and will be fully operational in 1983. It has been in limited use since 1981.

Current plans for additional high-speed trains include, in Britain, the introduction of a tilt-body train at 125 mph connecting London, Glasgow, Manchester, and Liverpool. France plans a line serving Bordeaux and Rennes, and in West Germany, two new sections of railway are under construction to be used at maximum speeds of 125 mph.

Conventional Equipment on Existing Track

France

With the introduction of diesel and electric traction in the 1960's, maximum speeds of 100 mph became commonplace. Regular use of maximum speeds of 125 mph first occurred in France when SNCF introduced a limited number of trains on three routes. Normally, such speeds were limited to morning and evening trains to and from Paris with first class accommodation at a supplementary fare.[2] Table 2 shows trip times and speeds for major flows.

Most trains on each route operated no faster than 100 mph. The high-speed trains were aimed at the business market, against growing air competition. A small number of special locomotives were built and used with new conventional coaches (known as "grand comfort"). No special attention was given to the track, and existing signaling was used.

West Germany

The Deutches Bundesbahn (DB) introduced a small number of locomotive-hauled trains at 125

Table 2.—SNCF 125-mph Trains

Sector	Miles	Overall trip time		Average speed (mph)
		Hours	Minutes	
Paris — Bordeaux	363	3	50	95
Paris — Limoges	250	2	50	88
Paris — Dijon	197	2	19	85
Paris — Lyon	320	3	47	85

SOURCE: SNCF Timetable.

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[1] Japanese National Railways, "Shinkansen," February 1982.

[2] SNCF.

mph, and an experimental electric multiple-unit train ran for a period between Munich and Hamburg.[3] These trains, like the French, were placed on the existing network as a separate luxury service at supplemental fares.

Details are not available on costs of these high-speed services, but both SNCF and DB state that the extra maintenance costs for the trains were offset by the increased mileage per vehicle, so that extra cost resulted only from the additional fuel consumed at higher speeds.

Great Britain

BR is operating complete routes at maximum speeds of 125 mph on existing track. The British considered the possibility of a new high-speed railway similar to the Japanese system, but rejected it because of extremely high projected capital costs and anticipated environmental opposition. Instead they designed high-speed trains (known in Britain as "HSTs") for existing track, at wear-and-tear levels equal to the existing intercity trains, but with maximum speeds of 125 mph and braking systems capable of stopping the trains within the distances provided by the existing signaling. All main routes were examined for opportunities to reduce trip times by eliminating speed restrictions and upgrading line at moderate capital expenditure. When applied to U.S. conditions, BR officials estimate that upgrading for high-speed trains approximates $2.5 million per mile, * though it can vary considerably by route and condition of the track.

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[3] DB Timetable.

● British Rail data extrapolated to U.S. track conditions for a Michigan corridor.

Photo credits: TRANSMARK

British Railways High Speed Train: insert shows the interior

In addition to the HST designs, and to prevent having to develop totally new railbeds to meet long-term needs, the British decided to develop the advanced passenger train (APT), which has a tilt mechanism** to improve speeds on curves. To date, however, APT has been delayed by technical difficulties.

First introduced in the mid-1970's, HSTs now provide daytime service on six routes, a total of 18 million train-miles per year, at speeds up to 125 mph.[4] They are standard intercity trains, available to all riders, and marketed with the full range of selective fares offered on the whole intercity network.

The characteristics of the lines where HSTs were introduced varied widely. On some routes, up to 50 miles between stops was common; others had nonstop runs of up to 220 miles. Table 3 gives a cross section of trip times and speeds before and after introduction.

In 1982, HSTs ran 18 million train-miles and probably will continue at this level. BR officials state that ridership increases of 30 percent have been achieved in areas where there already was a major intercity route.[5] HST service reportedly covers operating costs (including depreciation) and makes a significant contribution to track and signaling costs. However, it does not earn enough revenues to repay full expenses and capital investment, typically running 10 to 15 percent short.

The 87 HSTs sets now in service provide 205,000 miles per year each. This compares with 100,000 to 150,000 miles per year by the diesel locomotives the HSTs replaced.[6]

New Equipment on Existing Track

Great Britain, Canada

BR has continued development of APT. This train has advanced concepts including a hydrokinetics braking system, * articulation (using one truck to support the ends of adjoining cars), and an active tilting system. APT has experienced persistent troubles and is still undergoing refinement to the tilting mechanism. APT is designed for speeds of 150 mph, but could be engineered to 200 mph. Present plans are to use APT for all daytime service on the electrified lines at 125 mph within 5 years.[7] APT operating costs per passenger-mile are expected to be comparable with HST, with the additional costs of maintaining the tilt mechanism being offset by improved fuel economy.[8]

The Canadian LRC train (light, rapid, comfortable) also features an active tilt-body system designed to improve trip times by better performance on heavily curved track.

In 1981, two LRC train sets were leased to Amtrak for 2 years with an option to purchase. At the end of the lease, they were returned to the manufacturer (Bombardier), Amtrak having decided that the benefits in reduced trip times did not offset the disbenefits of lack of compatibility with other equipment. In addition to British and Canadian tilt-body equipment, Swiss, Italian, and Swedish manufacturers are also developing such equipment.

Table 3.—HST Comparison of Trip Times

Sector	Miles	Before HST Time (hours/minutes)	Before HST Average speed (mph)	With HST Time (hours/minutes	With HST Average speed (mph)
London — Reading	32	0.30	72	0.22	98
London — Chippenham	94	1.27	58	0.54	104
Reading — Swindon	41	0.44	56	0.26	95
London — Bristol	112	1.55	62	1.05	103
London — Doncaster	156	2.12	71	1.39	95
London — Newcastle	269	3,35	75	2.57	91

SOURCE: British Rail Timetable,

•● The tilt mechanism reduces lateral forces on passengers and is analogous to banking in an aircraft.

[4] British Rail Information.

[5] Contractor discussions with British Rail Passenger Department.

[6] British Rail statistics.

● Hydrokinetics braking is a nonwearing braking system which allows the train's kinetic energy to be converted into heat in the braking fluid rather than heat in a braking disk or wheel tread.

[7] British Rail officials.

[8] D. Boocock and M. Newman, *The Advanced Passenger Train*, (London: Institute of Mechanical Engineers, December 1976).

Generally, tilt-body equipment has some problems that remain unresolved, particularly commercial viability of the equipment due to maintenance costs.

State-of-the-Art Equipment on New Track

The construction cost of new track is high and typically *is* considered for use with state-of-the-art equipment only where existing track is unsuitable. Some situations may require the construction of new track for high-speed trains, e.g., where the tracks have been used extensively by other trains, or where the tracks may be completely unsuitable for high speed.

Japan

In Japan, the existing lines were both unsuitable for high speed and overloaded with traffic. Ridership was expected to increase rapidly. There was no question of running high-speed trains on the existing track because of narrow track gage, nor of running more trains to increase capacity. The new railway built by JNR had a design speed of 160 mph, although until now it has been operated at a maximum of 131 mph.

The World Bank provided part of the original financing for the first bullet train. The 320-mile line between Tokyo and Osaka (Tokaido) opened in 1964 and was an immediate success. Circumstances were especially favorable for development of a high-speed railway:

1. the existing railroad line, the predominant transportation system, was overloaded;
2. traffic was expanding rapidly;
3. competition from road and highway use was minimal;
4. the costs of a new highway (as an alternative) were estimated at more than five times that of the railway; and
5. there was a fully developed transit feeder system. Japan at that time did not build an interstate system for automobile use.

Table 4 shows ridership figures for the original Shinkansen as well as ridership resulting from the additions built from 1972 to 1975. While ridership increased dramatically on the Shinkansen, it began dropping on the conventional routes, as shown in figure 1. Ridership on the conventional route stabilized in the early 1970's while Shinkansen ridership grew with the addition of the Okayama extension in 1972 and the Hakata extension in 1975. The average distance traveled per passenger remained fairly constant. Ridership for the entire line peaked at 157 million (33,3oo million passenger-miles) in 1975. However, fare increases (resulting from overall JNR system deficits) reduced demand by about 20 percent in the late 1970's, and ridership stabilized at about 125 million annually in 1980. With the extension from Tokyo to Hakata, the route mileage increased to 663. The express trains call at a limited number of major cities, with the second service reaching stations not served by the faster trains.

Photo credit: ISP Photo by Joan Bluestone

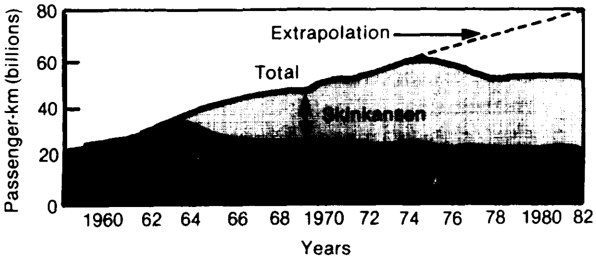
Shinkansen Bullet Train in station

Table 4.—Ridership: Shinkansen, 1965-70, 1975.80

Year	Passengers (millions)	Passenger-miles	Average distance per passenger (miles)
1965	31	6,658	213
1966	44	9,058	205
1967	55	1 1,18a	200
1968	66	13,139	198
1969	72	14,270	198
1970	85	17,454	204
Line extensions occurred-1972, 1975:			
1975	157	33,300	210
1976	143	29,850	208
1977	127	26,160	206
1978	124	26,700	206
1979	124	25,400	205
1980	126	25,900	205

SOURCE: Japanese National Railways, "Shinkansen," February 1982; Japanese National Railways, *Facts and Figures, 1981* edition.

Figure 1.—Rail Travel: Tokyo - Osaka



Year	Pass. km (billions)	Increase	Average annual increase
1964	38.5	—	—
1980	53.1	38%	2%

SOURCE: Ichiroh Mitsui, Japanese National Railways.

As of October 1982, according to JNR, *express* trains between Tokyo and Hakata carry approximately 69 percent of all passengers on the route. On weekdays, 58 percent of travel is for business reasons. Access to the rail station is approximately 75 percent by public transit, 20 percent by taxi, and 5 percent by auto. Access from the train to final destination is 60 percent public transit, 35 percent taxi, and 5 percent auto.[9]

Between Nagoya and Osaka on the original (Tokaido) section, 204 trains are run daily. On the three sections between Osaka and Hakata, this number reduces to 131 trains, 100 trains, and 75 trains.[10]

Two new northern lines, the Tohoku and Joetsu, have been opened recently. The new lines start from Omiya, a suburb of Tokyo, with access by a shuttle service on existing tracks. It will be some time before the connection from Omiya to Tokyo is completed (see fig. 2). The scheduled trips are fewer on the two new lines than on other Shinkansen sectors, and the trains have only 12 cars instead of the standard 16 used on the Tokaido Shinkansen. Ridership on the new lines is expected to be less than on the existing network, and revenue is likely to fall short of operating costs. JNR expects that these two sectors eventually will become profitable, but there are substantial doubts about the remainder of the planned network* because the ridership forecast in sparsely populated areas is less than 10 percent of the capacity of the proposed new lines.[11]

Tables shows the trip times and average speeds for the two new sections of the Shinkansen service.

The construction of the new lines has been expensive, largely as a result of the very difficult climatic conditions, difficult terrain, the need for shallow curves and easy gradients to permit speeds of 160 mph, and the high cost of providing access to cities. Table 6 shows the proportion of each Shinkansen line in tunnels or viaducts. Because of the Japanese terrain, Japanese engineers working on the Shinkansen system have become the world leaders in tunneling technology.

The two latest sections are estimated to have cost about $35 million to $40 million per mile, while the earlier routes were estimated to cost about $20 million per mile in 1979 dollars.[12]

The original section from Tokyo to Osaka has been highly profitable, and the sections from Osaka to Hakata currently are recovering costs. Operating costs for 1980 were reported by JNR as 4.3 cents per passenger-mile, with total costs as 6.9 cents per passenger-mile. Revenue earned was 11.7 cents per passenger-mile. From a review of JNR's trends in operating ratios, it is apparent that opening lines south of Osaka did not significantly improve the overall financial performance of the system. The operating ratio (costs to revenues) was a low of 0.44 in 1970. A decade later in 1980 it was 0.59; still a better ratio than anywhere else in the world.[13]

The first section that opened between Tokyo and Osaka created a great deal of opposition because of noise and vibration. Later sections featured construction methods designed to reduce noise and vibration, including noise barriers on certain sections. Because of the original problems, however, there has been very vocal opposition to increasing the speed to 160 mph. However, JNR still expects to increase speeds to perhaps 140 mph soon as a first step toward achieving design speed (160 mph) for the line and equipment. While the

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[9] Ichiroh Mitsui, Japanese National Railways representative, Washington, D.C.

[10] Japanese National Railways, op. cit.

● JNR anticipates building additional Shinkansen lines however, whether this construction will occur appears uncertain according to recent trade journals.

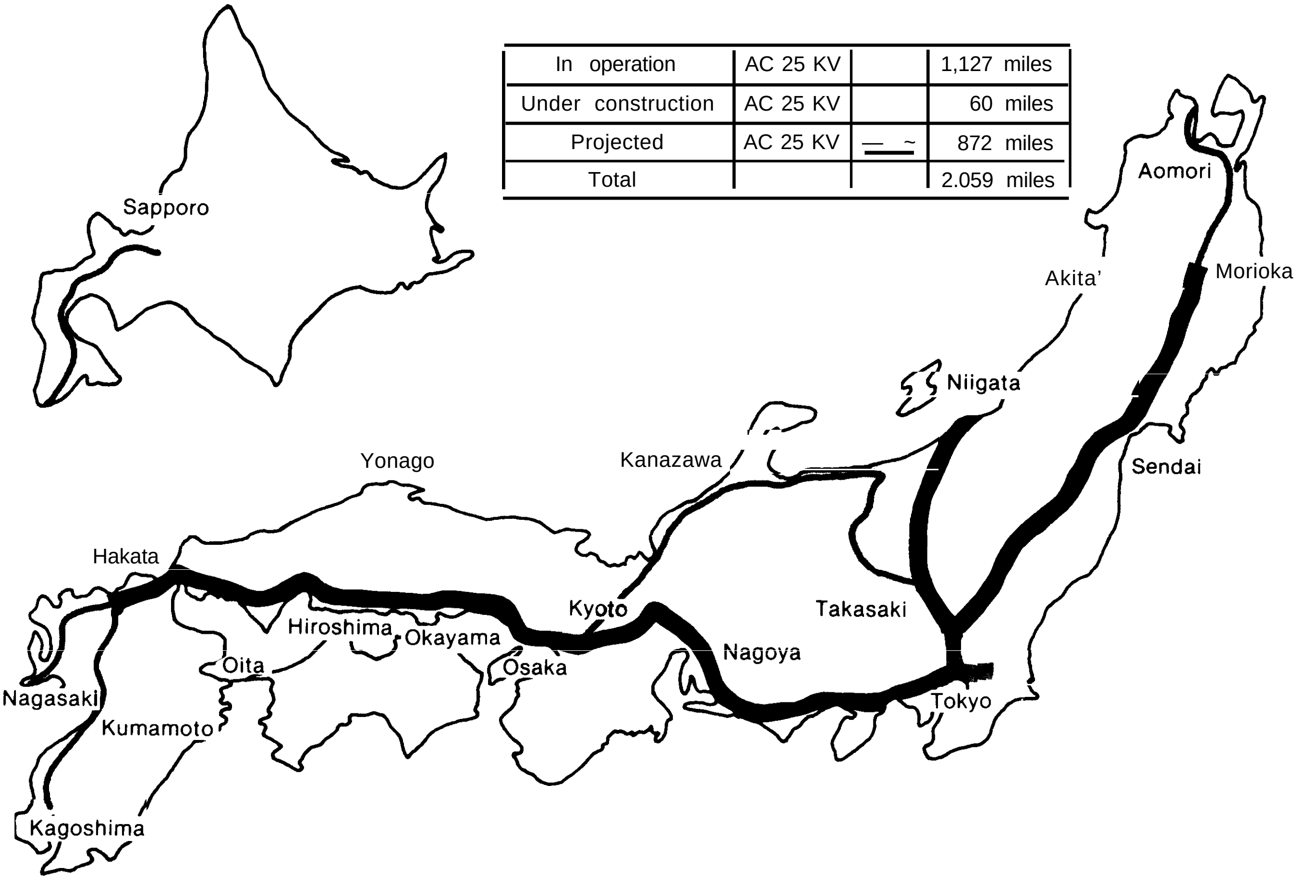
[11] Mitsui, op. cit.

[12] Ibid.

[13] Japanese National Railways, oP. Cit.

Figure 2.—Japanese National Railways Standard Gage (Shinkansen) Lines

As of January 1983



In operation	AC 25 KV		1,127 miles
Under construction	AC 25 KV		60 miles
Projected	AC 25 KV	— ~	872 miles
Total			2.059 miles

SOURCE: Japanese National Railways.

Table 5.—Trip Times on Shinkansen

	Miles	Before trip-time (hours/minutes)	Average speed (mph)	Shinkansen trip-time (hours/minutes)	Average speed (mph)
Omiya-Marioka	291	5.37	52	3.17	89
Omiya-Nigata	168	3.30	48	1.50	92

SOURCE: Japanese National Railways.

Table 6.—Proportion of Tunnels and Viaducts

	Tunnel		Viaduct		Other		Total viaduct and tunnel	
	Miles	Percentage	Miles	Percentage	Miles	Percentage	Miles	Percentage
Tokyo — Osaka	43	13	36	11	243	76	79	24
Osaka — Hakata	176	51	32	9	138	40	208	60
Omiya — Marioka	72	23	49	16	189	61	121	39
Omiya — Niigata	66	39	19	11	84	50	85	50

SOURCE: Ichiroh Mitsui, Japanese National Railways Representative, Washington, D.C.

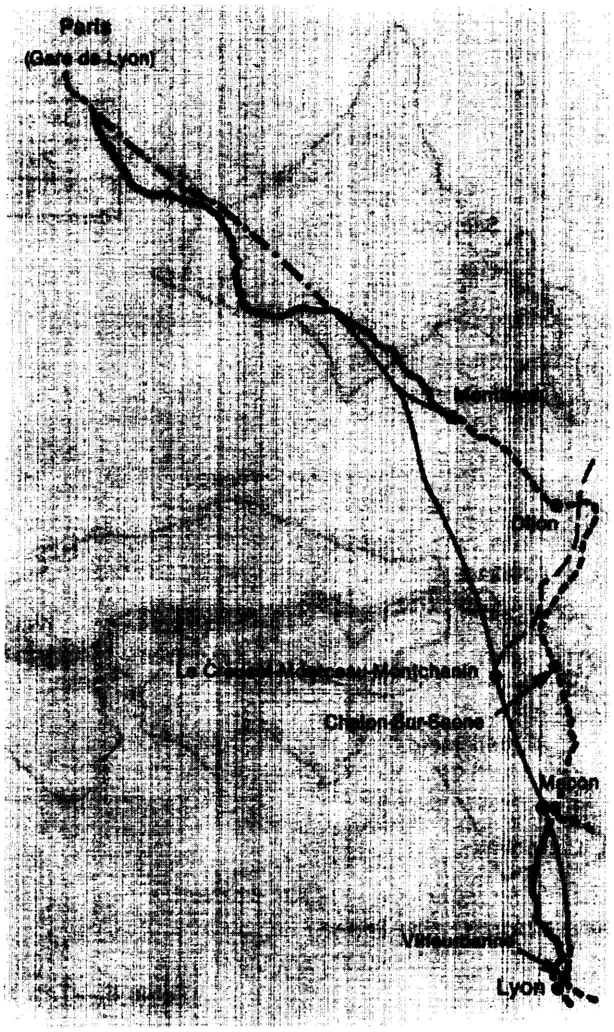
early bullet trains have been highly successful in terms of ridership and costs, the entire JNR system, like those of other countries, experiences financial problems.

France

In France, the use of conventional trains at 125 mph demonstrated the benefits in ridership from faster trip times. In the late 1960's, the French Government faced two choices for relieving severe congestion in the Dijon area: add tracks in the hilly area approaching Dijon, or build a completely new line diverting a major part of the intercity passenger train service away from the congested areas. The Government decided to build a new line (see fig. 3).[14] The French have maintained national policy of promoting their rail service. As a part of that policy, intercity bus travel on highways and expressways has been prohibited in order to encourage rail use, according to SNCF officials. Buses are permitted on other roads.[15]

The French designed their system to fit their needs and topography. It used existing track into Paris and Lyon, eliminating the high construction costs in urban areas. The intermediate sections of line pass through sparsely populated areas. Gradients, mainly into and out of river valleys, were negotiated at up to 3.5 percent, eliminating the need for expensive tunnels and requiring only 2 miles of viaduct. The line has excellent feeder systems serving surrounding Dijon and Lyon, and existing routes provide good access to many cities farther south. The long distances with few intermediate stops afford maximum opportunity to utilize the trains' speed—currently to 170 mph, with an average speed between Paris and Lyon of 133 mph. The Paris to Lyon TGV line includes **244** miles of new track. The remaining mileage used existing right-of-way into Paris and Lyon.

Figure 3.—SNCF-TGV Line Between Paris-Lyon



New line in service as of October 1981
▬•▬ New line in service as of October 1983
Present Paris-Lyons line
Present lines used by TGV trains in October 1981
Present lines used subsequently by TGV trains

SOURCE: SNCF.

SNCF estimates the construction cost was $4 million per mile. Total land acquisition was about 9 square miles. Ridership forecasts were for 25 percent of the total between Paris and Lyon and the remaining from the wider areas surrounding the end points. In just over 1 year, the French have achieved 5.6 million riders on the Paris-Lyon axis alone and in 16 months the ridership has increased to 10 million. SNCF officials are confident of reaching the forecast of 16 million riders for the whole network by 1987. Revenues in the first full year were reported $140 million, and operating costs were estimated at $70 million, with revenue per passenger-mile estimated at 10 cents and costs

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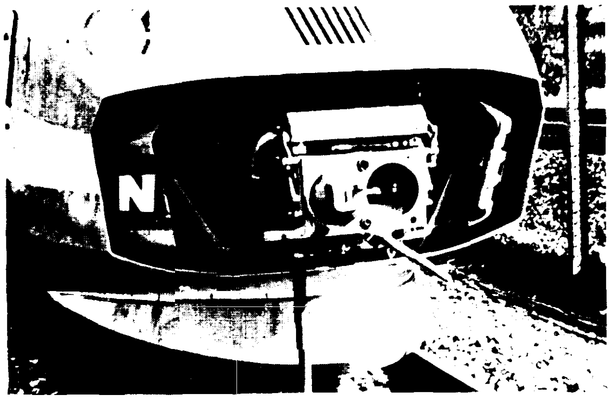
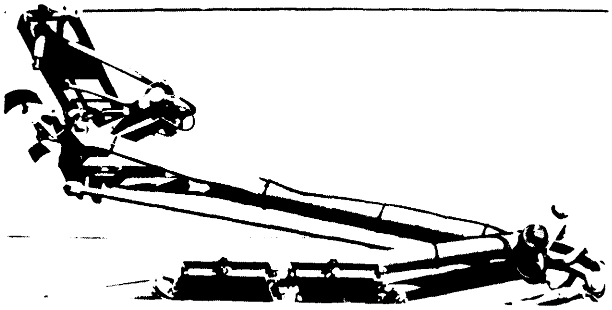
[14] Contractor discussion with SNCF officials.

[15] Hughes deVillele, French National Railways, U.S. Office.



TGV coupler



Pantographs for railcars used on the TGV

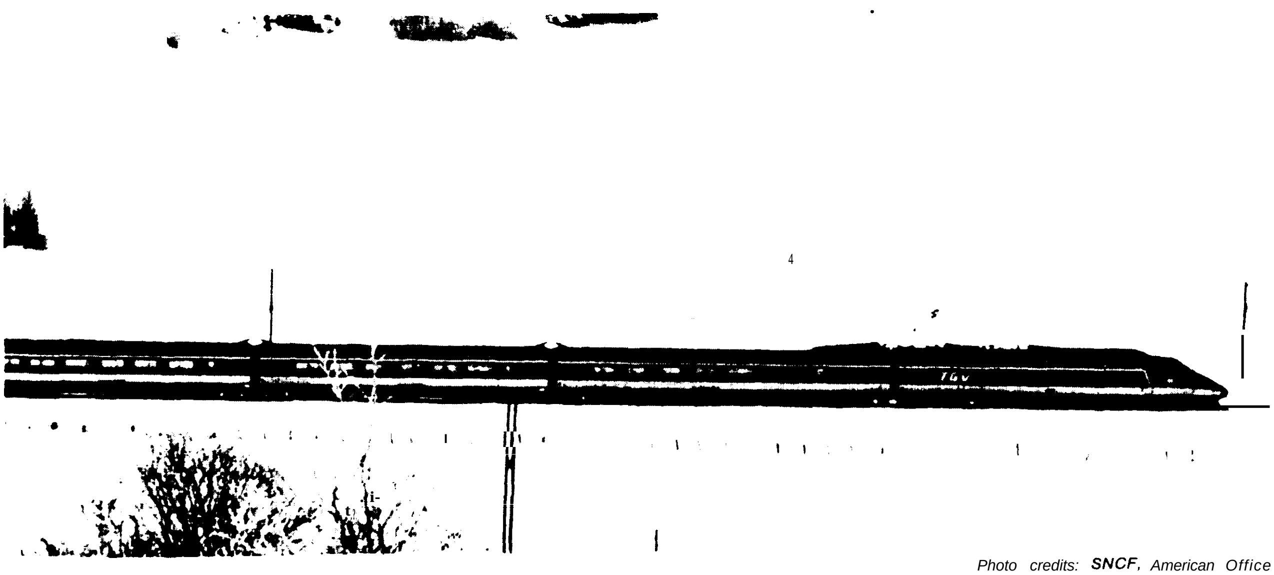


Photo credits: ***SNCF,*** *American Office*

TGV from Paris to Lyon

at 5 cents per passenger-mile. * SNCF expects to cover fully allocated costs (including track, signaling, etc.) in 1984 and to break even in 1989.[16]

When the new line is in full operation, **87** train sets will be used, of which **64** were in service at the end of 1982. Each set is expected to run between 280,000 and 300,000 miles per year. All maintenance is confined to one facility outside Paris, and most servicing is performed at a single facility, also at the Paris end of the route. New maintenance facilities were not constructed for the new TGV route. Sophisticated pantographs (for electric current collection) allowed for the use of a simple catenary (overhead wire system of power supply). The trains have been designed with overall axle weight of **161/2** metric tons (tonnes), and the vehicles are articulated (with one truck supporting the ends of two cars). Lightweight construction (64 tonnes per power car and 36 tonnes per passenger car) has reduced wear on the track

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***Operating costs include different items for each railway and are not comparable with one another.**

[16] SNCF.

and the new line is maintained to the standards required for 100-mph operation. Fuel consumption is less per seat-mile than the conventional trains displaced by TGV.[17]

Table 7 gives details of trip times and speeds for a selection of routes served by TGV. In each case, the times are those for full operation, planned for September 1983.

SNCF plans the construction of a second line of 120 miles between Paris and Bordeaux, although the increased traffic forecast will be insufficient to pay interest charges on the investment. It will therefore only consider actual construction of this line if the government offsets the interest charges.[18]

Table 7.—TGV: Comparison of Trip Times

		Conventional		TGV	
Sector	Miles (original route)	Time (hours/minutes)	Speed (mph)	Time (hours/minutes)	Average speed (mph)
Paris — Dijon	197	2.19	85	1.37	122
Paris — Lyon.	320	3.47	85	2.00	133
Paris — Marseilles	439	6.35	82	4.43	99
Paris — Besancon	254	3.30	73	2.21	108

SOURCE: TGV Timetable.

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[17] Data provided b, SNCF-TGV Maintenance Facility officials, Villeneuve, Paris, January 1983.

[18] SNCF discussions.