Chapter 3

FACTORS AFFECTING THE ECONOMIC FEASIBILITY OF HIGH-SPEED PASSENGER RAIL SYSTEMS

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FACTORS AFFECTING THE ECONOMIC FEASIBILITY OF HIGHSPEED PASSENGER RAIL SYSTEMS

This chapter discusses the basic factors likely to affect the economic feasibility of high-speed passenger rail systems in the United States. It describes the overall size and character of the travel market required for a successful high-speed system as well as the basic service features that will enable a system to attract ridership. It examines methods for developing economic forecasts for a system and outlines the basic cost to revenue relationships of building and operating a high-speed service.

SUMMARY

OTA's analysis of the factors that influence transportation preferences and of the experience of foreign high-speed systems suggests that the following minimum corridor characteristics are important for economic feasibility of high-speed systems:

- cities with high populations and high population densities;
- cities with a strong "travel affinity" between them, generally because one is a dominant center of commercial, cultural, financial, governmental, or other activity;
- cities grouped along a route giving major passenger traffic flows in the 100- to 300-mile trip range; and
- cities with developed local transit systems to feed the high-speed rail.

Data on current U.S. travel, aggregated on a national basis, show that automobiles and airplanes are the most extensively used modes for intercity travel. Rail represents less than 1 percent of current intercity revenue travel. *Nationally, rail's share of the intercity market is not likely to increase dramatically if additionalhigh-speed rail systems are built, because only a few U.S. corridors may be likely candidates for such systems.*

Considering speed and schedule frequency together, it appears that the major rail markets start at about 100 miles and reach up to 300 miles. Outside these limits, rail competes successfully only where special factors compensate for the relative disadvantage in trip time compared with the automobile at short distances, and aircraft at long distances. For shorter distances, the use of a high-speed rail is essentially equivalent to creating a transit system.

The overall ridership and the choice of travel modes by riders are determined by a number of interrelated factors: total trip times, speed, frequency, distance, cost, comfort, and convenience. Each of these factors, and the tradeoffs among them, must be examined for specific rail corridors. *In terms of time, what matters to the traveler is not the speed of the main mode used on any single trip but the total time (the trip time) it takes to travel—by whatever combination of modes—from departure to final destination.* Thus, the speed of the airplane may be offset by the time spent getting to and from airports or of getting around within airports. Conversely, the slower speed of the automobile is often outweighed by the fact that it does not involve the access, egress, and terminal waiting times—or the relatively infrequent departure times—required by the public modes.

Major purposes for intercity travel are business, family, and other private travel. For each of these trip purposes, the factors discussed above have different relative values. The business traveler places a high value on time and will pay for comfort and convenience. Thus, fare is often less important than trip time, frequency, comfort, or convenience. At the other end of the spectrum are riders for whom the cost of the trip is paramount. For example, a family of four would calculate the cost of a 200-mile round trip by automobile at perhaps $26 ($20 gasoline plus $6 parking), or

$6.50 per person. The family would find unacceptable the standard rail fare of about $100 plus access costs (over *$25* per person). Even a total round-trip fare of *$7o* for a family of four would be only nominally more attractive.

Frequency of service equates to increased convenience and attractiveness and can have the same perceived value to the customer as increasing speed.

High-speedrail systems are costly to construct. How costly depends on such factors as location, length of route, right-of-way, terrain, technology selected, and the service levels to be provided. The French estimate, for example, that the construction of their TGV cost an average of $4 million per mile. The Japanese estimate that the last two links of the Bullet Train will cost an average of between $35 million to $40 million per mile due to significant tunneling and viaduct requirements. The earlier links cost about $20 million per mile in 1979 dollars. For purposes of comparison, the *$35* million to $40 million per mile costs are similar to those of the Century Freeway in Los Angeles.

The costs of the infrastructure (land, track, signaling and control systems, terminals) will vary widely among corridors. Infrastructure costs depend on topography and technology selected. Operating costs primarily include maintenance costs for track and equipment and "over the road" costs such as the labor and fuel. As such, the operating costs can vary according to the technology selected and the corridor characteristics.

Travel demand required to support high-speed rail service can be much lower where existing track can be used or, alternatively, new track added to existing rights-of-way. *Demand must be extremely high to support newly constructed high-speed rail lines, even if the land acquisition costs for expensive city sections of the route are avoided by using the existing right-of-way. Demand also must be extremely high if it is to pay back all capital costs and to break even* on *operating costs.*

Mathematical models can be and have been used to develop forecasts of passenger demand, Such models, however, have suffered from the paucity of good data on automobile travel. The most prudent approach to developing reliable ridership forecasts is to construct a realistic multimodal profile of the traveler through in-depth surveys (similar to the National Travel Survey), then use that data to validate the computer model.

DISCUSSION

Market Size

All high-speed passenger rail systems are costly and require high ridership if they are to generate enough revenue to cover operating costs, let alone capital costs. Existing high-speed rail corridors including corridors between Tokyo and Osaka, the West Coast Main Line between London and Glasgow, and the Northeast Corridor (NEC) between Boston, New York, and Washington, D. C., typically serve only major population centers. Each corridor links very large cities that are between 100 and 400 miles apart, one of which dominates as a national center (although not necessarily the administrative capital city). Table 8 shows the population densities for the countries now operating some part of their intercity network of rail services at high frequency and speed and for the city pairs linked by high-speed rail service. It also shows population densities of selected U.S. cities.

Population and population density determine both the size and potential of the market to support the high-speed rail service and transit feeder systems. The greater the population density, the more highly developed the transit system is likely to be. The ability of the NEC to provide high-speed intercity rail service is aided by the substantial local transit systems feeding the high-speed trains. Unless there is a heavy concentration of population in a relatively small area, such an infrastructure is not feasible. Without a highly developed local transit system, i.e., "feeder system, " a great deal of the potential travel by high-speed rail is not likely to be achieved. Some argue that improved local transit should be part of the plans

Table 8.—Population Density (approximate)

	Population 1980 (000s)	Area (mi²)	Population density per square mile	Approximate "radius" (mi)
U.S. population density:				
Chicago (S)(C)	3,005	228.1	13,174	9
SMSA	7,104	3,723.6	1,908	
Detroit	1,203	135.6	8,874	7
SMSA	4,353	3,939.0	1,105	
Cleveland	574	79.0	7,264	5
SMSA	1,899	1,519.7	1,250	
Cincinnati	385	78.1	4,935	5
SMSA	1,401	2,139.0	655	
St. Louis	453	61.4	7,379	4
SMSA	2,356	4,967.6	474	
Miami	347	34.3	10,113	3
SMSA	1,626	1,955.3	831	
New York(S)(C)..	7,072	301.5	23,455	10
Newark (S)(C).	329	24.1	13,662	3
Philadelphia(S)(C)	1,688	136.0	12,413	7
SMSA	4,717	3,531.7	1,336	
Baltimore (S)(C)...	787	80.3	9,793	5
SMSA	2,174	2,246.9	968	
Washington, D.C. (S)(C)	638	62.7	10,181	5
SMSA	3,061	2,809.7	1,089	
Los Angeles	2,967	464.7	6,384	12
SMSA	7,478	4,070.1	1,837	
San Diego	876	320.0	2,736	10
SMSA	1,862	4,211.6	442	
Anaheim	219	41.7	5,259	4
SMSA	1,932	797.8	2,422	
All USA	229,300	3,615,000	60	
Foreign population and density—Japan Corridor:Tokyo-Hakata:				
Tokyo (S)(C)	11,649	357.3	32,604	11
Kyoto	1,470	70.7	20,796	5
Osaka (S)(C).	2,648	97.7	27,106	6
Okayama	546	42.8	13,107	2
Hiroshima	899	50.4	17,859	4
All Japan	117,059	147,517	794	
Foreign population and density—France:				
Paris	8,548	827.1	10,335	16
Dijon	208	52.3	3,988	4
Lyon	1,171	278.7	4,201	9
All France	53,500,000	213,000	251	
Forelgn popu/ation anddenslty—United Kingdom:				
Greater London.	6,900	621	11,105	14
Outer metropolitan area	5,400	3,557	1,518	—
Total	12,300	4,178	2,944	36
West Midlands Metrop County	2,700	353	7,652	11
Includes Birmingham	1,007	81.6	12,335	5
Greater Manchester	2,617	499	5,243	13
Merseyside	1,500	252	5,962	9
Includes Liverpool	504	44.1	11,418	4
Lothian	736	100	7,360	6
Includes Edinburgh	446	527	8,463	4
Central Clydeside	1,700	666	2,552	15
Includes Glasgow..	763	61.3	12,447	4
All United Kingdom	—	50,300	910	

KEY: S=Subway, C=Commuter.

SOURCE: U.S. Department of Commerce, 1980 Census of Population, PC 80 Series, February 1882; Far East and Australia Statistics, 1881-82) Europa Publications; Whittaker's Almanac, 1983; U.K. Statistical Yearbook, 1981, by HerMajesty'sSt atistics Office.

for high-speed rail systems. However, such systems are in themselves extremely costly and unlikely to be justified solely on the grounds of providing feeder service to high-speed systems.[1] According to Japanese National Railways (JNR), as of October 1982, access to the Shinkansen from home to station is 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.

[1]A study of "The Full Costs of An Urban Work Trip" concluded: "Given that practically all commutation corridors in the (San Francisco) Bay Area have peak traffic densities below 20,000, it would seem possible that BART trips were costlier to provide than the auto trips they were supposed to supplant. . . . Given these results, it would appear that the only circumstance under which it could make economic sense for a metropolitan area with characteristics of the San Francisco Bay Area to build a new fixed-rail transit system such as BART would be if a very large fraction of commuters were willing to pay a stiff premium price, in both fares and in their own time, for the privilege of riding a train instead of a bus." From Theodore E. Keeler, "Chapter III, The Full Costs of An Urban Work Trip: Auto vs. Bus and Rail Transit," *The Full Costs of Urban Transport* (Berkeley, Calif.: University of California, Berkeley, Institute of Urban and Regional Development, July 1975).

The Intercity Travel Market

Intercity travel consists of trips between urban areas conducted by airplane, bus, railroad, and automobile. Travel forecasts are as difficult to make as economic forecasts, and there is a wide divergence of views on the future growth rates in travel.

As presented in the aggregated data, air and automobile are preferred intercity modes of travel (see table 9). However, these patterns are likely to be less uniform between individual city pairs because modal choice depends on factors which

Table 9.—Intercity Passenger-Miles by Mode of Travel

	Automobiles[a]	Motor coaches[a]	Total motor vehicles[a]	Railways, revenue passengers	Airways, domestic revenue services	Total
Passenger-miles by mode (in billions):						
1981	1,344.0	27.2	1,371.2	11.8	216.0	1,599,0
1980[b]	1,300.4	27.7	1,328.1	11.5	219.4	1,559.0
1979[b]	1,322.4	27.2	1,349.6	11.6	228.2	1,589.4
1978[b]	1,362.3	25.4	1,387.7	10.5	203.2	1,601.4
1977[b]	1,316.0	25.7	1,341.7	10.4	177.0	1,529.1
1976[b]	1,259.6	25.1	1,284.7	10.5	164.4	1,459.6
1975[b]	1,170.7	25.4	1,196.1	10.1	148.3	1,354.5
1974[b]	1,121.9	27.7	1,149.6	10.5	146.6	1,306.7
1973[b] ., . . .	1,162.8	26.4	1,189.2	9.3	143.1	1,341.6
1972	1,129.0	25.6	1,154,6	8.7	133.0	1,296.3
1971	1,071.0	25.5	1,096.5	8.9	119.9	1,225.3
1970	1,026.0	25.3	1,051.3	10.9	118.6	1,180,8
1965	817.7	23.8	841.4	17.6	58.1	917.2
1960	706.1	19.3	725.4	21.6	34.0	781.0
Passenger-miles by mode (percent):						
1981	84.1	1.7	85.8	0.7	13.5	100%
1980[b]	83.4	1.8	85.2	0.7	14.1	100%
1979[b]	83.2	1.7	84.9	0.7	14,4	100%
1978[b] ., . . .	85.1	1.6	86.7	0.7	12.6	100%
1977[b]	86.1	1.7	87.8	0.7	11.5	100%
1976[b]	86.3	1.7	88.0	0.7	11.3	100%
1975[b]	86.5	1.9	88.4	0.7	10.9	100%
1974[b] ., . . .	85.8	2.1	87.9	0.8	11.3	100%
1973	86.7	2.0	88.7	0.7	10.6	100%
1972	87.1	1.9	89.0	0.7	10.3	100%
1971	87.4	2.1	89.5	0.7	9.8	100%
1970	86.9	2.1	89.0	0.9	10.1	100%
1965	89.2	2.6	91.8	1.9	6.4	100%
1960	90.4	2.5	92.9	2.8	4.4	100%

[a] Includes intracity portions of intercity trips, Omits rural t. rural trips, and intracity trips with both origin and destination confined to same city for local bus or transit movements, nonrevenue school and government bus operations.
[b] Revised.

SOURCE: Interstate Commerce Commission and Transportation Association of America.

vary by geographic location. Typically, distance between cities and trip purpose are two major factors influencing modal choice. For very long distances, the airplane is the preferred mode of travel; for shorter distances, the automobile. Between extremes, choices between carriers involve a compromise between two other critical factors—cost and speed. Business travelers, who place a higher monetary value on time than do nonbusiness travelers, tend to be more heavily influenced by speed than costs, though cost does factor in their decision. Nonbusiness travelers are also attracted by fast trip times, but are primarily concerned with total trip costs.

The automobile is the predominant mode of travel today in the United States. For any given intercity trip, people typically consider only the marginal costs of operating the automobile (fuel, tolls, oil, etc.)—rather than including the cost of the automobile—in comparing prices of one mode with another.

Market Requirements of a High-Speed Rail System

Any high-speed rail system must compete for riders with other public and private transport. Travel surveys show that ridership and choice of mode are influenced by several major factors: total trip time, speed, frequency, distance, cost, comfort, and convenience. Each of these factors, as well as the tradeoffs among them, must be examined in any market analysis of specific corridors.

Trip Time

The total time required to get from the point of departure to the final destination is defined as the trip time. This includes travel to and from the station or airport, access time or waiting time in the station or while parking, actual travel time, and egress time (time to obtain transportation from main mode to the final destination). Generally what matters to a traveler is the total elapsed time it takes from origin to destination rather than simply the speed of the mode used for the main part of the trip. Figure 4 portrays the modal choices for a hypothetical 100-mile trip available to a potential rider desiring to reach his arrival point at a set time. As the figure shows, all modes have a similar total elapsed time at a 100-mile distance despite the differences in speed between the main modes, assuming an hourly frequency for the public modes. Other assumptions concerning terminal access and egress, and the speed and frequency of the public modes, would swing the balance one way or the other. In general, the speed of the aircraft is tempered by the long access and egress times, while the slower speed of the automobile largely is offset by the fact that it does not involve the access and terminal service time of the public modes. Thus, the speed of the main mode cannot be considered apart from the extra access and service time required by that mode.

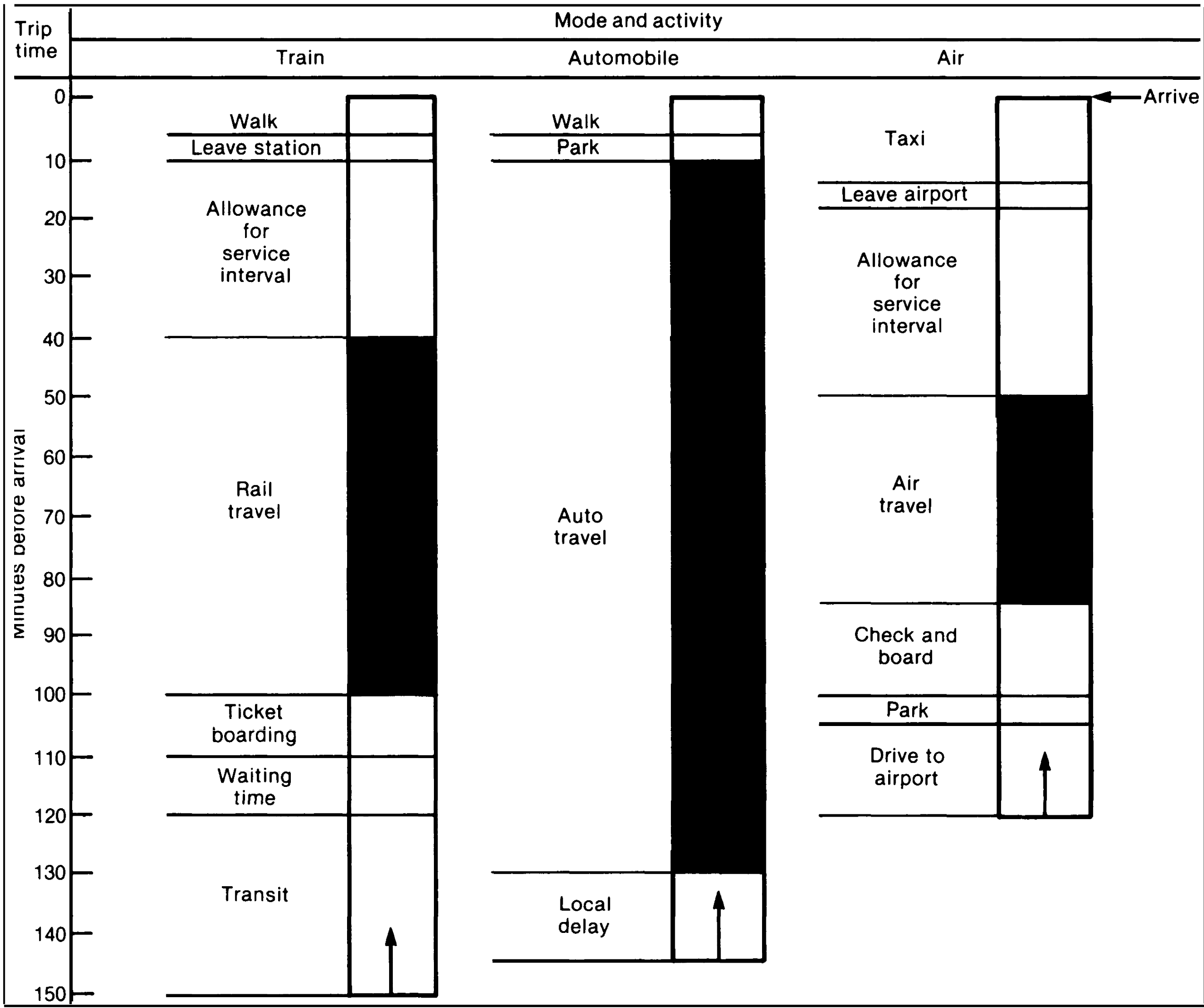
Frequency and Speed

There is a tradeoff between frequency and speed, where increased frequency can, to a certain extent, provide the additional attraction that increased speed can also give. The exact nature of this tradeoff is difficult to quantify. Figure 5 shows the effect of increased maximum speed *on* trip time for a 100-mile high-speed system.

The Effect of Distance

The relative value of speed will vary with distance, as shown in figure 6. At short distances, the transit bus and automobile dominate the market in both convenience and trip time. Rail is attractive for short trips only where special circumstances nullify the advantages of the automobile, such as peak time commuting access to a major city, center city congestion, cost of parking, access to airports or other major attractions for large numbers of people such as an exhibition center. In these cases, at short distances, frequency of service is essential, as is a single point of access. Travel time to and from stations is increasingly important to the individual traveler as trends show the U.S. population spreading out. Many people live further away from city centers, thus increasing travel times to and from stations and airports. Use of a rail link for airports usually involves some form of shuttle transport from the railhead to individual terminals, as at Logan Airport in Boston. Unless a high frequency service is maintained, all the benefit of a high-speed

Figure 4.—Components of Total Trip Time for a 100-Mile Trip (hypothetical)



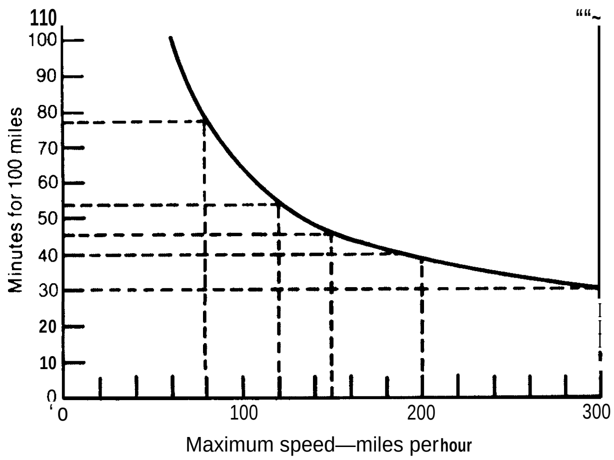
SOURCE: Jack Smith, Office of Technology Assessment contractor report.

movement will be lost in waiting time where trip distances are short.

As demonstrated in figure 6, for a trip of 30 miles the automobile has a substantial time advantage over a train that runs hourly at a 125-mph maximum speed. Increasing the top speed to 200 mph or even 300 mph still leaves rail at a substantial disadvantage in trip time. At this distance, increases in frequency do more than increases in speed to improve the trip times of trains. (Note that the figure assumes a nonstop rail trip. Each intermediate stop adds at least 4 minutes to trip time, and increases the rail trip time disadvantage.) For a trip of 50 to 100 miles, rail becomes progressively more competitive on trip time. At the lower end of the range, flows between intermediate stations will be confined to those trips where no automobile is available, or there are special circumstances favorable to rail.

At a distance of about 100 miles, the automobile loses all trip time advantage and competes only on price and convenience. At this distance, the trip time advantages of improved rail frequency and higher top speed are about the same. This

Figure 5.—Effect of Increased Maximum Speed on Trip Time



SOURCE Jack Smith, Office of Technology Assessment contractor report. Data derived from Information on acceleration/deceleration rates, British Rail Research Department, SNCF.

raises the difficult question of what should be the planned top speed of the rail link. Most rail lines are likely to have less than 100-mile intervals between stations. For example, between New York and Washington, there are, on average, major stations at 45-mile intervals. Only four trains a day each way run 90 miles nonstop (Philadelphia to New York). In these cases, the intermediate stations have the best overall trip times from high frequency trains at maximum 120 mph. However, major long-distance flows achieve greater benefit from higher top speeds.

Fares

Fare is the most complex of the factors the rider considers, but it is a fundamental determinant of demand and the financial viability of any public mode of transportation. Figure 7 illustrates the range of current rail fares and perceived marginal automobile costs, including access and parking costs.

At the shorter distances, the price of travel by public mode is most often measured against the perceived marginal cost of the automobile, except in cases where an automobile is not an available alternative. It is sometimes argued that intercity automobile trip costs should include maintenance, tire wear, and even depreciation and interest on capital. However, intercity trips in competition with public modes are normally only a tiny fraction of the trips made by automobile; only on rare occasions is intercity use part of the justification for purchase of an automobile. Maintenance and tire wear both have an element related to total mileage, but are small, and in most cases are not included by riders in cost calculations. Thus, for the rider, the calculation of trip cost by automobile normally includes gasoline, parking, and tolls, if any. This cost is then divided by the number of persons in the automobile. A cost of perhaps 10 cents per mile becomes 2½ cents per mile for four riders. Party size, therefore, is a major factor in its own right. The typical automobile load factor for intercity trips is 1.6 passengers per vehicle, which means that probably less than 40 percent of automobile riders travel alone. To compete in a market where the dominant mode (automobile) has a competitive price that can vary widely with party size requires very sophisticated fare policies on the part of the operators of public modes of transportation.

Political or social objectives can alter the competitive position. For example, the French Government pays French National Railways (SNCF) a large annual sum to provide cheaper fares for children, the elderly, and socially disadvantaged groups. This payment is calculated as the difference between the fare charged by SNCF to these groups and the standard fare. Other railroads such as British Railways (BR) and Amtrak provide such reduced fares as a matter of commercial judgment to widen the market covered.

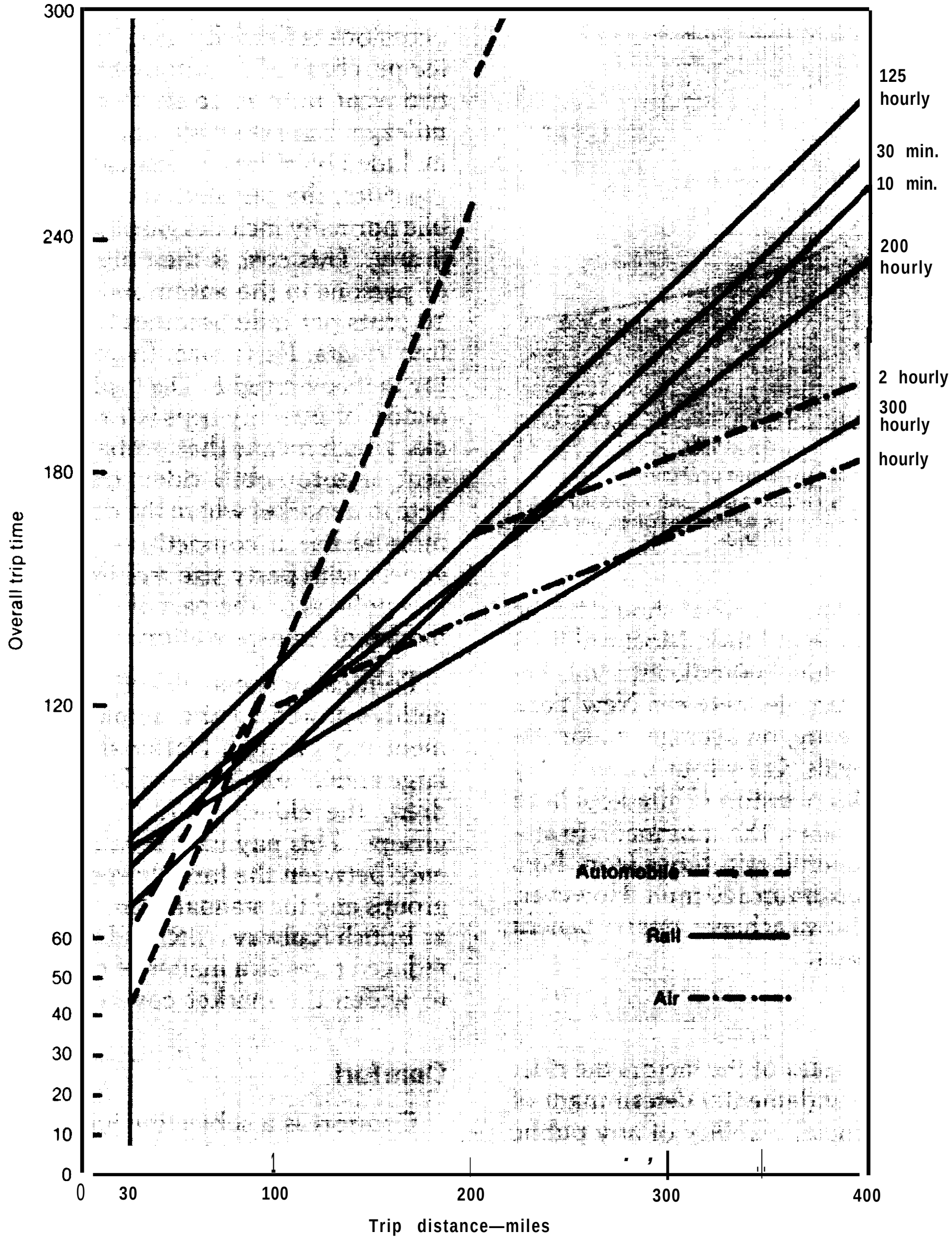
Comfort

Comfort is a subjective judgment. For the rail mode, it involves the travel environment—seating, company, catering facilities, relaxation, and ability to read, work, or sleep. While other modes offer comfort in seating and environment, flying, or driving or riding in an automobile all present added anxieties. Food choice will be more limited on short-haul flights and an automobile trip will require stops.

Convenience

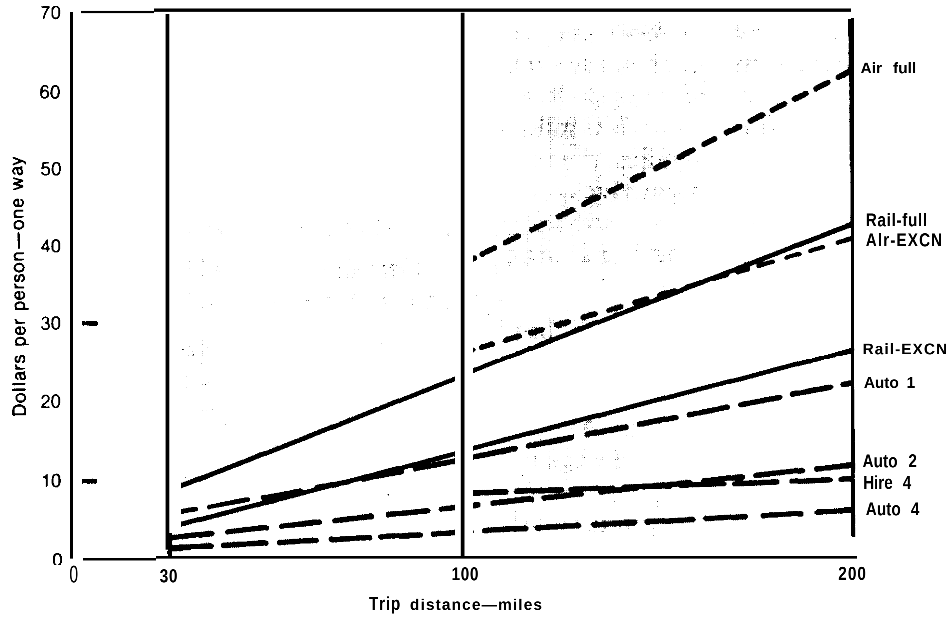
Auto travel, with its infinite choice of starting times, is far more convenient than public modes

Figure 6.—Effect of Distance and Mode: Nonstop Trips Up to 400 Miles



SOURCE: Jack Smith, Office of Technology Assessment contractor report

Figure 7.—0ne-Way Fare-Price in Dollars per Person (includes access/parking)



SOURCE: Jack Smith, Off Ice of Technology Assessment contractor report. Data compiled from modal fare comparisons using the following assumptions automobile— 10¢/mile plus $2.50 parking; train — N EC Am fleet fares, air— Los Angeles-San Diego and New York-Washington.

with limited service frequencies. With auto travel, changes in itinerary can be made at any suitable time, and luggage handling is minimal.

Public modes always involve transfer, which is inconvenient and time-consuming. Some travel modes allow an elapsed time of up to 40 minutes as the perceived time equivalent to the inconvenience factor of having to change from one mode to another. Even where arrangements are made to handle luggage at terminals, public transportation cannot match the convenience of the automobile which moves large quantities of baggage from origin to destination without any intermediate handling.

Market Sectors

Major purposes for intercity travel are business, family, and other private travel. For each of these trip purposes, the factors discussed above have different relative values. The business traveler places a high value on time and will pay for comfort and convenience. Thus, fare is often less important than trip time, frequency, comfort, or convenience. At the other end of the spectrum are riders for whom the cost of the trip is paramount. For example, a family of four would calculate the cost of a 200-mile round trip by automobile at perhaps $26 ($20 gasoline plus $6 parking or $6.5o per person). The family would find unacceptable the standard rail fare of about $100 plus access costs (over $25 per person). Even a total round-trip fare of $70 for a family of four would be only nominally more attractive.

Between these extremes are other groups traveling on personal business or for leisure and recreation. The public modes become more attractive to the extent that riders travel alone, value time more than money, or find the convenience of rail preferable in major cities where auto congestion and parking are difficult in downtown areas. Much of such travel is commuter, traditionally at cheap fares, and by nature confined to peak periods or to special events. Public modes can capture sizable shares of these markets only by incurring high peak costs, and such market penetration requires low fares to offset the advantage of a multiple-occupancy automobile.

Figure 7 shows the present pattern of rail, air fares, and automobile cost. The rail round-trip excursion fare is at about the level of cost of an automobile used by only one person. Multiple use brings automobile costs substantially below rail fare. Thus, for trips where two or more people travel together, some further reduction in rail fare may well be needed, even where rail is competitive on trip time, for example, for trips of 100 miles or more. At distances less than 100 miles, the rail mode becomes progressively less attractive compared with automobiles in multiple use, since rail travel is slower, more expensive, and less convenient in many cases.

Air fares have fluctuated widely recently, but figure 7 shows a typical situation where excursion discounts of up to perhaps 30 percent are offered for certain times of the day or week. At present fare levels, rail has a clear fare advantage to offset any time disadvantage. Any move to raise fares on high-speed rail to increase revenue could erode the differential between rail and air fares. However, for the business market, higher rail fares should be possible if rail trip time is brought significantly nearer to air. Rail fares need to distinguish between the air and auto markets by time of day and duration of stay if rail is to have maximum ridership and revenue. At 100 and 300 miles, competition exists between air and automobile, with rail having a slower overall trip than either. Those individuals who now prefer the automobile have had the option of a faster, more expensive air mode, but did not take it. For this group, the costs and the convenience of the automobile have priority over speed at the longer distances. High-speed rail would offer a speed advantage, and a smaller fare differential, than the existing air mode. The likelihood of attracting automobile users to the new rail mode will depend on the level of fare that can be offered, and on whether use of these fares can be protected against penetration from the business sector, which is carried by rail at higher fares.

In each of the market sectors, there is an interaction between fare and ridership, as well as between trip time and ridership. Selective fare reductions to achieve high market success will have the effect of reducing the average fare per mile (the "fares yield"). Where trip times are relatively close, rail can offer a fare approaching the air fare (although in self defense the airlines could reduce fares), but substantial penetration of the automobile sector, or generation of new travel, will take place only at much lower fares. It maybe unwise for rail planners to expect the overall rail fare to be higher than it is now; it may have to be lower to generate the required level of travel and, in some cases, to realize the maximum cost to revenue ratio.

Methods of Evaluating Future Demand

Demand for travel by any mode (including rail) can be forecast in either of two ways:

1. by predicting directly the future of the mode in question, taking into account its relationship with other modes; or
2. by first predicting the future level of all intercity travel and then determining the share likely to fall to the mode in question.

Regardless of the approach taken, the task of trying to forecast the demand for a particular mode, or even travel in general, is a difficult one. The process by which the public chooses between competing modes for any particular trip is complex, and changes in the price, speed, or frequency of one or more modes may alter their relative attractiveness. Computer models have been used to develop forecasts of travel demand. However, for prediction of intercity demand for high-speed rail, such models have been adversely affected by the paucity of good data on automobile travel. For most U.S. corridors, the rail demand data are available only for the currently limited train service. The present service is offered at speeds lower than those envisioned for high-speed service. Thus, models may have limitations in predicting ridership, which is clearly critical to predicting accurately the economic potential of a proposed rail system.

High-speed rail is an intercity mass transit mode requiring high frequencies to be attractive. Table 10 is a matrix of frequency, train size, and capacity showing one possible calculation of annual ridership. In table 10 an average load factor of 60 percent has been assumed for rail, which is above the present Shinkansen level of 53 percent, and probably is as high as can be expected even under favorable circumstances in the United States. The load factor used in the table is translated into ridership on the assumption that the average trip

Table 10.—60 Percent of Maximum Round-Trip Capacity[a] (In millions per year)

Size of train		Frequency		
Cars	Seats	Hourly	30 min.	10 min.
3	200	3	5	16
7	500	7	13	40
14	1,000	13	26	79

[a]Assumes average trip length is one-half route length. Assumes service for 16 hours per day.

SOURCE: Office of Technology Assessment.

is about half the length of the route, which is roughly equal to the travel distance for the upgraded NEC and not quite as high as Shinkansen experience.

Cost Analysis of High-Speed Rail

Basically, there are two categories of costs:

- capital costs (the costs of assembling and constructing the infrastructure), and
- operating costs (the costs of running the system once it has been constructed):

Capital Investment Costs

Capital costs for new high-speed railways comprises several elements:

- Land acquisition. —Land acquisition cost generally is lower in rural and desert areas than in urbanized areas.
- *Terrain.—On* relatively flat, unobstructed terrain, a new line can be built without major excavation, or viaduct and tunnel construction. In such circumstances, costs will be lowest, although still substantially more than using existing right-of-way.

  On the other hand, it is very expensive to construct embankments and to cut through hillsides to make acceptable gradients, and even more expensive where long viaducts and tunnels are needed. The costs for this work will increase with the maximum speed planned. As speed increases, the acceptable curve radius will increase. This, in turn, increases the need to cut through the natural features of the terrain rather than avoiding them.

  Also, environmental problems may have a substantial effect on construction cost—if, for example, tunneling is needed to avoid exposure in sensitive areas, or if diversion is needed to avoid residential areas or areas of natural beauty.
- *Urban areas.* —Construction in urban areas would be difficult without powers of eminent domain. In addition to the cost of land required for the right-of-way, it may be necessary to purchase land and buildings likely to be affected environmentally. Road crossings are a major cost item, and the track may have to be sunk below ground level for environmental reasons.

  New construction in urban areas therefore generally will be the most expensive and difficult to achieve.
- *Buildings and facilities.* —Using existing facilities avoids capital costs for stations, parking, and service facilities. For new construction, the very substantial costs of these items are inevitable, and, in addition, operating costs may be higher because sharing with other operations on routes will not be possible. Where the new route becomes part of an existing network, much of the cost of new buildings and facilities can be avoided.
- *Use of existing track.—Where* an existing railway route is available and suitable for high-speed rail, construction costs will be minimized by using it. However, major realinement of tracks to improve speed can be very expensive and may approach the cost of new construction.

Thus, the options for high-speed railway are, in ascending cost order:

1. use existing right-of-way where suitable, with minimum upgrading (BR—$2½ million per mile);*
2. use existing right-of-way with major upgrading (NEC—$4.5 million to $6 million per mile);
3. construct new right-of-way for inexpensive sectors (SNCF—$4 million per mile);
4. construct completely new right-of-way (JNR–$20 million to $40 million per mile).[2]

Operating Costs

Operating costs can vary considerably depending on track, equipment technology options, and operating conditions in a given corridor, including service frequencies and equipment utilization. Higher levels of service frequency and equipment use should result in lower unit operating costs. For the purposes of simplicity, there are three basic operating cost components: "over the road" operating costs, maintenance of equipment, and maintenance of track. The discussion of these costs that follows is based on steel-wheel on steel rail technology. Magnetic levitation (maglev) is not a technology with a history of revenue service operation. However, manufacturers have suggested that track and equipment maintenance costs promise to be lower for maglev because of friction-free operation and reduction in the number of moving parts.

Equipment maintenance costs naturally are dependent on the type of equipment operated. Electric-powered trains have inherently lower maintenance costs than diesel units. Within a given category of propulsion, operating costs will differ somewhat according to the basic equipment design and construction. Tilt-body equipment, for example, would require more maintenance than nontilting equipment. Equipment utilization depends on the number of train sets required to provide service, the length of the corridor, the schedule, and the required maintenance cycle. Labor agreements and productivity levels also will affect equipment maintenance costs.

*British Rail data extrapolated for U.S. track conditions for a Michigan corridor. Cost per mile will vary with the corridor.

[2]JNR costs are likely to be the maximum due to rugged terrain and congested city areas encountered in building its lines. Elsewhere costs could be cheaper.

A number of variables similarly influence track maintenance costs. These variables include equipment weight, ride characteristics, springs, and wheel profiles. Another important variable is track technology and the relation between it and the vehicles to be operated. Elements of track design include the use of cross ties or slab track construction. The design and formulation of the rail itself is another influence. The most successful systems have designed the track and trains as a unified system. Both the French and British high-speed trains have been designed to run at much higher top speeds than the trains they replaced without adding to the level of track wear. Specific corridor conditions also have an effect on railbed maintenance costs. These include climate, type of subgrade material, and the nature of the alinement selected (e.g., number and extent of curves).

Track maintenance costs also depend on vehicle weight and on unsuspended mass. Heavier trains place greater stress on the track structure. Consequently, maintenance requirements are greater. Variation in equipment design is the principle component of vehicle weight. If higher speeds are to be achieved with locomotive hauled trains, lighter axle loading is necessary. Some high-speed rail systems have managed successfully to reduce track maintenance costs by locating several power units within each train for more uniform, lower axle loadings. Trains also have been designed so that adjacent cars share a single set of axles. Maintenance-of-way costs also depend somewhat on the type of motive power used. In U.S. experience, electric trains generally weigh less than diesel-powered trains and, therefore, require less track maintenance. However, there are design differences. For example, French trains have been designed specifically with low axle loadings in mind and weigh less than the Shinkansen trains.

Direct operating costs associated with actual "over-the-road" operations such as energy, depend on several variables noted earlier; namely, type of propulsion and equipment design, operating speeds, and the specific corridor alinement. Lightweight trains offer lower energy consumption rates. Corridors with low gradients and few curves similarly offer the optimum conditions for low energy costs. Perhaps the most important component of "over-the-road" costs is that associated with labor. Here, costs will depend on such factors as the number of workers required to operate a given train, the basis and rates of pay (hourly v. mileage rates), and the need to change crews.[3]

[3]Information on operating costs was provided by Gordon Peters, Chief, Rail Marketing, New York State Department of Transportation.