Interaction of Air and High-Speed Rail in Japan

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There has been a unique convergence of factors that have contributed to Japan's outstanding public transportation system. The paper focuses on two modes of transportation: air and high-speed rail (HSR). These two modes do not complement each other as in Europe, but compete head-on in Japan. Moreover, Japan does not have to contend with market-distorting public subsidies, because both companies operating HSR in the corridor of interest are highly profitable, primarily because of their HSR service. The Japanese transportation system therefore provides an excellent environment in which to study the nature of competition between air and HSR. (Conventional rail is also discussed where appropriate.) Individual contributors to terminal pair choice are contrasted between air and HSR, and the trade-offs between accessibility, frequency, and speed are analyzed in detail.

This paper addresses the following questions: How do air and high-speed rail (HSR) compete with each other in the absence of market-distorting subsidies and government regulations, under conditions of perfect competition? What effect do capacity limitations have on the competitive environment? How does competition affect the trade-offs that each operator has to make? For example, an airline hub-and-spoke system allows high-frequency service between many small origins and destinations, but increases the probability of delay and lengthens travel times. Also, more frequent stops on a high-speed rail line result in better accessibility but slower service. Most of all, the authors aim to help the reader understand the interactions between different mode choice determinants, both within the mode (air and HSR) and between the two modes.

GEOGRAPHIC FOCUS

The largest high-speed rail systems in operation today are located in Japan and Europe. Air and high-speed rail compete head-on in Japan and do not complement each other as in Europe. Moreover, in two of the Japanese corridors, Tokyo–Osaka and Osaka–Fukuoka, HSR services are highly profitable. In fact, profits derived from HSR service between Tokyo and Osaka have to subsidize the construction cost of newer HSR lines, built for political reasons in less populated areas, which increases its capital cost by over 30%. This forces the operator to set fare levels higher than the inherent cost of providing the service. In the face of cutthroat airline competition, Yoshiyuki Kasai, president of JR Central, calls this a "distortion" (*1*). The analysis presented in this paper focuses on the Tokyo–Osaka and Osaka–Fukuoka corridors.

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ORGANIZATION OF PAPER

The reader cannot be expected to be intimately familiar with Japanese geography and the peculiarities of the Japanese transportation system. A short introduction makes later sections easier to understand. After a brief discussion of the data collection and model estimation, the results are presented in the following sections. Essential mode choice determinants are discussed with the emphasis placed on their interaction. The authors also point out important mode choice determinants that tend to be either underappreciated or completely neglected in contemporary high-speed rail studies. In the concluding sections, the authors summarize the trade-offs that each operator has to make in order to adapt to its competitive environment. A checklist of essential mode choice determinants is also presented as a benefit to other researchers. After outlining their conclusions, the authors speculate on what effect intense HSR competition on the Eastern Seaboard would have on the U.S. air transportation system in that region.

BACKGROUND: JAPANESE TRANSPORTATION SYSTEM

Figure 1*a* illustrates Japan's unusual high mode share of both transit rail and intercity passenger rail compared with other industrial nations (*2*). The United States has the lowest mode share of passenger rail. It is interesting to note that for freight transportation the reverse is true. Railroads in the United States have one of the highest shares of the total freight market (40.6% of tonne-kilometers in 1995), but in Japan rail, cargo is insignificant (4.5% of tonne-kilometers) (*3*). In North America, rail is mostly used for freight transportation, whereas the Japanese rail system is almost exclusively employed for passenger transport. As shown in Figure 2, most major cities in Japan are seaports, which explains both the importance of coastal shipping for freight and ferries for passenger transportation. Coastal shipping accounts for about half of all domestic "tonnes lifted" (*4*).

Air also plays a significant role in passenger travel in Japan (Figure 1*b*). However, Figure 1*c* shows that personal vehicles are used much less than in other countries. There are two reasons for this:

1. Japanese cities are extremely densely populated, making them ideal for rail but not conducive for automobile transportation. Parking is very limited.

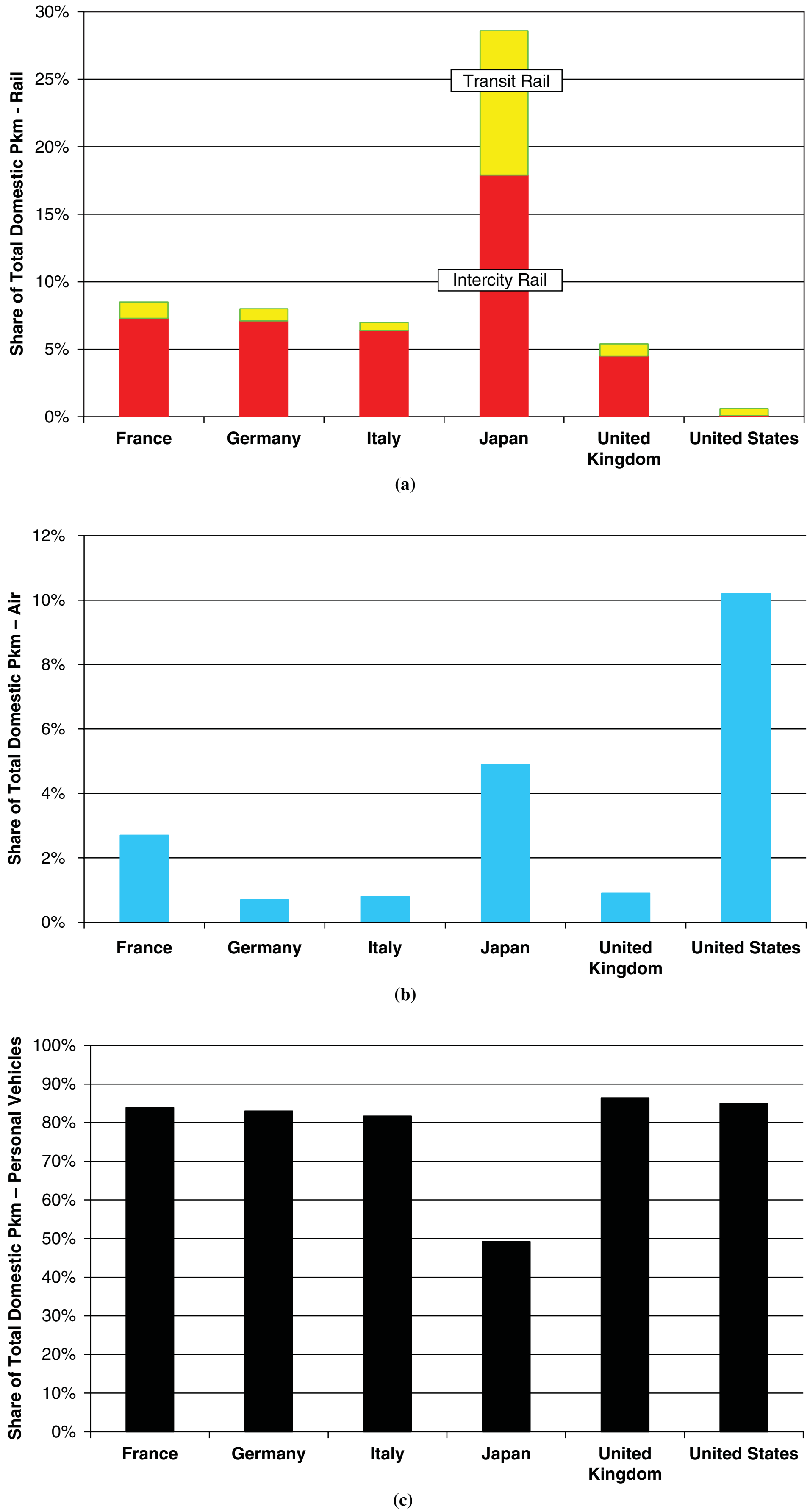

FIGURE 1 The 1999 share of total domestic passenger kilometers (Pkm) by country: (*a*) transit rail and intercity rail, (*b*) air, and (*c*) personal vehicles.

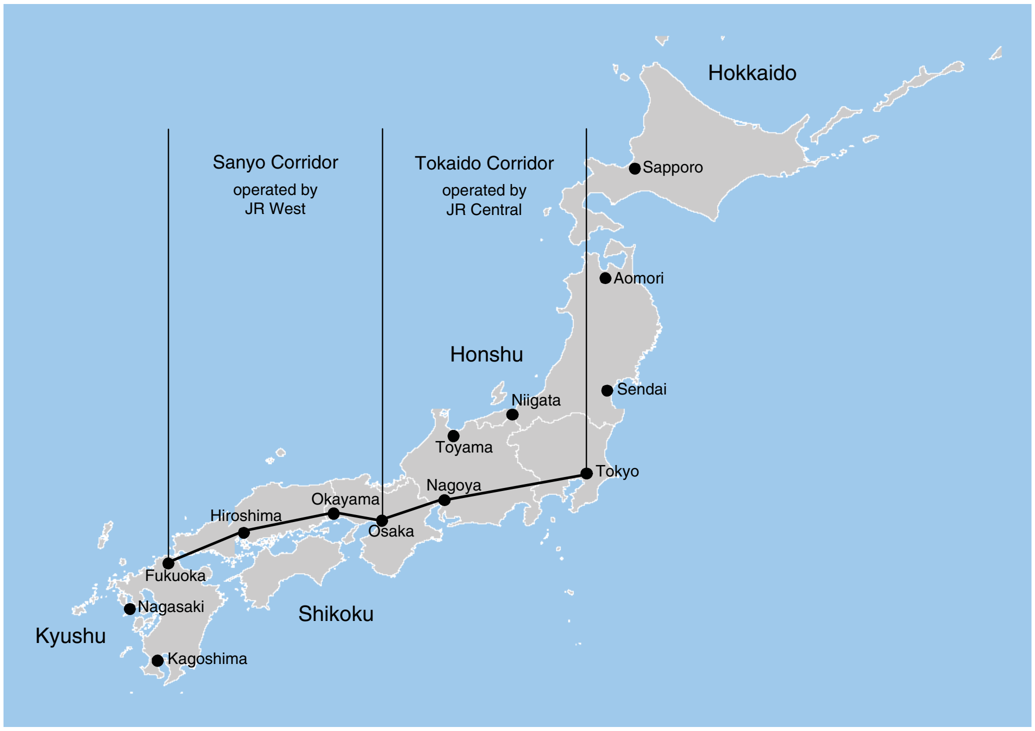

FIGURE 2 Tokaido and Sanyo corridors in relationship to major islands and cities.

2. Japan has 9,000 km of private tollways, including most of the important interurban roads (*2*). This makes intercity travel by car very expensive.

The bus share of total domestic passenger-kilometers is 6.7%, which is average for most industrial countries. This leaves 11.2% of the domestic passenger-kilometers (*4*). Ferries dominate this "other modes" category.

Competition between air and high-speed rail was boosted by the breakup and privatization of the former Japanese National Railroad (JNR) into six vertically integrated regional passenger railways and one national freight carrier in 1987, followed by domestic airline deregulation introduced in stages in the 1990s. The main island, Honshu, is served by three passenger railways: JR East, headquartered in Tokyo, controls the region to the east and north of Tokyo. JR Central (jr-central.co.jp/eng.nsf) operates out of Nagoya and runs the nation's busiest intercity corridor between Tokyo and Osaka. JR West (www.westjr.co.jp/english/) is based in Osaka and is responsible for the Sanyo corridor between Osaka and Fukuoka (Figure 2).

Japan's conventional railways are narrow gauge (1,067 mm). Their advantage is the smaller footprint, which is the reason why meter gauges (1,000 mm) are often used for streetcars and special mountain railroads elsewhere. However, the small gauge limits both transport capacity and speed.

On October 1, 1964, the first standard-gauge "new trunk line" (in Japanese: "shin kan sen") was opened in the heavily populated Tokyo–Osaka ("Tokaido") corridor. By 1975 the line was extended through the Sanyo ("Mountain Sunshine") area to Hakata/Fukuoka on the island of Kyushu. The Tokaido and Sanyo Shinkansen lines serve two-thirds of the Japanese population. Three-quarters of the Japanese economy (the second largest in the world) is concentrated in the Tokaido and Sanyo areas (*5*).

To help decentralization and regional development efforts, Shinkansen lines from Tokyo into the eastern parts of the country began operation in the early 1980s. Because these lines were built into regions with low population densities, they did not necessarily have to be profitable.

Standard-gauge (1,435 mm), high-speed Shinkansen services give travelers a choice of three train categories. Local and regional service with stops every 30 to 40 km is called Kodama or "Echo." There are two long-distance services: Hikari ("Lightning") and the extra-fast, premium service Nozomi or "Hope" (Figure 3). The fare for Kodama and Hikari service is the same, so no passengers would use a Kodama between two Hikari stations. Nozomi requires a surcharge and Japanese rail passes are not valid on this train. Figure 3 compares the Tokaido and Sanyo Shinkansen lines with Amtrack services in the Northeast and Crescent (New York–Atlanta, Georgia–New Orleans, Louisiana) corridors.

The distance from Tokyo to Nagoya is equivalent to the distance from New York to Washington, D.C. Because of the fast Nozomi and Hikari train service, this market was abandoned by the airlines shortly after the opening of the Tokaido line in 1964. By contrast, New York to Washington, D.C., is one of the largest air travel markets in the United States. If the Acela Express were to make six additional stops between New York and Washington, D.C., and still made the trip in 2 h 50 min, its service would be equivalent to the all-stop Kodama. The average speed including all stops is the same for both Kodama and Acela Express trains: 130 km/h or about 80 mph.

Punctuality is one of the railways' strengths. "The average delay per train throughout the year is 0.4 minutes, including delays caused by typhoons, earthquakes, snowfall, heavy rain, and other natural disasters" (*1*). The distance between Tokyo and Fukuoka is about the same as from New York to the border between South Carolina

km			*Travel Time from NY* Crescent	*Travel Time from NY* Acela Express	*Average Speed in km/h* Crescent	*Average Speed in km/h* Acela Express
0	**New York**	**NY**	0:00	0:00	0.0	0.0
16	Newark	NJ	0:22	0:14	43.9	69.0
40	Metropark	NJ		0:27		88.9
93	Trenton	NJ	1:00		93.3	
146	Philadelphia	PA	1:40	1:13	87.9	120.4
187	Wilmington	DE	2:04	1:32	90.3	121.8
298	Baltimore	MD	3:02	2:15	98.2	132.3
318	BWI Airport	MD				
362	**Washington**	**DC**	4:15	2:50	85.2	127.8
375	Alexandria	VA	4:34		82.1	
415	Manassas	VA	5:07		81.1	
472	Culpeper	VA	5:40		83.2	
542	**Charlottesville**	**VA**	6:37		82.0	
641	Lynchburg	VA	7:51		81.6	
742	Danville	VA	8:59		82.6	
824	Greensboro	NC	10:00		82.4	
843	High Point	NC	10:24		81.1	
900	Salisbury	NC	11:02		81.5	
967	Charlotte	NC	12:05		80.0	
1003	Gastonia	NC	12:57		77.4	
1091	Spartanburg	SC	13:59		78.0	
1141	Greenville	SC	14:39		77.9	
1189	Clemson	SC	15:24		77.2	
1244	Toccoa	GA	16:00		77.8	
1304	Gainsville	GA	16:43		78.0	
1382	**Atlanta**	**GA**	17:58		76.9	

km		*Travel Time from Tokyo* KODAMA *fast*	*Travel Time from Tokyo* HIKARI *faster*	*Travel Time from Tokyo* NOZOMI *fastest*	*Average Speed from Tokyo in km/h* KODAMA *fast*	*Average Speed from Tokyo in km/h* HIKARI *faster*	*Average Speed from Tokyo in km/h* NOZOMI *fastest*
0	**Tokyo**	0:00	0:00	0:00	0.0	0.0	0.0
9	Shinagawa	0:08	0:07	0:07	67.5	77.1	77.1
29	Shin-Yokohama	0:20	0:17	0:18	87.0	102.4	96.7
84	Odawara	0:41	0:34		122.9	148.2	
105	Atami	0:51			123.5		
121	Mishima	1:04			113.4		
146	Shin-Fuji	1:14			118.4		
180	Shizuoka	1:29			121.3		
229	Kakegawa	1:45			130.9		
257	Hamamatsu	2:03			125.4		
294	Toyohashi	2:22			124.2		
336	Mikawa-Anjo	2:38			127.6		
366	**Nagoya**	2:50	1:46	1:36	129.2	207.2	228.8
396	Gifuhashima	3:03	2:00		129.8	198.0	
446	Maibara	3:23	2:21		131.8	189.8	
514	**Kyoto**	3:45	2:45	2:12	137.1	186.9	233.6
553	**Shin-Osaka**	4:00	3:00	2:25	138.3	184.3	228.8
590	Shin-Kobe	4:17	3:15		137.7		
612	Nishi-Akashi	4:27			137.5		
644	Himeji	4:47	3:32		134.6	182.3	
665	Aioi	4:59			133.4		
733	**Okayama**	5:19	3:54	3:13	137.9	187.9	227.9
758	Shin-Kurashiki	5:33			136.6		
791	Fukuyama	5:47	4:12		136.8	188.3	
811	Shin-Onomichi	6:01			134.8		
823	Mihara	6:08			134.2		
862	Higashi-Hiroshima	6:22			135.4		
894	**Hiroshima**	6:49	4:37	3:48	131.1	193.6	235.3
936	Shin-Iwakuni	7:08			131.2		
987	Tokuyama	7:28			132.2		
1031	Shin Yamaguchi	7:48	5:10		132.2	199.5	
1070	Asa	8:10			131.0		
1093	Shin-Shimonoseki	8:22			130.6		
1112	Kokura	8:31	5:30	4:33	130.6	202.2	244.4
1180	**Hakata (Fukuoka)**	8:52	5:47	4:50	133.1	204.0	244.1

FIGURE 3 Tokaido and Sanyo Shinkansen compared with the Northeast and Crescent corridors. (Source: Amtrak timetable effective October 29, 2007; JR Central/JR West timetable effective October 1, 2007 through November 30, 2007.)

and Georgia. Once the Shinkansen line is extended to Nagasaki, it would be equivalent to New York to Atlanta.

By December 1, 2002, the total length of high-speed double-track Shinkansen lines had reached 2,049 km. However, the original 515-km Tokaido line still carries well over half of all passenger-kilometers (*6*). Air competition is significant in the Tokyo–Osaka market where the Shinkansen line still carried 80% of all passengers in 2003. However, that means a decrease over 5 years by 6% (Table 1). Three airlines have gone on the offensive and introduced cheap fares and frequent flights. After the opening of the Shinagawa station 9 km southwest of Tokyo Central on October 1, 2003, Nozomi service was improved from three to seven trains per hour (one every 8.5 min). Three cars in each Nozomi train are now available for passengers without reservations (*7*). The number of Hikari semi-fast trains was reduced, as was the fare differential between Nozomi and Hikari.

Shinagawa station shortened access time by 20 to 30 min for travelers in Tokyo's southwestern suburbs (*8*). Tokyo-Ueno, 4 km north of Tokyo Central, was connected to Tokyo Central by underground tunnel in 1990. This allows passengers from the eastern parts of the country to reach Tokyo Central. However, no Shinkansen trains run beyond Tokyo Central.

DATA COLLECTION AND MODEL ESTIMATION

Main Data Source and Estimation Results

The main data source for this analysis was the 1995 Japanese Intercity Travel Survey. Each observation corresponds to an actual intercity trip taken in the fall of 1995 of a single traveler with one origin and one destination. The data were used to estimate lower-level terminal pair choice models for each mode and an upper-level mode choice model (Figure 4). A total of 30,126 records for the airport pair choice and 18,395 records for the HSR station pair choice models were used. The choice set consisted of 82 airport pairs and 1,260 HSR station pairs. A detailed description of data sources, sampling issues, and model results can be found in Clever (*9,* pp. 162–264). This paper summarizes a few key results.

Utility Impact Analysis

A utility impact analysis was performed by using the travel survey to describe a "typical" intercity air and HSR traveler in the fall of 1995 and by employing median values for the other socioeconomic and land use variables. The total positive utility and the absolute value of the total negative utility were added to yield a total absolute utility. This allowed the authors to calculate the impact of each terminal pair choice determinant on the total absolute utility. Utility was calculated for three different scenarios (*9,* pp. 226–230):

- Both access and egress distances are at the 25th percentile.
- Both access and egress distances are at the median.
- Both access and egress distances are at the 75th percentile.

TABLE 1 Combined Air and HSR Market Shares in the Tokaido and Sanyo Corridors, 1999 (*7*)

		Market Share (%)		
km	Market	Air	HSR	Passengers/Day
366	Tokyo—Nagoya	0	100	54,000
553	Tokyo—Osaka	14	86	103,000
733	Tokyo—Okayama	18	82	6,000
894	Tokyo—Hiroshima	44	56	12,000
1,180	Tokyo—Fukuoka	88	12	22,000

MODE AND TERMINAL PAIR CHOICE DETERMINANTS

Line-Haul Time

It is self-evident that line-haul time is the most important mode choice determinant when modeling a binary choice between air and HSR and the utility impact analysis confirmed this. All the other attributes remained relatively constant with the introduction of HSR in Europe and Japan. This is also the most easily obtainable supply-side attribute because of widely available published timetables.

Line-haul time is probably air's strongest competitive advantage. In markets in which air competes vigorously with HSR, it tends to defend its edge by offering nonstop flights with high schedule reliability as discussed below.

Accessibility

Utility Impact of Access- and Egress-Related Variables

The utility impact of access- and egress-related variables was fairly similar between air and HSR. It ranged from 26% at the 25th percentile to about 42% at the 75% percentile of access and egress distance. Forty-two percent of total absolute utility deserves close attention by the researcher. Access and egress have been the stepchild of intercity mode choice models. Often only a linear specification is used to model access and egress distance—an approach that can underestimate its disutility by two-thirds. A better approach is outlined below.

Correct Functional Form of Feeder Distance

Let feeder distance be the sum of access distance plus egress distance. Common sense and experience lead us to believe that reducing access distance from 2 km to 1 km increases the utility of that choice far more than reducing the distance from 102 km to 101 km. It can be presumed that a solely linear specification would not represent the data faithfully.

Linear, quadratic, cubic, log plus linear, and piecewise linear models were estimated. Only the logarithmic line reflected the pattern observed through piecewise linear approximation. For almost half of the data points, between 20 km and 140 km, the slope of all functional forms was very similar, resulting in approximately the same marginal disutility. But for the first half of the data points, the linear, quadratic, and cubic forms depicted the underlying data inaccurately and vastly underestimated the disutility of access distance.

The problem is that if those functions tried to match the slope of the piecewise linear or logarithmic curves for the first half of the data points, the negative utility for long access distances would be so

Upper Nest Mode Choice Model

	Parameter Estimate	*Standard Error*
HSR Intercept	2.9299	0.04170
Inclusive Value for Air	0.0638	0.00631
Inclusive Value for HSR	0.7271	0.01160

Airport Pair Choice Model (A 1-2)

	Parameter Estimate	*Standard Error*
Access Distance	**-0.050**	**0.001**
log (Access Distance)	**-0.695**	**0.048**
Acc Dist * Origin Pop Dens	9.44E-07	8.19E-08
Acc Dist * Vacation	0.016	0.001
Egress Distance	**-0.037**	**0.001**
log (Egress Distance)	**-0.724**	**0.054**
Egr Dist * Co Business	**-0.011**	**0.001**
log (Air Frequency)	0.990	0.044
Air Time	-0.037	0.006
Air Fare / Home Zone	-2.33E-04	2.73E-05
Tokyo Narita	-0.575	0.147
Fukuoka Itazuke	-1.496	0.294
Osaka Itami	1.250	0.277
Kagoshima	-1.617	0.302
Miyazaki	-1.417	0.303
Nagoya	0.477	0.214
Nagasaki	-1.813	0.293
Oita	-1.973	0.303
Kumamoto	-2.222	0.297
Hiroshima	0.266	0.302
Osaka Kansai	1.765	0.278
Yamaguchi Ube	-2.803	0.316
Okayama	0.073	0.287
Fukuoka Kita-Kyushu	-3.577	0.329
Tokyo Haneda	0.000	.

HSR Station Pair Choice Model (R 300-2)

	Parameter Estimate	*Standard Error*
Access Distance	**-0.013**	**0.001**
log (Access Distance)	**-0.867**	**0.016**
Acc Dist * Co Business	0.002	0.001
Acc Dist * Veh Ownership	-6.71E-05	7.91E-06
Acc Dist * Linehaul Time	4.13E-05	2.35E-06
Acc Dist * Origin Pop Dens	2.14E-07	4.01E-08
Acc Dist * Vacation	0.004	0.001
Acc Dist * (Age < 30)	*5.14E-04*	*4.76E-04*
Egress Distance	**-0.019**	**0.001**
log (Egress Distance)	**-0.695**	**0.014**
Egr Dist * Co Business	**0.003**	**0.001**
Egr Dist * Male	1.47E-03	5.83E-04
Egr Dist * Veh Ownership	-1.63E-05	7.31E-06
Egr Dist * Linehaul Time	3.10E-05	2.62E-06
Egr Dist * Dest Pop Dens	1.70E-07	4.04E-08
Egr Dist * Vacation	0.002	0.001
Egr Dist * (Age < 30)	1.29E-03	4.62E-04
Nozomi Time	-0.019	0.001
Nozomi Transfers	-0.343	0.033
Origin Sta = Tokyo Central	0.735	0.050
Dest Sta = Tokyo Central	0.684	0.050
Origin Sta = Shin Osaka	0.668	0.043
Dest Sta = Shin Osaka	0.601	0.042
Nozomi Origin Sta	1.508	0.036
Nozomi Dest Sta	1.444	0.035

$$\frac{\text{Access Distance} \quad -0.050}{\text{log (Access Distance)} \quad -0.695} = 0.072 \qquad \frac{\text{Access Distance} \quad -0.013}{\text{log (Access Distance)} \quad -0.867} = 0.015$$

$$\frac{\text{Egress Distance} \quad -0.037}{\text{log (Egress Distance)} \quad -0.724} = 0.051 \qquad \frac{\text{Egress Distance} \quad -0.019}{\text{log (Egress Distance)} \quad -0.695} = 0.027$$

FIGURE 4 Model estimation results.

high that the model would predict that they would never be chosen. And, as with all regressions based on minimizing least squares, outliers have a disproportionate influence on the final estimate.

Logarithms make small numbers big and big numbers small. This adds to their ability to pick up gradually decreasing slopes in a relatively small interval at the beginning of the data series (Figure 5). It also provides a counterbalance to the impact of large outliers in ordinary least-squares regressions and the resulting difficulty of many functional forms to reflect important patterns in intervals of small numbers, as is the case with quadratic and cubic specifications. The log plus linear function composition allows the linear element to minimize squared deviations for the longer distances, while the logarithmic component can match the data in the small but densely populated segment of short access distances.

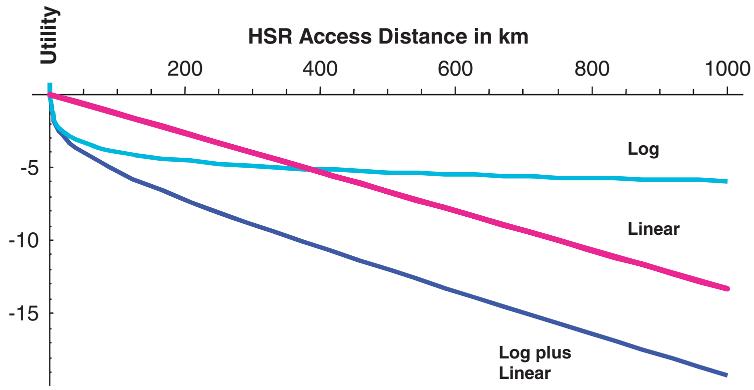

FIGURE 5 Graphical addition of logarithmic and linear component for HSR access distance.

Access Versus Egress Distance

The flexibility of the log plus linear specification is illustrated by the difference in estimation between HSR access and egress distance. The logarithmic coefficient is larger for access, but the linear parameter is greater for egress distance. Because of the larger logarithmic element, the utility of access distance falls faster at the beginning of the range where the logarithmic component dominates the linear. As distance increases, the linear term becomes more important and the access curve falls more slowly than the egress line. The authors' estimation found that for small and medium distances access has a higher influence on utility, whereas for longer distances egress becomes more onerous. The log plus linear function lines crossed at 157 km. The access and egress lines of the piecewise linear specification intersected at 144 km.

Air Versus Rail Accessibility

By analyzing the distance distributions to and from the chosen airport or station, it was found that the rail distributions have fatter tails, or more very short and more very long access journeys compared with air. The relatively high number of short access trips is easy to explain with station locations in the center of urban activity. Very long access trips are likely to be made by rail, given this mode's dominance of intercity travel in Japan. High-speed rail stations are almost by definition easier to reach by rail than airports, which makes the trip continuation on HSR very sensible.

The terminal pair choice models confirm what the descriptive statistics seem to indicate: airport access and egress distance appear to be perceived as being more onerous for longer distances than access and egress to and from an HSR station.

- The linear component of both access and egress distance in log plus linear specifications of access and egress distance was found to be more dominant in airport pair choice models, pointing to a rapid decline in utility as distance increases (Figure 4).
- Piecewise linear specifications of access and egress distance indicated that the range in which air travelers are the most indifferent to changes in access or egress distance is between 15 km and 30 km. For HSR travelers, the equivalent range is between 60 km and 120 km.
- The coefficient for business travel interacted with egress distance has a negative sign for air, but is positive for HSR (Figure 4). The term was positive in seven HSR models, significant at the 5% level in five of them, and fairly stable at around 0.002 to 0.003. The difference in signs is not likely due to chance fluctuation.

HSR passengers can easily and conveniently continue their journey on the narrow-gauge (1,067 mm) railway. Except for a lower speed, the travel experience on the conventional railroad is likely to be very comparable to the high-speed rail segment. Most business travelers would probably transfer from the high-speed train's First Class to the conventional train's First Class and continue their work. Except for the inconvenience of a transfer, the marginal disutility of travel time might not change markedly.

While the distinction between access, egress, and line-haul can be somewhat blurred for HSR passengers, air travelers may perceive those transitions as very abrupt. Egress from the airport can seldom be used productively and most business travelers might think of it as a "waste of time." That makes egress from the airport more onerous for the business segment than for people traveling for a different purpose. The distinction between access and line-haul is really the distinction between productive and unproductive time. On the other hand, egress on the conventional rail network can be used productively, so business travelers find it less onerous than leisure travelers who are eager to get home.

It is against this background that the opposite sign of the company business indicator for air and HSR egress distance might be understood. It can be concluded that HSR dominates market segments in which it has an access advantage over air. HSR does well with trips that start or end in the center of the city, because of short access distances, or with trips that start or end far away from the city, because of the ubiquitous and convenient transit rail system in Japan (Figure 1). It does not do as well with suburban origins and destinations.

This does not bode well for HSR prospects in the United States. Downtown-to-downtown connections do not offer a great access advantage in decentralized, widely dispersed U.S. metropolitan areas. In North America, outside of the Northeast corridor, most business trips do not originate or terminate in the central business district. At the other end of the spectrum, for very long access distances, the extensive feeder system of conventional rail lines on which the Shinkansen relies is almost nonexistent in the United States. So HSR in the United States will have to compete with air in the suburb-to-suburb market, which means that a much more sophisticated approach than simple downtown-to-downtown connections will probably be necessary for HSR to be competitive with air.

Relationships Between Line-Haul Time, Number of Transfers, Frequency, and Fare

Table 2 summarizes the discussion in this section for easy reference.

Air Transfers: Nonexistent

If all of the possible origins and destinations (O's and D's) in the United States were considered, most O and D combinations would be found to have no direct air service. But if one transfer was allowed, the number of O's and D's with air service would increase dramatically due to the hub-and-spoke system of most airlines. It can be surmised that there is basically no hub-and-spoke system for domestic air travel in Japan in the authors' area of interest, most likely because flight connections through hubs are unappealing not only for short distances, but also for medium distances such as Tokyo to Fukuoka (comparable to New York to Atlanta), when the competing HSR mode only takes 5 hours.

A domestic hub-and-spoke system in Japan is not only undesirable, it is also infeasible. Because most of the daily flights at a hub airport operate within a few relatively short time windows, the space requirements are extremely high. The area of the new Denver, Colorado, International Airport is 135 km^2 or 35% larger than the city of San Francisco. Building a new airport of that size in Europe or Asia is only possible in exceptional circumstances (e.g., in Hong Kong) (*10*). Major international hubs, such as Osaka Kansai, have only one runway. Tokyo Narita did not open its second runway until 2002, and that second runway is barely over 2,000 m long.

TABLE 2 Mode and Terminal Choice Determinants in the Tokyo–Fukuoka Corridor

	Relationships Between Mode Choice Determinants by Mode	
	Air	HSR
Mode		
Transfers Frequency	Constant (0) Great variability	Great variability Almost constant
Fares Distance	Low correlation	Highly correlated
Distance Line-haul time	Low correlation	Highly correlated
Line-haul time Fares	Two distinct effects	Same effect
Distinct Mode		
Transfers Frequency	 Yes	Yes
Fares Distance		
Distance Line-haul time		
Line-haul time Fares	Yes Yes	Yes

HSR Transfers: An Important Choice Determinant

Many American and European studies quantify the disutility of a transfer in the middle of a long-distance trip (*11–14*). Here are similar experiences in Japan.

JR West reports that it was able to increase its market share on the Sanyo corridor by 10% in the 4 years since the introduction of improved Hikari service in March 2000. Because of the policy differences with JR Central, however, that success could not be repeated for services to the capital. Many of the Nozomi and Hikari services terminated in Osaka, which meant that passengers who wanted to travel between a station on the Tokaido line and a station on the Sanyo line had to change trains in Osaka.

These problems were overcome with the opening of the Shinagawa station and the timetable change in October 2003. More through services were offered between Nozomi stops on the Tokaido line and Nozomi stops on the Sanyo line. More important, several stations west of Osaka, which were formerly served only by local Kodama and semi-fast Hikari trains now received through Nozomi services to Tokyo. As an example, Shin-Yamaguchi–Tokyo business increased by 30% in the first 6 months because of "passengers' natural disinclination to change trains en route when traveling with heavy baggage," and the 1-h journey time savings compared with the previous semi-fast Hikari train (*15*).

JR West was willing to break the pattern of fast trains only stopping at certain stations mainly because of the ridership penalty of a transfer in the middle of a long-distance trip.

Air Frequency Varies Between Terminal Pairs; HSR Frequency Does Not

Air frequency has significant explanatory power because it varies greatly between airport pairs. Airlines in general and especially airlines in Japan tend to concentrate their service offerings in a few highly competitive markets for two reasons:

- Unlike HSR competing with air, airlines competing with HSR have to offer almost exclusively nonstop service because the time penalty and incremental cost for an additional stop is comparatively high.
- Unlike HSR, airlines have to compete with each other. The S-curve explains their tendency to "oversupply" competitive markets (*10,* pp. 120–121).

Airfares and Air Time: Two Distinct Effects, But Not So for HSR

Because of asymmetric supply in different markets, the correlation between airfares and distance tends to be much weaker than between rail fares and distance. Highly competitive markets generally have lower fares than less competitive ones. As a case in point of the strong correlation (almost a perfect 1) between rail fare and distance, consider that the majority of European railways priced their services exclusively on a per-kilometer basis. Only with the advent of HSR did the tariff structure for most long-distance connections change to a city pair-based system.

Additionally, air time and distance are not as highly correlated as rail line-haul time and distance. In relatively short-haul domestic markets, take-off and landing, ascent and descent, and taxiing to and from the gate take up a much greater portion of total air time than cruising. The data used in this analysis show a range of 60 min for air time versus almost 6 h for rail line-haul time.

Airfares and air time are also not strongly correlated because each one is driven by different factors. That enables us to distinguish between the two effects in airport pair choice models.

While neither airfare nor air time are strongly correlated with air distance, the HSR fare estimated using a linear regression on available data was highly collinear with time and distance. A few attempts to use the estimated fare gave counterintuitive results.

The lack of accurate fare data can be a significant shortcoming of an air/rail mode choice model if a HSR operator uses pricing to compensate for longer line-haul times. The fare offered between Tokyo and Fukuoka (HSR market share 12%) might be much lower on a per kilometer basis than between Tokyo and Osaka (HSR market share 86%). However, this was not apparent from the available fare data used for the regression, and the authors do not have any other indication that this might be the case in Japan. The reason is the significant capacity constraint under which the Shinkansen system operates.

HSR Transfers: Corollary to Air Frequency

"Transfers being a terminal pair choice determinant only for HSR" is the corollary to "frequency being a significant explanatory variable only for airport pair choice models." Because airlines cannot offer service requiring a transfer in markets where they compete with HSR because it would destroy their line-haul time advantage, they have to focus on a few city pairs that allow them to fly frequent nonstops. The concentration on major airport pairs leads to a clear distinction between different markets in terms of air frequency and makes this an important terminal pair choice determinant for air.

HSR operators are able to offer service between many different cities, but can only do so by requiring transfers. In order for rail travel to and from smaller and medium-size cities to be fast enough, the major portion of the trip has to be spent aboard superfast express trains making relatively few stops. When traveling to smaller destinations, this is generally not possible without a transfer in a major city. If potential rail travelers were forced to take local trains, such as the Kodama, for the whole length of the trip, many might choose air even if it necessitated driving to and from a distant airport.

HSR Frequency

Line capacity is continuously being improved, and after the introduction of digital ATC (automatic train control) in 2004/2005, JR Central was able to increase its peak frequency to 13 trains per hour: eight Nozomi, two Hikari, and three Kodama (*17*). This means that one superfast Nozomi train leaves Tokyo or Osaka every 7½ min, causing the frequency delay at least in peak hours to be zero.

The rate of 13 trains per hour means one train every 4.6 min, which in and of itself would not indicate an extraordinarily efficient use of track capacity. In France, all high-speed trains from a particular section of the country (e.g., the southeast) are bundled on the same high-speed line approaching Paris. In this bottleneck, the railway can handle 20 trains per hour running at 300 km/h. That is one train every 3 min. However, the French railroad does not have intermediate stops with which to contend. By studying Figure 3 and only considering the peak hour frequency of eight Nozomi and three Kodama trains, one can see just by inspection that the Kodama trains on their 2 h 50 min journey from Tokyo to Nagoya are being passed continuously by faster Nozomi trains, which cover the same distance in only 1 h 36 min. This line only has two tracks, with sidings facing outside platforms at each intermediate stop.

The Japanese railways use their given capacity extremely efficiently considering the simultaneous operation of three train categories. But overall line capacity is reduced precisely because of the operation of three train categories. It would not be possible to offer such a high frequency with three different train categories without train operators following their schedules extremely closely.

Schedule Reliability

Reliability is an important consideration for the traveler, because the better the on-time performance, the closer the trip maker is able to schedule the arrival time to the actual time he or she needs to be at the destination. If air and rail compete vigorously in a particular market and rail has an excellent reliability, air service will have to match approximately that performance or its shorter line-haul time advantage will become completely meaningless—which is what generally tends to happen in those markets.

Before JNR was privatized in 1987, the average deviation from schedule on the Tokaido (Tokyo–Osaka) Shinkansen line was 3.1 min. This improved in the first decade after privatization to 0.7 min, and then fell to 0.4 min (*16*).

But the average delay of 0.4 min is misleading. Except for 1 or 2 days a year, when a natural disaster causes the whole system to be delayed by a few hours, driving up the average, trains are operating within a few seconds of schedule.

It comes as no surprise that domestic airlines also have a very good on-time performance. In 2000 All Nippon Airways (ana.co.jp/eng/) reported 97.7% of all of its flights between Tokyo Haneda and Osaka (Itami and Kansai) were either on time or no more than 15 min late. The equivalent figure for Tokyo–Fukuoka was 97.1%. The corresponding statistics from the Airline Service Quality Performance data for all flight arrivals in February 2001 at the Los Angeles International and San Francisco International airports in California are 60% and 60.3%, respectively (*17*).

Figure 6 directly compares the reliability statistics mentioned in this subsection. It is not a major inconvenience for an air traveler between Tokyo and Osaka to add a little more than 15 min to the schedule to ensure his or her arrival by a certain time.

However, the 1 h 15 min extra time required by passengers using Los Angeles International Airport would cut the line-haul time advantage of air over a potential HSR system by more than one-half, significantly reducing its competitiveness. The same can be said about San Francisco International Airport. We could reasonably expect airlines to assign a higher priority to on-time performance in the face of direct HSR competition. At this point, U.S. high-speed rail proposals generally do not consider the likely benefit of much improved on-time performance on the part of domestic carriers, not even in the corridor where a HSR line would be built.

Safety

With the sole exception of Germany, where a high-speed train set derailed on a conventional line between Hamburg and Hanover in 1998, no HSR passenger has ever been killed, making it the safest

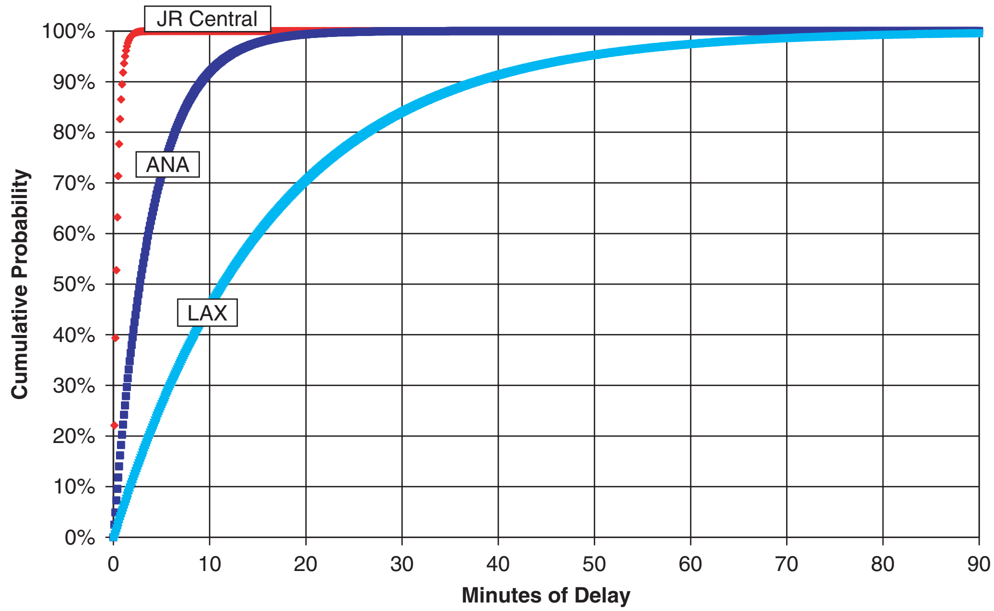

FIGURE 6 Cumulative distribution functions of schedule delays. (ANA = All Nippon Airways; LAX = Los Angeles International Airport.)

mode available to date. Because of frequent earthquakes, Japan has developed a very sophisticated early warning system, which brings high-speed trains to an immediate stop before the earthquake shockwave has reached the respective train positions. This system, however, was of no help during an earthquake in 2004 near Niigata that occurred right underneath a train traveling at high speed. The train derailed but remained upright and no passengers were injured. Similarly, a train traveling at 300 km/h derailed between Paris and Lille because a tunnel dating back to World War I had weakened the foundation of the rail bed. Again, the train remained upright and no passenger was hurt. These two events illustrate the resilience of this mode to potentially very dangerous situations.

In the absence of any accident in Japan in which a HSR passenger was injured since HSR's inception in 1964, it may be useful to consider briefly a train crash on Japan's conventional network. The extreme attention to schedule adherence discussed in the previous section is not only an integral part of HSR but also conventional rail operations in Japan. The accident on April 25, 2005, of a suburban commuter train near Osaka focused attention on the high price that had to be paid for exemplary on-time performance. JR West also operates the Sanyo Shinkansen line between Osaka and Fukuoka.

The Ministry of Transport has ordered JR West to draw up a strategy to improve safety and driver training. This follows allegations that JR West reprimands drivers too harshly when they are believed to have caused delays. According to union officials, punishments include pay cuts, demotions, or a long-winded re-education process. JR West says it may change its re-education policy (*18*).

Before the accident, it was well known that train operators were being fired for what most people would consider minor delays. The facts that the derailment occurred in a 300-m-radius curve restricted to 70 km/h and that passengers reported unusually high speeds for a train which was running late called this policy into question. The train was running 90 s late because the driver had overshot the previous station by 40 m, forcing him to back up to the platform. At the time of the accident, the train was traveling at a speed of 108 km/h (*19*).

CONCLUSION 1. UNDERSTANDING TRADE-OFFS

In order to appreciate fully the uniqueness of the Japanese high-speed rail system, the trade-offs made in France and Germany are briefly considered.

German HSR: High Accessibility, High Frequency, and Low Speed

Germany is somewhat of a special case among high-speed train systems. The German ICE system, unlike any other, trades off speed against frequency. It offers pulse scheduling (hourly or half-hourly) and short average distances between stops (about 90 km) in order to serve every station with high frequency. This, and the fact that HSR lines do not bypass medium-size cities as in other countries, causes Germany to have the slowest "high-speed" rail system in the world (*20,* p. 162, Figure 9).

French HSR: Low Accessibility, Low Frequency, and High Speed

While an individual train needs to trade longer line-haul time for better accessibility because of the extra stops required, the HSR system as a whole will usually trade frequency for better accessibility. Finite demand only supports a fixed number of hourly trains. If one of those trips serves intermediate stations, it cannot be used for nonstops. A good example of this kind of HSR operation is in France, with a limited number of fast nonstop connections between Paris and provincial centers.

Japanese HSR: High Accessibility, High Frequency, High Speed

The uniqueness of Japan's transportation system stems from the fact that two-thirds of its population, or almost 100 million people, live in a narrow, densely populated corridor along the south shore of Honshu Island between Tokyo and Fukuoka. This corridor is ideally suited for rail operations. Because of the extreme economies of density, the Japanese HSR system in the Tokaido and Sanyo corridors does not need to trade frequency for accessibility. With extremely high schedule reliability, it can operate several train categories on the same track, not having to trade speed for accessibility.

The different supply-side attributes discussed so far are interrelated in the following ways:

1. Japanese railway companies are in the enviable position to be able to offer high speed, high frequency, and high accessibility because of very strong demand for their services in a narrow, densely populated corridor ideally suited for rail operations.
2. Because their customers experience no schedule delay and can enjoy very fast downtown-to-downtown connections, fare levels for HSR overlap with those for air in highly competitive markets such as Tokyo–Osaka.
3. Offering superfast Nozomi service every 7½ min in peak hours while at the same time operating two other train categories with a much larger number of intermediate stops requires severe attention to schedule reliability.
4. This, however, could lead to a safety problem in the future, as the recent commuter train accident has illustrated.

Japanese railway companies, of course, do not consciously trade off safety in order to achieve high speed, frequency, and accessibility simultaneously, although the recent accident seems to indicate that they may have pushed the safety envelope a little too far. However, what is being compromised is capacity. Thirteen trains per hour are noticeably fewer than the 20 trains per hour achieved in France. The Tokaido line has been consistently operating at capacity and the options for a capacity increase (better signaling system, higher speed, etc.) have almost been exhausted. Airports operate close to capacity and expansion possibilities are limited. Domestic airlines already employ the largest equipment available, 747's with high-density seating. This is the reason for the Railway Technical Research Institute (www.rtri.or.jp) conducting research on superconducting maglev technology at the Yamanashi test track, which will eventually become an integral part of the Chuo maglev line between Tokyo and Osaka.

Japanese Airlines: Focus on Few Large Markets with Frequent Nonstop Service

In order to compete with potent ground transportation, airlines focus on frequent point-to-point flights in a few select markets. A large domestic hub-and-spoke system would be neither desirable nor feasible.

HSR cannot achieve high accessibility, high frequency, and high speed simultaneously without impeccable on-time performance. This forces competing airlines to operate with a high level of schedule reliability lest they lose their most important competitive advantage: a shorter line-haul time.

CONCLUSION 2. HSR USES ITS NATURAL ACCESS ADVANTAGE

Trips with either very short or very long access distances are almost exclusively made by HSR. Air only competes in the middle segment of access and egress distances. That means that HSR in Japan is able to use its natural access advantage to compensate for the shorter line-haul time of air.

CONCLUSION 3. A CHECKLIST OF ESSENTIAL CHOICE DETERMINANTS

Table 3 summarizes Table 2 and the discussion of the correct functional form of feeder distance. It presents the essential mode and terminal choice determinants which should be considered in every intercity mode choice model. Inclusion of HSR fares is necessary if the operator uses fares to compensate for longer line-haul times—in other words, if the relationship between HSR fares and HSR distance is not linear. Recall that feeder distance is the sum of access plus egress distance.

EPILOGUE

The distance from New York to Atlanta is similar to the distance from Tokyo to Fukuoka. After understanding the interaction between air and HSR in Japan, one might be tempted to speculate on how HSR on the Eastern seaboard might affect the air transportation system in that region.

The Tokyo–Fukuoka corridor is considerably more densely populated than the New York–Atlanta corridor. Land use is different because many businesses in the New York–Atlanta corridor are located in the suburbs, and a downtown-to-downtown connection does not give rail the competitive advantage that it has in Japan. Ridership would be lower, which means that HSR could not offer the high-accessibility, high-frequency, and high-speed service as in Japan and would have to find an optimal trade-off for the region. Figure 1*a* compares transit rail's share of domestic passenger-kilometers of the United States and Japan. It is evident that HSR in this country would lack the conventional rail feeder services it enjoys in Japan.

All of this would imply that the impact of high-speed rail competition would not nearly be as dramatic as in Japan. It would be extremely unlikely for airlines to abandon markets such as New York–Washington, D.C. (equivalent to Tokyo–Nagoya) or to severely

TABLE 3 Checklist of Essential Mode and Terminal Choice Determinants in Intercity Travel

	Air	HSR
Feeder distance	Yes	Yes
Log (feeder distance)	Yes	Yes
Transfers	—	Yes
Frequency	Yes	—
Line-haul time	Yes	Yes
Fares	Yes	—
Fixed effects	Yes	Yes

curtail their hub-and-spoke system. However, it would be reasonable to expect a lot more point-to-point flights (mostly nonstop), with those flights operating with an on-time performance not seen for a long time in the United States.

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