
Monorails In Japan: An Overview

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Leroy W. Demery, Jr.

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P.O. Box 6076
Vallejo, CA. 94591-6076
(707) 557-7563
(707) 557-6735 fax

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Table of Contents

Abstract	4
I. Introduction	5
Notes on Transcription	8
Other Details	8
II. The Monorail Market Niche	11
III. Monorail and Other Modal Specifications	14
IV. Criteria For Application	16
V. Small-Scale Installations	18
東京 Tōkyō 豊島園 Toshima-en amusement park (1951-?)	19
東京 Tōkyō 上野懸垂線 Ueno Suspended Line (Ueno Park)	19
奈良 Nara 奈良ドリームラン Nara Dreamland	20
犬山 Inuyama	20
川崎 Kawasaki 読売（よみうり）ランド Yomiuriland (1964-1978)	21
名古屋 Nagoya 東山公園 Higashiyama Park (1964-1974)	22
川崎 Kawasaki - 向ヶ丘 Mukōgaoka (1966-2000)	23
姫路 Himeji (1966-1974)	24
横浜 Yokohama (1966-1967)	25
大阪 Ōsaka - Expo '70 (1970)	26
VI. The Large-Scale Prototypes	26

東京 Tōkyō 東京モノレール Tōkyō Monorail	26
鎌倉 Kamakura 湘南モノレール Shōnan Monorail	33
VII. Unrealized Plans	35
VIII. Standards Adopted For Supported and Suspended Monorails	39
IX. Mature Technologies Gain Application	40
北九州 Kitakyūshū	40
千葉 Chiba	45
大阪 Ōsaka	49
東京 Tōkyō	52
東京 Tōkyō - Maihama	54
那覇 Naha	55
X. Prospects	57
XI. Preserved Monorail Rolling Stock	58
Acknowledgements	58
References	59
References-Online	63
References-Online - Newspapers	64
Periodicals	64
Document History	65

Abstract

Japan has ten monorail lines with a total route length of about 110 km (70 mi), worked by more than 300 vehicles, carrying about 500,000 passengers per day. Several short lines were built during a long formative period. Most of these have been closed (6 km / 10 mi total), but monorail technology was proven practical. Two large-scale prototypes were built, including the well-known Tôkyô Monorail. Design standards for supported and suspended monorails were adopted, and criteria for application were established. Practical considerations have limited monorails to special-purpose applications, where surface right-of-way is not available and traffic is not sufficient to justify full-scale rail lines, either in tunnel or on viaduct. (No meaningful distinction between "light rail" and "heavy rail" can be made in Japan.) Most monorail lines were built along new expressways and surface roads. At mid-2005, the only active monorail projects were short extensions to three existing systems. No "new" monorail systems were under planning, according to Japanese-language sources. By contrast, many new rail lines were under construction or planned. There was also considerable interest in "LRT," which in Japan refers to modern tramway systems using low-floor cars. Japanese monorail lines will continue to expand, if slowly, but play a very small role in the overall transport picture. Conventional rail will remain the dominant mode for major urban corridors for the foreseeable future.

I. Introduction

This paper was written to provide information and statistics regarding monorail development in Japan, derived from Japanese primary sources, i.e., in the Japanese language. Only those lines classified formally as "Monorail" (モノレール) are included herein. A companion paper will cover those lines classified as "New Transport System" (新交通システム), e.g. the "Skyrail Service" (スカイレールサービス) monocab line near Hiroshima. Monorail operating statistics for the 2003 fiscal year are presented in Table 1.

The Japanese experience demonstrates that the technology is workable and reliable, and suitable for application in a variety of urban and suburban travel markets. However, practical considerations have limited monorails to special-purpose applications, and there is little current prospect for significant expansion. Existing lines were built primarily along new expressways, in corridors where the cost of full-scale heavy-rail construction could not be justified. The Japanese-language literature contains no hint that any "new" monorails will be authorized as near-term or medium-term projects. At autumn 2003, following completion of the Naha monorail, the only active monorail projects in Japan were a short extension under construction in Tôkyô, and short extensions planned in Ôsaka and Chiba.

Monorail development in Japan has occurred in three phases. First, several short lines were built to demonstrate monorail technologies. Most of the early lines, built to serve amusement parks, expositions, or other recreational destinations, have been closed but one new "recreational" line has opened recently. Two full-scale prototypes, the Tôkyô and Shônân monorails, were also built during the formative years and remain in operation. Next, an industry association adopted standards for supported and suspended monorails. In addition, planners developed criteria for application of various urban transit modes. The third stage of monorail development, the gradual application of these two "standard" configurations, began during the mid-1980s. This did not mark the beginning of a monorail "revival," but rather the beginning of practical application. (There could hardly be a "revival" for a mode that never fell out of favor, but instead resembled a "solution in search of a problem" for many years.)

"Alternative" transport technologies tend to attract considerable attention from overseas, and some sources tend to overstate the role of monorail and other intermediate-capacity systems in the overall Japanese transport picture. Other, less exotic systems play a much larger role. For example, Japan began developing small-profile linear-motor metro (subway) trains during

the 1980s. The idea was to reduce construction costs by reducing tunnel diameter. Ōsaka opened the first such line in 1990, followed by Tōkyō and Kōbe; the total route length is now significantly greater than that for all monorail lines yet built in Japan. Additional small-profile metros are being built in Fukuoka, Ōsaka, Sendai and Yokohama.

TABLE 1: JAPANESE MONORAIL OPERATING STATISTICS, 2002 FISCAL YEAR

Operator	Route Length km / mi	Vehicle-km / vehicle-mi (annual)	Staff Members	Passengers per Day (average)	Increase (or decrease) from 1985 (percent)	Density (passenger-km (mi) per route-km (mi) per day)
Chiba	15.2	2,601,000	178	44,000	opened 1988	11,801
	9.4	1,613,000				
Inuyama - Nagoya RR	1.2	82,000	7	2,000	nil	1,240
	0.7	51,000				
Kitakyūshū	8.8	2,633,000	140	31,000	22	17,303
	5.5	1,632,000				
Maihama	5.0	2,249,000	178	53,000	opened 2001	26,699
	3.1	1,394,000				
Naha	12.9			(est.) 29,000	opened 2003	(est.) 11,000
	8.0					
Ōsaka	23.8	6,903,000	186	79,000	opened 1990	22,028
	14.8	4,280,000				
Shōnan	6.6	1,877,000	100	28,000	26	14,356
	4.1	1,164,000				
Tōkyō Monorail	16.9	18,050,00	308	136,000	54	92,732
	10.5	11,190,000				
Tōkyō Tama	16.0	5,424,000	202	97,000	opened 1998	33,634
	9.9	3,363,000				
Tōkyō Toei Ueno Park	0.3	21,000	6	2,500	(38)	3,043
	0.2	13,000				

Japanese urban transport systems operate in a much different economic environment than in the U.S. Auto operating costs in Japan are very high. At mid-2003, regular gasoline cost roughly \$3 per gallon. Most autos (including the sport utility vehicles built for the domestic market) are very small by U.S. standards, offsetting high fuel prices to some degree. In large cities, most hotels, some restaurants and most department stores provide free parking for customers. Metered on-street parking cost about \$2 per hour, and parking structures charged \$3 - \$7 per hour (in central Tōkyō, parking costs up to twice as much) . Suburban retail outlets and mini-malls, together with parking lots, have proliferated rapidly since 1980. Such development tends to occur around smaller cities and towns, where land is cheaper.

TABLE 2: JAPANESE MONORAIL FINANCIAL RESULTS, 2002 FISCAL YEAR

Operator	Operating Receipts	Operating Expenses, ¥	Operating Profit (or loss), ¥
Chiba Urban Monorail Co., Ltd.	3,158,000,000	4,160,000,000	(1,002,000,000)
Inuyama - Nagoya RR Co., Ltd., Monkey Park Monorail	89,000,000	114,000,000	(25,000,000)
Kitakyūshū Rapid Railway Co., Ltd.	2,254,000,000	1,945,000,000	309,000,000
Maihama Resort Line Co., Ltd.	3,643,000,000	4,438,000,000	(795,000,000)
Okinawa Urban Monorail Co., Ltd.	opened 2003		
Ōsaka Rapid Railway Co., Ltd.	7,414,000,000	6,091,000,000	1,323,000,000
Shōnan Monorail Co., Ltd.	1,678,000,000	1,477,000,000	201,000,000
Tōkyō Monorail Co., Ltd.	14,734,000,000	12,138,000,000	2,596,000,000
Tōkyō Tama Intercity Monorail Co., Ltd.	5,893,000,000	6,937,000,000	(1,044,000,000)
Bureau of Transportation, Tōkyō Metropolitan Government (Toei) Ueno Park monorail	107,000,000	108,000,000	1,000,000

Notes for Table 2:

Conversion between currencies may introduce considerable uncertainty, because of exchange-rate fluctuations. Financial data are therefore presented without conversion.

Japan has no "freeways," and expressway tolls are very high. The flat toll for travel on the Tôkyô metropolitan expressway network was about \$6.00 at early 2002. In Nagoya, the flat toll was about \$5.00. Intercity expressway tolls ("intercity" includes short trips such as Tôkyô - Yokohama) cost about \$0.12 per km (\$0.20 per mi). The 524-km (325-mi) trip between Tôkyô and Kyôto, for example, cost about \$75 for tolls alone. By comparison, the same trip cost about \$110 by *shinkansen* (high-speed rail) or about \$70 by local train. Bridge tolls are also very high. The "Tôkyô Bay Aqualine" bridge-tunnel charged \$25 per car, or \$20 per small car, at early 2002. However, the Kawasaki - Kisarazu bus service, crossing the same bridge, charged less than \$12 per passenger.

Notes on Transcription

Transcription of Japanese into the Latin alphabet raises a number of issues. Two distinct systems are currently in use, which are similar but not identical. In addition, Japanese script makes no distinction between capital and lower-case characters, and Japanese is not normally written with spaces or hyphens. There are also no "rules" on how, or if, long vowels should be indicated in romanized form (*rômaji*), no agreement on how to spell foreign loanwords, and so forth. The author has used the Modified Hepburn (*Hebon-shiki*) system herein, with long-vowel symbols, adding capitals and hyphens as appropriate (using an ad-hoc style devised in collaboration with J. Wallace Higgins). The author has also used mean-value symbols (< >) to set apart foreign loanwords as appropriate (e.g. <monorail>). Spellings of Japanese personal names in the Latin alphabet may differ from those preferred by the authors cited.

Some World Wide Web sites require Japanese-compatible browsers and software for proper display of text. However, graphics and photos are usually displayed even when text appears as gibberish because of compatibility problems. Some Japanese websites have "English" versions, but these seldom contain more than a fraction of the information available in Japanese.

Other Details

All schedule and fare information is current as of February 2002, except for the Naha monorail, which is current to the time of opening (August 2003).

Conversions from Japanese yen to U.S. dollars were based on the rate current at November 2002: ¥120 = US\$1.00. Readers are reminded that exchange-rate fluctuations may introduce considerable uncertainty when prices are converted between currencies.

TABLE 3: ANNUAL TRAFFIC DATA FOR MAJOR JAPANESE MONORAILS

Fiscal Year	Tôkyô	Kita-kyûshû	Ôsaka	Tama	Mai-hama	Naha	Shônán	Chiba	Total	Average Daily Passengers
1964	2,475								2,475	12.6
1965	2,743								2,743	7.5
1966	3,312								3,312	9.1
1967	6,438								6,438	17.6
1968	8,159								8,159	22.4
1969	11,348						136		11,484	31.5
1970	15,157						172		15,329	42.0
1971	17,440						3,997		21,437	58.7
1972	20,017						5,355		25,373	69.5
1973	23,681						6,630		30,311	83.0
1974	25,998						7,331		33,329	81.3
1975	28,945						7,293		34,238	93.8
1976	28,788						7,578		36,366	99.0
1977	30,775						7,535		38,310	105.0
1978	26,017						7,750		33,767	82.5
1979	25,405						7,621		34,027	93.2
1980	26,539						7,916		34,455	94.4
1981	27,942						7,691		35,633	97.6
1982	28,118						7,724		35,842	88.2

Fiscal Year	Tôkyô	Kita-kyûshû	Ôsaka	Tama	Mai-hama	Naha	Shônân	Chiba	Total	Average Daily Passengers
1983	28,440						7,820		36,260	99.3
1984	31,269	2,706					8,060		42,035	115.2
1985	31,984	9,987					8,079		50,050	137.1
1986	33,957	10,135					8,324		52,416	143.6
1987	35,707	9,529					8,615	60	53,911	147.7
1988	37,637	9,291					9,239	3,604	59,771	163.8
1989	41,523	9,237					9,768	4,952	65,480	179.4
1990	44,574	9,750	4,700				10,328	5,549	74,901	205.2
1991	47,127	10,408	7,365				10,772	10,425	86,097	235.9
1992	51,081	11,143	7,827				11,298	12,451	93,800	257.0
1993	57,013	11,691	8,373				11,346	13,279	101,702	278.6
1994	61,364	11,846	8,766				11,165	13,274	106,345	291.6
1995	62,006	11,424	10,523				11,073	15,450	110,476	302.7
1996	64,693	11,181	10,992				11,107	16,689	114,662	314.1
1997	65,208	11,047	21,485				10,939	16,465	125,144	342.9
1998	63,148	12,346	26,298	2,387			10,848	16,061	131,088	359.1
1999	53,905	12,485	27,591	11,059			10,553	16,654	132,247	362.6
2000	51,413	12,148	28,499	29,132			10,429	16,482	148,053	405.6
2001	50,341	11,587	28,425	33,834	17,377		10,362	16,178	168,104	460.6
2002	49,532	11,497	29,016	35,512	19,375		10,088	16,059	171,079	468.7
2003	46,688	11,528	28,745	37,528	18,123		10,128	15,940	168,680	462.1
2004										
2005										
Total	1,366,938	210,966	248,605	149,452	54,875		295,181	209,520	2,537,537	

Notes for Table 3:

All data in thousands. "Average Daily" traffic is annual total divided by 365, per Japanese convention.

Column totals may differ from sum of individual entries due to rounding.

"Average Daily" traffic for 1964, which included only the Tōkyō Monorail, adjusted to reflect opening on September 17, 1964, nearly halfway through the fiscal year which began on April 1, 1964.

Sources:

都市モノレール年間来客数の推移 *toshi <monorail> nenkan raikyakusū no sui*,

都市モノレール計画 *toshi <monorail> keikaku*, Japan Monorail Association.

II. The Monorail Market Niche

Boudalon's concept of the "transport gap" refers to situations where traffic levels are too high for efficient bus operation, but too low to justify full-scale conventional rail lines (Boudalon 1967.4; 1967.10). Japanese planners have identified a need for "intermediate-capacity" transit systems, able to carry 5,000 - 15,000 passengers per hour, with an average travel distance in the range of 3-15 km (2-9 mi), at (passenger) speeds in the range of 20-40 km/h (12-25 mph). The need is to provide faster travel times than buses in mixed traffic (which are often very slow in Japan), a high service frequency, and high service reliability for medium-sized cities, for links to new suburban development, and for connections between suburbs where underground metro construction cannot be justified.

These criteria are remarkably similar to the "field of application" for light rail transit (LRT) in the U.S. and Canada. However, urban land is costly and scarce in Japan. New surface rail alignments are almost prohibitively expensive (Kikuchi and Ohta 1989). Land has been reserved for future rail development in some locations, typically new suburban development in the largest metropolitan areas, but this is not the typical practice elsewhere. Except for short freight branches, abandoned rail corridors are essentially nonexistent in large Japanese cities. All that have ever existed remain in service (or were built over decades ago following abandonment). A few freight lines serving large cities (Nagoya and Ōsaka) are planned for rebuilding as passenger lines, but as electrified suburban railways, not U.S.- or Canadian-style LRT.

Finding roads wide enough to build a conventional "full-scale" rail line on viaduct is extremely difficult. Required overall road width, permitting space for columns and stations, is 25 meters (82 feet) between stations, and 35 m (115 ft) at stations. This is for a full-scale "conventional" railway on viaduct, with roadways on either side. The problem is that most Japanese cities have very narrow streets. In large cities, the typical residential street is no wider than the typical alley in U.S. cities. Few major roads are 25-35 m (82-115 ft) wide. Of the largest cities, only Nagoya undertook large-scale street widening during postwar reconstruction.

Since the modest beginnings Japan's streetcar (tramway) revival during the 1990s, the label <LRT> has come into use with reference to streetcar lines, built in streets but with track areas reserved, using modern cars providing low-floor (バリアフリー <barrier free>) access.

Although there is much in common, <LRT> as a concept in Japan is quite distinct from "light rail transit" as built in the U.S. and Canada. Nor, for historic and legal reasons, is there any meaningful distinction between "light rail" and "heavy rail" in Japan. Under Japanese law, rail lines are licensed as "railways" (鉄道 *tetsudô*) or "tramways" (軌道 *kidô*). The principal distinction between the two is that a "tramway" may be built within the alignment of a public road. Another distinction: "railway" lines invariably use car-floor level platforms at all stations, but "tramway" lines may use low platforms or ground-level loading. A 1921 law limits the maximum "tramway" vehicle or train length to 30 m (98 ft) and to a maximum speed of 40 km/h (25 mph) when operating in streets.

The "tramway" and "railway" categories are not immutable: many large private-sector operators in major cities were built under "tramway" concessions, and were later re-licensed as "railways." The "tramway" heritage of such operators becomes immediately apparent to knowledgeable observers, who will note that lines built as "tramways" use European standard (1,435mm = 4' 8 1/2") or Tôkyô tramway (1,372mm = 4'6") gauge, rather than the usual Japanese standard gauge (1,067mm = 3'6"). Other "tramway" characteristics include close spacing between stations and many grade crossings. Nor are other "rules" immutable: Ôtsu is linked to nearby Kyôto by an upgraded "tramway" line, which now gains access to central Kyôto over metro tracks. This line has a short section of street track in central Ôtsu. The Transport Ministry issued a special license to permit operation of four-car trains of metro-type rolling stock over this segment.

If built in Japan, a line with high platforms throughout and no street running would not be classified as "LRT," but as a "regional railway." U.S. examples include the St. Louis MetroLink LRT line and the LRT Green Line in Los Angeles. Japan has several examples of similar lines, li-

censed as "railways," that are never listed as "tramways" or <LRT>. Lines similar to those built recently in the U.S. and Canada might well be licensed as "railways" in Japan.

The major stated disadvantage of monorail, compared to <LRT> or other rail lines, is inability to operate in a network:

"Thus, system expansion and future integration with other monorail lines to form a network with vehicles traveling from one line to another cannot be expected" (Kikuchi and Ohta 1989).

Operators in Chiba and Ôsaka have since demonstrated that operation of monorail networks is practical, at least on a very limited scale. Another disadvantage: If a monorail is built underground or in a tunnel, the required vertical clearance is at least 5.6 m (18' 5"), compared to 3.2 m (10' 6") for <LRT> (Kikuchi and Onaka 1988).

Other factors have stimulated interest in monorails and other intermediate-capacity transit systems. Among these has been strong pressure to reduce the weight of trains in order to reduce the size, and cost, of support structures. In Japan, <New Transport System> (新交通システム) or <NTS> refers generally to elevated lines using relatively small, rubber-tired rolling stock, although other technologies are now classified as <NTS>. Some Japanese authors also use the term AGT, "Automated Guideway Transit," when writing in English. This is something of a misnomer because some such lines use manually driven trains.

Since 1972, road construction funds have been available for transit "guideways" so long as this is constructed within the road alignment:

"This is based on the concept that the transit system is part of the road and helps alleviate the traffic congestion on the roadway, and thus, encourages the utilization of transit to complement the people carrying capacity of the corridor" (Kikuchi and Ohta 1989).

State and local authorities share the infrastructure cost, up to 44.9 percent of the total cost. This has encouraged construction of monorail and other ICTS lines along roadways, particularly when these roads are widened and improved.

By contrast, no large-scale funding has been provided for improvement of urban bus and tramway (streetcar) systems. (At the end of the 1990s, the state provided funds to pay part of the cost of an urban tramway extension; it had not done so before.). This situation has encouraged development of new technology rather than gradual upgrading of existing systems. Nagoya has made the most significant investment in upgraded bus systems. Its *Key Route Bus*

System (基幹バス *kikan* <bus>) services include reserved lanes, traffic signal priority, and widely spaced stops. However, Nagoya is probably the only large Japanese city (other than Hiroshima) able to implement such measures. A new, elevated <Guideway Bus> (ガイドウェイバス) or guided busway line opened in 2001.

New transit systems have "novelty" and "symbolism" appeal, particularly for newly-developed suburbs. Kikuchi and Ohta (1989) emphasize this point:

"Novelty and symbolism play an important part of the decision process. This tendency is particularly manifested in Japan."

Unfortunately, these authors provide no elaboration, and lines built primarily for "novelty" and "symbolism" tend not to show favorable financial results.

Division of responsibility between ministries also spurred a proliferation of monorails and <NTS> systems. The Construction Ministry responsible for roads, tended to favor various rubber-tired systems and monorails, while the Transport Ministry, responsible for railways, favored conventional rail lines. The new Ministry of Land, Infrastructure and Transport is responsible for airports, rail lines of all types and roads.

III. Monorail and Other Modal Specifications

Intermediate-capacity transport systems in Japan include monorail, "new transport systems," and <LRT>.

"Monorail" is defined as traveling along a single guideway, on rubber tires, either straddling the guideway or suspended from it. Advantages over conventional rail include: less land requirement, and an ability to negotiate steeper grades and sharper curves, making construction within the alignment of existing roads more practical.

Recent monorail specifications include (Nehashi 1998):

--Construction cost: \$30-60 million / km (\$50-100 mn per mi) for infrastructure; \$25-55 million / km (\$40-90 mn per mi) for equipment and rolling stock.

--Commercial (schedule) speed: 30 km/h (19 mph).

--Maximum capacity: 26,000 passengers per hour per direction (phd). This is based on 6-car trains, 2-minute headways, and 95 passengers per vehicle (p/v), about 6.1 passengers per meter of vehicle length (p/m).

Outside of the four most crowded and congested urban centers (Boston, Montréal, New York and Toronto), U.S. and Canadian consumers do not tolerate the levels of peak-period crowding aboard transit vehicles that may be observed in many Japanese cities. Therefore, a similar service level, with identical vehicles, in most U.S. or Canadian urban corridors, would carry significantly less traffic: no more than 17,000 - 20,000 phd, assuming the existence of sufficient demand.

--Average annual operating cost for monorail is estimated at \$2 million / route-km (\$3 mn per rt-mi). Thus, a monorail line would need to attract 4,000 passengers per route-km per day (pkd, or 6,500 per rt-mi, pmd), each paying an average fare of \$1.25, in order to cover operating costs.

Comparative figures for underground metros (subways):

---Construction cost: \$210-250 million / km (\$340-400 mn per mi), or \$170-175 million / km (\$270-280 mn per mi) for small-profile underground metros.

---Commercial speed: 32 km/h (20 mph), or 34 km/h (21 mph) for small-profile lines, probably because of higher acceleration rates.

---Maximum capacity: 64,000 phd (24,000 - 30,000 phd in most U.S. or Canadian corridors, assuming the existence of sufficient demand). This is based on 10-car trains, 2-minute headways, and 214 passengers per vehicle, about 10.7 passengers per meter of vehicle length.

---Maximum capacity for a small-profile metro is 35,000 phd, based on 8-car trains, and 146 p/v, about 8.9 p/m (16,000 - 20,000 phd in most U.S. or Canadian corridors).

---Average annual operating cost: \$6 million / route-km (\$9 mn per route-mi), requiring 12,200 pkd (19,700 pmd), each paying an average fare of \$1.25, to cover operating costs.

Comparative figures for "New Transport Systems" (<NTS> or "Automated Guideway Transit"):

---Construction cost: \$30-80 million / km (\$50-130 mn per mile) for infrastructure; \$25-55 million / km (\$40-90 mn per mile) for equipment and rolling stock.

---Commercial speed: 27 km/h (17 mph).

---Maximum capacity: 18,000 phd (6,000 - 8,000 phd in most U.S. or Canadian corridors, assuming the existence of sufficient demand). This is based on 6-car trains, 2-minute headways, and 98 p/v, about 11.5 p/m.

---Average annual operating cost: \$2 million / route-km (\$3 mn per rt-mile), requiring 4,000 pkd (7,000 pmd), each paying an average fare of \$1.25, to cover operating costs.

As noted above, <LRT> refers essentially to high-performance tramway lines providing <barrier-free> passenger access, operating on tracks built in roads but separated from other traffic. Comparative figures for <LRT>:

---Construction cost: \$27 million / km (\$44 mn per mi).

---Commercial speed: 19-26 km/h (12-16 mph).

---Maximum capacity: 14,000 phd (6,000 - 8,000 phd in most U.S. or Canadian corridors, assuming the existence of sufficient demand). This is based on two-car trains (or single articulated cars), 2-minute headways, and 225 p/v, about 8.9 p/m.

---Average annual operating cost: \$1 million / route-km (\$1.5 mn per rt-mi), requiring 2,100 pkd (3,400 pmd), each paying an average fare of \$1.25, to cover operating costs.

IV. Criteria For Application

Japan has established practical fields of application for various urban transit modes, including monorail." The "domain of efficiency" for each mode has been worked out, based on technical and economic factors. The criteria are very well defined (Nehashi 1998) but defy straightforward explanation. U.S. planners and decision makers tend to overlook the fact that transportation "workload," or traffic density, depends on both the number of people who travel and the average distance traveled. This workload is measured in terms of passenger-km (mi) per km (mi) of route. This simply refers to the number of people, on average, who travel over each kilometer (mile) of guideway (in both directions) during some interval. The traffic-density statistic used in Japan is an annual average per calendar day, not per weekday. It should be noted that traffic density statistics do not change in value when converted from "passenger-kilometers per kilometer of route" to "passenger-miles per mile of route."

A large daily passenger count is generally required to justify a short-distance fixed-guideway facility. On most such facilities, the average travel distance (ATD) is low relative to the route length (e.g. ATD is 20-30 percent of route length). As a consequence, traffic density is relatively low, and operating cost per passenger-mile relatively high. By contrast, on many longer facilities, ATD is high relative to the route length (e.g. ATD is 60-70 percent of route length). Traffic density is also relatively high, and operating cost per passenger-mile relatively low. The longer

facility therefore does not require such a large daily passenger count to justify its construction. This would be true from the standpoint of operating efficiency even if passenger revenue were not considered. (In Japan, distance-based or "stage" fares are long-established and universally accepted.)

It is possible to design a fixed-guideway facility that cannot carry enough passengers to justify its construction, because of insufficient traffic density. The best example, in the Japanese context at least, is personal rapid transit (PRT).

Summarizing the Japanese modal criteria for urban transportation:

Individual transportation is considered adequate for all trips shorter than 1 km (0.6 mi), and for all trips along corridors where the one-way traffic density is less than 2,000. Moving sidewalks might be provided in locations where traffic volume is great enough to justify the investment.

For example, no public transportation would be provided where ATD was 2 km (1 mi) and the daily (two-way) traffic volume was less than 1,500 passengers (or, more correctly, boardings) per route-km (2,500 per rt-mi).

Japanese transportation literature emphasizes that buses provide no economies of scale. Given a 2-km (1-mi) ATD, buses are economical for traffic volumes up to 3,000 daily boardings per route-km (5,000 per rt-mi).

At higher volumes, bus operation becomes uneconomical, because economies of scale are lacking. However, the minimum threshold for conventional urban railways (given a 2-km (1-mi) average trip length) is 8,000 boardings per route-km (12,500 per rt-mi) per day.

These "thresholds" change drastically as average trip length changes - again, because of economies of scale.

One critical fact is often overlooked in the U.S.: if ATD increases, more service (vehicle-km (veh-mi)) must be operated, even if "ridership" (boardings per route-km (rt-mi)) does not change. If additional service is not provided, then average vehicle occupancy will increase (more passenger-km (pass-mi) per route-km (rt-mi)), and by implication peak period crowding will also increase.

Given a 3-km (5-mi) ATD, public transport becomes viable with fewer than 300 boardings per route-km (500 per rt-mi) per day. Buses become uneconomic with more than 500 boardings per route-km (750 per rt-mi) per day, but conventional railways are not justified with fewer than 1,200 boardings per route-km (2,000 per rt-mi) per day. The standard Japanese transit bus is about 11 m

(35 ft) long, 2.4 m (8 ft) wide and seats 28 passengers. The "maximum load" established under transport laws is 74 passengers, or 6.9 passengers per meter of vehicle length. Articulated buses are not used for urban transport services in Japan.

Under the Japanese criteria, it is more cost-effective to build a railway than operate buses given the following parameter range:

400 daily boardings per rt-km (700 per rt-mi), ATD 10 km (6 mi), to

80 daily boardings per rt-km (130 per rt-mi), ATD 50 km (31 mi).

Express buses (known as ハイウェイバス, <Highway Bus>, in Japan) are efficient only for longer trips. If the daily boarding count exceeds 120 passengers per route-km (200 per rt-mi), high-speed rail becomes more efficient.

It is essential to keep these numbers in context. A suburban rail line handling an average travel distance of 50 km (31 mi) would be longer than 50 km (31 mi) end-to-end. The minimum daily "boarding count" required to justify an 80-km (50-mi) suburban rail line becomes 6,500. Converting from "average daily" to "average weekday" ridership in line with U.S. practice, this implies more than 8,000 boardings per weekday.

It is also essential to keep in mind that these criteria were developed with reference to Japanese economic conditions. Longer trips require operation of more vehicle-km per passenger, and so the "economy of scale" effect reduces the boarding "threshold" required to justify rail lines as average trip length increases. Buses, by contrast, provide no such economies of scale.

V. Small-Scale Installations

Japan's first monorail proposal was submitted in 1913, for a short line in Tôkyô. This was to extend between Ueno station and Asakusa, using technology patterned after Germany's *Wuppertaler Schwebebahn*. Ten more monorail proposals followed between 1923 and 1931. All were rejected by transport officials skeptical of the technology, the ability of the promoters to secure financing, and other claims, including ridership estimates.

東京 Tōkyō 豊島園 Toshima-en amusement park (1951-?)

An 0.2-km (0.1-mi) suspended monorail opened at Toshima-en amusement park, in Tōkyō's northwest suburbs, in 1951. This little-known line was not much more than an amusement-park ride, and was dismantled some years ago. Other small-scale monorail lines have since been built to serve non-public transport functions (e.g. at amusement parks and golf courses).

東京 Tōkyō 上野懸垂線 Ueno Suspended Line (Ueno Park)

In 1957, the Bureau of Transportation, Tōkyō Metropolitan Government (東京都交通局 *tōkyō-to kōtsū-kyoku*, often abbreviated 都営 *Toei*), which operates surface transport and the smaller of Tōkyō's two metro networks, built a demonstration monorail line in Tōkyō's Ueno Park. This extends 0.3 km (0.2 mi), and connects the east and west sections of Ueno Zoo. It was patterned after the *Wuppertaler Schwebebahn*, although with rubber-tired "bogies" ("trucks") and a much smaller single-beam guideway. Toei used tramcar hardware when possible. Traction current is supplied at 600V dc. The line provides a commercial speed of 11 km/h (7 mph). Rolling stock is built to "half scale" - 9.3 m (30' 6") long and 1.7 m (5' 7") wide. The line has a single two-car train. The nominal construction cost (without attempting to adjust for inflation) was ¥200 million (\$550,000).

It is not clear what potential applications were considered. One proposal called for construction of monorails together with the urban tollway network, but this was not carried out. Replacement of major streetcar lines with monorails as an alternative to metros may have been an early idea, but this was not considered seriously for long.

This tiny line has operated successfully for more than 40 years, and currently carries an average of 2,500 people per day. It proved wholly inadequate for busy urban trunk lines, but serves a useful purpose and has become something of a technological monument. The original cars were replaced in 1967 and again in 1984-1985. Closure was threatened at the end of the 1990s, following a Transport Ministry inquiry regarding earthquake-safety standards, adopted after the 1997 Kōbe earthquake. The agencies responsible eventually decided to rebuild the line, and it was closed from January 2000 through the end of May 2001 to permit this. It currently operates during zoo opening hours; the one-way fare is \$1.25 (admission to the zoo is \$4.20).

奈良 Nara 奈良ドリームラン Nara Dreamland

Nara Dreamland, opened in 1961, was an attempt to replicate the original Disneyland theme park at Anaheim, CA, opened in 1955. Developers are said to have sought, without success, cooperation from Walt Disney Productions. Disney is said to have been furious when the project proceeded nonetheless. The 0.8-km (0.5-mi), figure-eight monorail loop, equipped by Tôshiba, was the first full-scale monorail in Japan and the first to use precast concrete beams. However, it was not licensed as a public-transport facility. The trains, lettered <SPACELINER>, bear a superficial resemblance to Disney monorail stock. Several of Japan's older and smaller amusement parks have closed recently, because of competition from newer, flashier theme parks and the country's decade-long recession. However, Nara Dreamland is a subsidiary of the Daiei supermarket chain, and its future appears secure.

犬山 Inuyama

名古屋鉄道モンキーパークモノレール線

nagoya tetsudô <monkey park monorail> sen

Nagoya Railroad Co., Ltd., Monkey Park Monorail Line

Supported system: Inuyama-yûen (犬山遊園) to Dôbutsuen (動物園), 1.2 km (0.7 mi).

Opened 1962.

The Hitachi group licensed Alweg monorail technology in 1960, and this became the first *Hitachi-<Alweg>* (日立アルウエーグ) monorail.

Meitetsu (名鉄 "May-tets") is a Sino-Japanese style abbreviation referring to the Nagoya Railroad Co., Ltd. (名古屋鉄道 *nagoya tetsudô*), the second-largest non-JR private-sector railway in Japan. "Japan Monkey Park" (日本モンキーパーク) known previously as *Meitetsu <Monkey Park>* (名鉄モンキーパーク), is a company-owned zoo and recreational facility,

noted for its collection of monkeys. The single-beam monorail extends between Inuyama-yûen station, on the company's Inuyama Line, and the zoo. A single intermediate station serves a Shingon Buddhist temple, *Inuyama Narita-san* (犬山成田山), which attracts large numbers of visitors on special occasions such as New Year's Day. The zoo provides a traffic base to support infrastructure that proves very useful on peak-traffic days.

Meitetsu began developing recreational facilities near Inuyama in 1925. One of these, opened in 1955, was a nature park, <Picnic Land> (ピクニックランド) later renamed <Rhein Park> (ラインパーク ; a section of the Kiso River near Inuyama was christened 日本ライン Nihon <Rhein>, "Japan Rhine," by a geologist inspired by the sight of Inuyama Castle perched on a hill overlooking the river.)

Transportation to Inuyama-yûen station was provided by a bus service, creatively named Momotarô Line (桃太郎線 ; 桃太郎 *Momotarô*, "Peach Boy," is the hero of a well-known Japanese folk tale). Then, in 1958, the company opened a 1.2-km (0.7-mi) miniature railway, おとぎ停車 *otogi-teisha* ("Fairy Train") from the eastern edge of Inuyama to the park. Development continued, and the zoo was opened in 1962. The company considered a full-scale railway branch but decided on the monorail. The nominal construction cost (without attempting to adjust for inflation) was ¥500 million (\$1.4 million). The line has grades to 9.7 percent (1 in 10), and one section is built in a cutting. Traction current is supplied 1500V dc. The two aluminum-bodied trains can be coupled. The line provides a commercial speed of 18 km/h (11 mph). Ridership averages about 2,000 per day. The basic midday service operates every 30 minutes, with additional service during peak travel periods.

川崎 Kawasaki 読売 (よみうり) ランド Yomiuriland (1964-1978)

This 2.9-km (1.8-mi) circular Hitachi-Alweg line was built by the Kantô Race Club (関東レース倶楽部) in an area later developed as the Yomiuriland amusement park. The nine cars operated as three-car formations. Traction current was supplied at 600V dc. The maximum permitted speed was 40 km/h (25 mph). The monorail closed near the end of 1978, a victim of "motorization." Much of the guideway now supports a one-lane roadway, with lateral safety barriers,

for a self-drive go-cart ride. The remainder has been demolished and removed. The precise reason for closure is not known to the author, but was believed to stem from light traffic and high operating costs.

名古屋 Nagoya 東山公園 Higashiyama Park (1964-1974)

Nagoya planned metro construction from the mid-1930s but was not able to start construction until 1954. The initial 2.4-km (1.5-mi) segment opened at the end of 1957. By 1963, when municipal authorities decided to replace tramcars because of growing traffic congestion, it had completed only 6.1 km (3.8 mi) of metro extensions. Fulfillment of the six-route, 50-km (30-mi) metro plan announced in 1950 seemed years away.

Meanwhile, the municipal Engineering Bureau became interested in monorail development. Perhaps inspired by the Tôkyô's Ueno Park monorail, the city joined forces with the private sector in 1962 to build a demonstration line in Higashiyama Park. Nippon Airway Development Co., Ltd. (日本エアウェイ開発 *nippon <airway> kaihatsu*), organized by Mitsubishi Heavy Industries and ten other firms in 1962, acquired license rights for Safège suspended-monorail technology in Japan. This enterprise was absorbed into parent Mitsubishi, apparently at an early stage. Mitsubishi Heavy Industries became the prime contractor and built the rolling stock, a single car. Construction started in 1963.

The 0.5-km (0.3-mi) single guideway connected Higashiyama Zoo (東山動物園 *higashiyama dôbutsuen*) with Higashiyama Botanical Garden (東山植物園 *higashiyama shokubutsuen*), and cost about ¥110 million (\$300,000) to build. Rolling stock and other equipment brought the total cost to about ¥220 million (\$600,000). Traction current was supplied at 600V dc.

The line opened early in 1964, and averaged of 1,000 passengers daily. It attracted considerable media attention but mechanical problems hindered operation. These led to two four-day suspensions of operation during the first year.

It is not clear what potential applications were envisioned for monorail technology. Nagoya continued to build metro lines and replaced trams with motorbuses. Surface rail operation ended in 1974. No proposals for additional monorails were advanced.

Instead of a showcase, the Higashiyama monorail became a deficit-ridden orphan. It earned a profit during its first two years, but losses began in 1966. Efforts to restore profitability failed, and the municipal transport bureau eventually lost interest. Plans for expansion of the zoo and botanical gardens apparently hastened the end, which came at the end of 1975. The car and a short section of guideway are preserved in Higashiyama Park, but the remainder was dismantled and removed.

川崎 **Kawasaki**- 向ヶ丘 **Mukōgaoka (1966-2000)**

小田急電鉄向ヶ丘モノレール線 *odakyū dentetsu mukōgaoka <monorail> sen*

Odakyū Electric Railway Co., Ltd.,

Mukōgaoka Monorail Line

This 1.1-km (0.7-mi) line connected Mukōgaoka-yūen (向ヶ丘遊園) station on the Odakyū main line with one of the company's many subsidiaries, the Mukōgaoka amusement park (at Mukōgaoka-yūen-seimon 向ヶ丘遊園正門 monorail station). It was closed after Odakyū decided that required major repairs could not be justified.

In 1962, Kawasaki Heavy Industries, Ltd., (Kōbe) licensed the rail-on-beam supported monorail system developed by Lockheed Aircraft Corporation. A subsidiary, Nihon-Lockheed Monorail Co., Ltd. (日本ロッキードモノレール), built a 0.8-km (0.5 mi) test line at the Kawasaki Aircraft Co., Ltd., plant near Gifu.

Odakyū opened its high-speed electric railway between Tōkyō (Shinjuku station) and Odawara, 82 km (51 mi), in 1927. The amusement park, and a miniature railway linking it to the nearby Odakyū station, also opened in 1927. This used gasoline locomotives, and was closed in 1941 because of wartime fuel rationing. It was restored in 1951 with battery locomotives. The amusement park was located northwest of central Kawasaki, in an area that was once well beyond Tōkyō 's suburban fringe. Urban development encroached following World War II. Plans by Kanagawa Prefecture for a bypass road on the same alignment led to replacement of the miniature railway by the first commercial installation of a *Nihon-<Lockheed>* monorail. The nominal construction cost (without attempting to adjust for inflation) was ¥200 million (\$550,000).

The monorail had a single two-car train, which operated every 15 minutes when the park was open. The trip required just three minutes, providing a commercial speed of 23 km/h (14 mph). Although equipped with resilient wheels, the train sounded much like a conventional rail vehicle when negotiating curves. It carried an average of 1,800 passengers during the 1980s, but traffic fell to 900 per day by the end of the 1990s.

A scheduled inspection in February 2000 discovered cracks in the running gear frame of one car. Operation was suspended while the company consulted the supplier. The running gear frames were judged to be life-expired, and Odakyû decided that the estimated ¥380 million (\$3 million) cost could not be justified. Closure was made permanent in December 2001. The amusement park was closed early in 2002 because of declining attendance.

姫路 Himeji (1966-1974)

姫路市交通局 himeji-shi kōtsū-kyoku Himeji City Transport Bureau

This regional center about 55 km (35 mi) west of Kôbe is best known for its magnificent castle, built from 1581 and considered the finest in Japan. This stands about 1.5 km (1 mi) north of Himeji station. Another attraction stands southeast of the station: Tegarayama hill (手柄山), which has a monument to the victims of the 1945 firebomb attacks against Japanese cities, a library, a concert hall and other cultural facilities.

Plans for a regional exposition stimulated interest in a monorail link between Himeji station and Tegarayama. This idea attracted strong support from the city's Mayor. The city received authority to build from the Transport Ministry in 1964 and began construction in 1965.

A 1.6-km (1-mi), single-beam *Nihon*-<Lockheed> line was built at a cost of about ¥1.8 thousand million (\$5 million), and opened in 1966. This had four cars, which could be coupled into trains of the desired length. Technical features included automatic train stop (<ATS>). Traction current was supplied at 600V dc. Two-car trains were standard, but three-car trains were operated during the exhibition. Service was provided every 15 minutes at first. The maximum permitted speed was 50 km/h (31 mph), and the line provided a commercial speed of 24 km/h (15 mph).

The Himeji Monorail carried an average of 1,000 passengers per day during its first year of operation, about one-third of the anticipated traffic. By 1968, when service was reduced to three trains per hour, traffic had fallen to 700 passengers per day. Operating losses and interest

payments increased, and by 1970 a new Mayor sought to close the line. Proposals for extensions north to Himeji Castle and south to the city's passenger ship terminal attracted some support, but were not carried out. Operation was suspended in 1974, and closure was made permanent from 1979. The city announced in 1991 that the monorail beam would be dismantled, but this had not been carried out at early 2002.

横浜 Yokohama (1966-1967)

横浜ドリームランド Yokohama Dreamland

This was the last monorail built for purely excursion or leisure traffic during the formative years of Japanese monorail development. It extended northwest from Ôfuna (大船) station northwest to the Yokohama Dreamland amusement park, 5.3 km (3.3 mi). A second stage was planned to extend from Dreamland to Mitsuai (六会) station on the Odakyû Enoshima Line, but was not built.

The parent company organized the Dream Transport Co., Ltd. (ドリーム交通 <dream> kô-tsû) to build the monorail. It was equipped by Tôshiba and had three two-car trains. The line opened in 1966, but failed to attract the anticipated traffic. A Transport Ministry inspection in 1967 found defects, and the company decided that repairs could not be justified. Service was suspended after less than one year of operation. The parent company announced plans for reopening in 1993 but did not proceed. It then announced plans to replace the monorail with a new line using <HSST> magnetic-levitation technology, but this also did not advance. The company considered a small-profile monorail line from 2001, but this idea soon faded. The amusement park closed early in 2002 because of declining attendance. Then, in summer 2002, the parent company, Daiei, Inc, announced that it would relinquish its rights and formally abandon the monorail line. The Ôfuna station has been removed, but the guideway remained in place at early 2001.

大阪 Ōsaka - Expo '70 (1970)

大阪万国博覧会 ōsaka bankoku hakurankai

Ōsaka Expo '70 world's fair association

This 4.4-km (2.7-mi) single-beam loop, although a temporary installation, marked an important stage in Japanese monorail development. It was the first built to uniform standards for supported monorails, and was the most technically advanced installation to that time. The line had six four-car trains, and featured centralized traffic control (<CTC>) and automatic train operation (<ATO>); trains were dispatched by computer but driven manually. Traction current was supplied at 1500V dc. The maximum permitted speed was 50 km/h (31 mph).

VI. The Large-Scale Prototypes

東京 Tōkyō 東京モノレール Tōkyō Monorail

Supported system: <Monorail>-Hamamatsu-chō (モノレール浜松町) to Haneda-kūkō (羽田空港), 16.9 km (10.5 mi). Opened 1964.

Fare	Up to	Equivalent per km (per mi)
\$1.20	1.5 km (0.9 mi)	\$0.80 (\$1.30)
\$1.60	4.5 km (2.8 mi)	\$0.40 (\$0.60)
\$2.20	7.4 km (4.6 mi)	\$0.30 (\$0.50)
\$2.70	10.5 km (6.5 mi)	\$0.25 (\$0.40)
\$3.30	13.5 km (8.4 mi)	" "
\$3.90	16.9 km (10.5 mi)	" "

The Tōkyō Monorail, built to connect the Ginza-Yūrakuchō business hub with Haneda Airport, was the first attempt to apply monorail technology to a major public transport facility in Japan. It has operated successfully for 40 years, for much of that time as a self-supporting enterprise.

The Tōkyō Monorail was not the first "urban transport" monorail in Japan. It was built as an "airport access railway" with no intermediate stations. It retains the "airport access railway" classification today although it now has several intermediate stations to serve on-line development. The Japanese regard the Kitakyūshū Rapid Railway, opened in 1985, as the country's first "urban transport" monorail line.

The Tōkyō Monorail was built to provide a fixed link to Haneda Airport in time for the 1964 Summer Olympic Games, held in Tōkyō. However, private interests believed that airport traffic at that time was not sufficient to justify a rail link - correctly, as things turned out. However, supplier Hitachi was willing to finance monorail construction.

Haneda Airport was built in an area once served by an electric railway branch, cut back after World War II but eventually re-extended to serve the airport. The civilian airfield, established in 1931, became a military airbase several years later and was taken over by the U.S. military in 1945. It was returned to Japanese control in 1952, and the Transport Ministry began building Tōkyō International Airport in 1954.

The rail spur was owned by today's Keihin Electric Express Railway (京浜急行電鉄), or *Keikyū* (京急 "kay-cue"). It terminated within sight of the airport terminal, but the company believed that the cost of an extension could not be justified. Air traffic accounted for a tiny fraction of all intercity transport during the 1950s and early 1960s, and air passengers would not bring much additional revenue. Instead, Keikyū and Japan Air Lines started an express bus service to Tōkyō station when the airport opened in 1955.

Planning for the 1964 Tōkyō Olympics started in 1959. Keikyū considered an underground extension to the airport but did not pursue this idea. Back then, Keikyū trains terminated at Shinagawa, south of central Tōkyō. The long-planned metro to Shinagawa, used by Keikyū trains today, was under construction but not complete.

A group of investors with ties to the Alweg firm joined with Hitachi, which had acquired license rights to Alweg technology in 1960. The Tōkyō Monorail Co., Ltd., received its concession in 1961 and began construction in 1963. It was financed exclusively by private investors, with no participation by the state, the airport authority or the aviation industry. The line as built extended 13.2 km (8.2 mi). The nominal construction cost (without attempting to adjust for inflation) was ¥21.1 thousand million (\$60 million), ¥20 thousand million for infrastructure and ¥1.1 thousand million for rolling stock.

Supplier Hitachi was undoubtedly well aware of the tenuous prospects for short-term profits. However, it certainly concluded that benefits - a major showcase for *Hitachi-<Alweg>* technology, and long-term profits as airport traffic grew - justified the risk.

The Hamamatsu-chô terminal is 3 km (2 mi) south of the Ginza-Yûrakuchô hub. This location was selected for economy reasons, but is easy accessible from most offices and hotels by Yamanote Line trains or taxi. The monorail was built along the railway, canals, and tidal areas reclaimed from Tôkyô Bay. The line has a short tunnel under a ship channel, and the original terminal had a single-beam tunnel beneath runways to a station below the main ticket counters.

The monorail had no intermediate stations when built, a fact which demonstrated that airport traffic alone could not support the line. A toll expressway to Haneda, also completed for the Olympics, provided strong competition. One intermediate station was added in 1965 to serve the Ôi Racetrack, but the line was still not able to earn a profit. The company was merged into the Hitachi group in 1967 as "Hitachi Transport Systems, Tôkyô Monorail" (日立運輸東京モノレール) eliminating all outside investment.

Traffic at Haneda Airport grew from 3.9 million at 1965 to 49.3 million at 1997, despite relocation of most international flights to Narita Airport in 1978. By this time, Haneda was the world's sixth busiest airport. Annual monorail traffic grew from three million to more than 60 million per year during the same period, owing in part to gradual addition of new stations to serve on-line development. The line currently has seven intermediate stations. The monorail became profitable in 1972, and resumed "independent" operation as Tôkyô Monorail Co., Ltd., in 1981. Hitachi Transport Systems remained the sole shareholder until very recently.

The Tôkyô Monorail enjoyed a 60 percent market share of airport traffic for many years, but plans for airport expansion finally attracted the attention of Keikyû management.

In 1983, the Transport Ministry began a project to expand Haneda Airport from an annual capacity of 22 million passengers annually to 85 million. It built new terminals 2.4 km (1.5 mi) east of the original. Tôkyô Monorail built a 5.2-km (3.2-mi) extension to the new west terminal. This opened in 1993, and the 1.0-km (0.6-mi) segment to the old terminal was closed at the same time. The new tunnels beneath the runways were built by the state and leased to Tôkyô Monorail for an annual payment of 2.5 percent of appraised value. At the end of construction (1993), the cost was stated as ¥61.6 thousand million, including ¥43.7 thousand million for tunnels, viaducts and guideways, ¥7.6 thousand million for electrical and other equipment, and ¥10.3 thousand million for improvements to the existing line. The final cost (including interest during

the construction period) was ¥67.6 thousand million (about \$900 million in 2002 dollars). Fifteen percent was paid by the state, and the remainder was financed by loans, with interest subsidized by central and local authorities.

Also in 1983, Keikyû secured authority to build an underground extension to the airport terminals. It started construction in 1988, opened a new underground station near the airport in 1993, and completed the project at the end of 1998. Estimated cost at the start of construction ¥93 thousand million (about \$700 million in 2002 dollars), with 17.5 percent paid by the state. Keikyû borrowed the remainder from the Japan Development Bank (a public corporation, i.e. a government agency), and pays an annual rent equal to 2.3 percent of appraised value for the tunnels within the airport perimeter. The extension was anticipated to increase traffic on the branch (long known as the "Airport Line" even though trains did not enter the airport) from 28,000 to 35,000 passengers daily. The new Haneda Airport East Terminal, planned for completion in 2003, will be served by a 0.8-km (0.5-mi) monorail extension and by the existing Keikyû station. At 1993, the second-stage monorail extension was estimated to cost ¥17.7 thousand million.

At 1997, prior to opening of the Keikyû extension, the monorail carried about 77,000 airport passengers per day. About 49 percent of all monorail passengers were airport passengers (Hirota).

The monorail is faster, and cheaper, for passengers traveling to and from Hamamatsu-chô. Travel time from the nearest metro station (Daimon) is 28 min, compared to 22 min by monorail, and the combined metro-Keikyû fare is about \$5, compared to about \$4 by monorail.

However, Hamamatsu-chô is not a major "destination." The monorail's cost and time differences disappear for passengers continuing north to major destinations such as Shimbashi, just one minute north of Daimon by metro or (two minutes by JR Yamanote Line from Hamamatsu-chô). Through trains from the Keikyû network continue over metro tracks to major destinations such as Ginza and Asakusa, then by connecting railways to points as far as Narita Airport. Keikyû now operates direct service to points south, connecting the airport with Kawasaki and Yokohama.

The Tôkyô Monorail is currently operating its fourth generation of rolling stock, all built by Hitachi. The line opened with 47 cars and two diesel shop switchers. The early cars were 10.8 meters (35' 5") long, and were coupled in three-car formations. A photo of a test run one month prior to opening shows a nine-car train. Cars purchased after 1969 were 15.2m (49' 10") long. Air conditioning was introduced in 1982. Today, the line has 114 aluminum-bodied cars, permanently coupled in 19 six-car trains. The newest vehicles are 3.0m (9' 11") wide overall, 4.5m (14' 10")

high overall, 2.8m (9' 4") over the support beam top surface, and 2.3m (7' 5") over the passenger compartment floor.

Guideway beam cross-section dimensions are 1.4m (4' 7") high x 0.8m (2' 7") wide. Traction current is supplied at 750V dc. Performance specifications include: acceleration 3.1 km/h/s (1.9 mph/s), service braking 3.5 km/h/s (2.2 mph per sec), emergency braking 4.5 km/h/s (2.8 mph per sec).

The minimum interval between trains is 3 min 20 sec, which is operated during the a.m. peak. However, this is not sustained over a 60-minute interval. The maximum service level is 19 trains per hour per direction (thd), which is typical of Japanese practice. Japanese rail systems avoid operation of headways shorter than 3 min when possible.

The minimum headway is set by the configuration of Hamamatsu-chô terminal, which is single-beam. A planned new double-beam terminal would permit a minimum headway of 2 min. The original Haneda terminal had two beams, but the 0.8-km (0.5-mi) tunnel leading to it had a single beam.

The company progressively increased midday service as traffic grew: from 10 to 8 min in 1970, to 7 minutes in 1971, to 6 min in 1973, and to 5 min in 1985. The new, longer "bogie" stock acquired from 1969 was operated in four-car trains until completion of platform lengthening in 1974. All trains were lengthened to six cars with the July 1983 timetable change. Following completion of automatic platform gates, the monorail was changed to driver-only operation from late September 2002.

The maximum hourly traffic volume is reported at 10,512 phd. As stated above, the maximum service level is 19 thd, and each six-car train is 93.6 m (307 ft) long. This works out to 92 p/v and 5.9 p/m, averaged over the busiest hour. These statistics are not remarkable for Japan - but are 20-50 percent higher than the 4 to 5 p/m "maximum" for most U.S. and Canadian cities. In order to carry 10,512 American or Canadian consumers per hour, the Tôkyô Monorail would have to provide 20 to 50 percent more peak-period service than it does - and can - today.

The East Japan Railway ("JR-East"), one of the privatized regional successors to the Japanese National Railways (JNR), announced in December 2001 that it would purchase the majority of Tôkyô Monorail stock from Hitachi Transport Systems. Under the agreement, JR-East was to purchase 70 percent of monorail stock for ¥7 thousand million (about \$60 million). The remaining 30 percent was to be purchased by Hitachi, Ltd., parent of the Hitachi Group, for ¥3 thousand million (about \$25 million, an amount equal to the company's capitalization). The decision to sell was prompted by high debt (¥50 thousand million, about \$420 million), and need for

capital investment that Hitachi wished to avoid. Newspapers reported that the monorail carried about 138,000 passengers per day at the end of 2001, down by 22 percent from the annual average for the 1997 fiscal year. The annual average for the 2003 fiscal year was 128,000 passengers per day.

Keikyû has conducted aggressive marketing campaigns since completing its extension (or "re-extension") to Haneda Airport at the end of 1998. Keikyû competition hurts JR-East as well as the Monorail, for 70-80 percent of Monorail passengers change to JR Yamanote Line trains at Hamamatsu-chô. The sale gives JR-East "access" to Haneda Airport - or, more precisely, control over its connection to Haneda Airport. JR-East improved connections between Yamanote Line and monorail trains, offered through discount tickets to the airport, and extended the validity of its Suica farecard to the monorail.

The Tôkyô Monorail is the world's busiest airport rail link and will certainly remain in operation for many years. However, the days of steadily increasing monorail traffic have ended. The national economy is mired in recession, and there is little prospect for short-term improvement. The long-term future does not look promising, since various new rail lines are planned to reach Haneda. Things might improve under JR-East control, owing to improved coordination with JR trains, promotion as part of the JR metropolitan rail network, and through-ticketing arrangements.

Additional rail services will reach Haneda within the next decade. A new metro line, paralleling the west side of the Yamanote loop line to serve major centers such as Ikebukuro, Shinjuku and Shibuya is under construction, and is planned for completion by 2007. This will connect at Shibuya with the Tôkyô Express Electric Railway, permitting regional through services from northwestern points to Kawasaki, Yokohama, and Kamata. A short connecting link to the Keikyû line is planned as a medium-term project. Through service to Haneda Airport would require either dual-gauge track (Keikyû uses standard gauge; the new metro will use 1,067 mm (3'6") gauge) or perfection of *<free gauge>* rolling stock that can pass between lines of different gauges while in motion. Long-term projects include passenger service on an underground freight bypass near Haneda Airport, and a new "middle-peripheral" rail line that will eventually reach Haneda. All of these projects will use conventional rail technology.

Tôkyô Monorail once planned extensions from Haneda to Yokohama (18 km / 11 mi) and to Kamata (4 km / 2.5 mi), but did not secure authority for these. The company relinquished its license to build northward from Hamamatsu-chô to Shimbashi in 1966. JR-East announced at the end of 2001 that it would study a monorail extension to Shimbashi. An underground extension to

Shimbashi and Tōkyō station would provide better connections with various JR services, but would be extremely expensive to build - ¥50-100 thousand million, according to an estimate released early in 2002. The high cost gives the appearance of a long-term project, one not likely to advance until Japan's economy improves.

Two additional points deserve comment. Sheer market size and traffic volume play an important role in facilitating profitable operation of enterprises such as the Tōkyō Monorail. The Tōkyō metropolitan region houses roughly 30 million people within a 50-km (31-mi) radius of Tōkyō station (claimed as the largest agglomeration of people, and economic activity, in human history). An estimated 2.5 million people commute to jobs in Tōkyō's three central wards each weekday. Along major transport corridors, traffic volumes are high enough to justify parallel tracks, and lines, to an extent unimaginable anywhere else. Tōkyō's busiest transport corridor extends southward from Tōkyō station, and includes nine pairs of tracks within an area about 0.8 km (0.5 mi) wide. These include two "urban" metro lines and a third underground line built for the "railway" network. On the surface, the Tōkaidō Main Line has three pairs of tracks, and one pair for Tōkaidō Shinkansen trains, which now carry substantial short-distance travel. Elevated structures carry the newest addition, the *Yurikamome* <NTS> line and the Tōkyō Monorail.

The monorail's profitability reflects the economic environment in which it operates. During the 2000 fiscal year, Tōkyō Monorail passengers paid an average of \$0.22 per km (\$0.35 per mi) in fares. By contrast, New York City Transit and San Francisco Bay Area Rapid Transit District (BART) passengers paid \$0.10 per km (\$0.16 per mi). If BART had collected \$0.22 per km (\$0.35 per mi) from each passenger, it would have returned an operating surplus of about \$70 million. If BART had also increased its traffic density to that carried by the Tōkyō Monorail, the surplus would have approached \$500 million. If NYCT had accomplished similar feats, it would have returned an operating surplus exceeding \$1 billion. (Metro operating surpluses are not unknown in Japan, and were reported by five of the country's ten operators for the 2000 fiscal year, and by seven of the ten operators for the 2002 fiscal year).

TABLE 4: JAPANESE MONORAIL ROLLING STOCK FLEETS

Operator	Route Length	Rolling Stock (cars)	Formations (trains)	Maximum Train Length
Chiba	15.2 km / 9.4 mi	40	20 two-car	four cars
Inuyama - Nagoya RR	1.2 km / 0.7 mi	6	3 two-car	six cars

Operator	Route Length	Rolling Stock (cars)	Formations (trains)	Maximum Train Length
Kitakyûshû	8.8 km / 5.5 mi	40	10 four-car	four cars
Naha	12.9 km / 8.0 mi	24	12 two-car	four cars
Ôsaka	23.8 km / 14.8 mi	52	13 four-car	four cars
Shônan	6.6 km / 4.1 mi	21	7 three-car	three cars
Tôkyô Maihama	5.0 km / 3.1 mi	30	5 six-car	six cars
Tôkyô Monorail	16.9 km / 10.5 mi	114	19 six-car	six cars
Tôkyô Tama	16.0 km / 9.9 mi	60	15 four-car	four cars

鎌倉 Kamakura 湘南モノレール Shōnan Monorail

Suspended system: Ôfuno (大船) to Shōnan-Enoshima (湘南江の島), 6.6 km (4.1 mi).

Opened 1970.

Fare	Up to	Equivalent per km (per mi)
\$1.40	1.9 km (1.2 mi)	\$0.70 (\$1.10)
\$1.70	3.5 km (2.2 mi)	\$0.50 (\$0.80)
\$2.00	5.0 km (3.1 mi)	\$0.40 (0.60)
\$2.20	5.5 km (3.4 mi)	" "
\$2.30	6.0 km (3.7 mi)	" "
\$2.50	6.6 km (4.1 mi)	" "

This line was built to provide improved transportation to an area, southwest of Tôkyô, which had considerable residential and commercial development but no local rail line. It terminates at Enoshima, a seaside resort town. Enoshima already had a rail connection to Tôkyô and a local electric railway, but the monorail provides useful additional capacity during peak travel periods.

"Interurban" monorail lines had been proposed in Japan since the 1920s, but this line has the character of a suburban connector. It was built over the area's major transport corridor, a two-lane road built by the Keihin Electric Express Railway (Keikyū) but open for toll-free public use. (Privately financed roads, toll and free, are not unknown in Japan.)

The Shōnan Monorail (湘南 *Shōnan* is a regional name) was also built as a full-scale prototype for suspended monorail technology in Japan, with substantial supplier financing. In this respect, it is the Safege-system analogue of the Alweg-system Tōkyō Monorail. Mitsubishi, the Japanese licensee for Safege technology, organized the company and secured permission to build between Ōfuna, southwest of Yokohama, and Enoshima.

Major shareholders include:

Mitsubishi Heavy Industries, Ltd.	55 percent of shares.
Mitsubishi Electric Corp., Ltd.	18 percent.
Mitsubishi, Ltd.	18 percent.
Nippon Steel Corp., Ltd. (world's largest steelmaker)	2 percent.
Keihin Electric Express Railway Co., Ltd.	1 percent.
Nippon Kōkan, Ltd. (Japan's second-largest steelmaker)	1 percent.

The Shōnan Monorail extends 6.6 km (4.1 mi) between terminals. Because it was built along a local road, the monorail has relatively sharp curves and grades to 7.4 percent (1 in 14). The line also has two short tunnels, required by local geography. It is single-beam with passing sidings at four of the six intermediate stations. Both terminals have single beams with a platform on either side. Trains operate with two-man crews, and the intermediate stations are unattended. Traction current is supplied at 1500V dc. The nominal construction cost (without attempting to adjust for inflation) was ¥5.3 thousand million.

The Shōnan Monorail provides an interesting ride and demonstrates, among other things, that there is such a thing as a practical monorail "switch" (as opposed to "turnout"). On the other hand, there is no prospect for extension, not even 1 km (0.6 mi) farther south to Enoshima island. This link was planned as a monorail line as long ago as 1927 and again during the early 1960s.

VII. Unrealized Plans

The formative years of monorail development in Japan coincided with plans for major investment to upgrade urban transport. After World War II, tramway lines in bomb-devastated cities were restored with relatively little investment. Large numbers of composite-bodied cars, with sturdy but obsolete hardware, were built to replace the thousands damaged or destroyed during the 1945 firebomb attacks. However, trams could not continue operation indefinitely without investment large-scale modernization and renewal. Transport and finance officials eventually decided that this investment could not be justified. Local and central authorities cited population shifts, falling ridership, financial difficulties and rapidly rising road congestion as factors requiring investment in some other mode.

Large Japanese cities began to consider tramway replacement during the mid-1950s. Trolleybuses and motorbuses required much less capital but were not adequate for busy trunk routes. Metros were the obvious choice for this application. Tôkyô, Ôsaka and Nagoya had long-standing plans for comprehensive networks, but progress was slow because of financial constraints. This generated some interest in monorail technology, but planners concluded that monorails were not suitable for the busiest trunk lines in Japan's largest cities. Ôsaka began replacing tramcars with trolleybuses in 1961, then decided to replace all remaining trams with motorbuses in 1966. Kôbe decided on tramcar replacement in 1965, followed by Nagoya in 1966. In Tôkyô, the municipal transportation bureau (*Toei*) invested considerable sums for temporary track to maintain tramcar service during service during metro construction, for permanent track after construction was finished, and for new track as part of street widening projects. This stopped in 1965, and Toei announced a five-year plan to replace all surface electric transport in 1967. Kyôto, the single holdout among the six large municipal transport operators, began tramcar replacement in 1970.

Japanese planners chose metros in corridors where traffic justified investment for new urban transport facilities. Short test lines and even the Tôkyô Monorail demonstrated that monorails could not carry the anticipated peak-period traffic volumes (Tôkyô metro lines carry up to eight times more traffic during the busiest hour than the Tôkyô Monorail). In addition, monorails are not compatible with conventional rail lines, and capability for through operation was an important consideration. In Tôkyô, plans date to the 1930s for extending operation of suburban trains over metro tracks. Implementation was spurred after WWII by the large and growing numbers of passengers changing between suburban and urban rail services at major interchange stations such as Ikebukuro, Shibuya and Shinjuku.

A plan for a new transport line in the Nagoya illustrates the importance given by planners to through-running capabilities - and how this placed monorail at a relative disadvantage. The Nagoya Railroad was interested in monorail development, no doubt stimulated by its Monkey Park Monorail described above. A rail line extending due east from Nagoya would have served an area of potential suburban development, but construction through the built-up area in Nagoya proper would have been very costly. The company considered a 21-km (13-mi) monorail from Yagoto, in southeastern Nagoya, eastward to the automaking center of Toyota. This would have connected with a planned metro line at Yagoto, and with an existing Meitetsu line at Toyota. However, passengers traveling to central Nagoya would have been forced to change at Yagoto, and the anticipated volume of traffic was sufficient to justify through running. Therefore, a conventional rail line was built as a joint project by Nagoya city and the Nagoya Railroad. The metro Tsurumai Line, using 1067-mm gauge track and 1500V dc overhead current collection, was built to the municipal boundary at Akaike, 5.3 km (3.3 mi) beyond Yagoto. From Akaike, the Nagoya Railroad built its Toyota New Line 15.2 km (9.4 mi) eastward to Toyota. This project was completed in 1979. Later, the metro was extended northward to a connection with the Nagoya Railroad Inuyama Line, provided a much-needed alternate route through central Nagoya.

Other unrealized plans include:

--A short excursion line at Atami, southwest of Tōkyō, connecting Atami station with the base station of an aerial cableway (ロープウェイ <ropeway>), 2.1 km (1.3 mi). The Atami Monorail Co., Ltd., (熱海モノレール) received a concession in 1963 but was not able to finance construction.

--Short excursion lines at Arashiyama (west of Kyōto), Hiroshima, and Shingū (on the Kii Peninsula between Nagoya and Ōsaka).

--Short lines in the Tōkyō region. One of these was planned to connect the Tōkyō Monorail terminal at Hamamatsu-chō with Tōkyō Tower. Another was planned in Narita, to connect Narita station with the Shinshōji, a Shingon Buddhist temple known popularly as Narita-san. (A small tramway line once served this market.)

Planned long-distance lines included:

--A 32-km (20-mi) line extending from Gifu southwest to Yōrō, with a 11-km (7-mi) branch from Usa to Hashima, studied by the Nagoya Railroad Co., Ltd. An estimate, probably dating to the early 1960s, placed the cost of building 19 km (12 mi) of double-beam line at \$22.5 million, more than \$1 million per km (nearly \$2 mn per mi); in 2002 dollars, \$130 mn, nearly \$7 mn per km

(\$11 mn per mi). This proposal evidently envisioned construction along the Nagara River - and, as such, seems to have been the "solution in search of a problem." This is illustrated by the following example:

One of the planned markets was to connect Gifu with the original Tōkyō - Ōsaka high-speed railway. This line, the Tōkaidō Shinkansen, bypassed Gifu some distance to the west. A station named Gifu-Hashima was built within Gifu Prefecture for political reasons. However, Nagoya station is just 31 km (19 mi) away, has many more shinkansen services than Gifu-Hashima, and has frequent service to Gifu by Nagoya Railroad trains. Most Gifu passengers preferred to make shinkansen connections at Nagoya. The area around Gifu-Hashima station developed very slowly. Not until 1982, 18 years after shinkansen service began, did the Nagoya Railroad build a 1.5-km (0.9-mi) spur from an existing line to Gifu-Hashima.

--Two Safege-system monorails proposed by Nippon Airways Development, extending from Ōtemachi, near Tōkyō station: one 23 km (14 mi) west to Mitaka, the other 50 km (31 mi) east to Chiba and Goi. These were proposed for construction apparently along toll expressways.

Urban monorail proposals were floated for a number of cities, including Fujisawa, Fukuoka, Gifu, Hiroshima, Kawasaki, Kitakyūshū, Kōbe, Kumamoto, Kyōto, Nagoya, Okayama-Kurashiki, Sendai, Shizuoka-Shimizu, Takamatsu, Tomakomai (Hokkaidō) Tōkyō and Utsunomiya. A circular monorail for Tōkyō was proposed to parallel much of the Yamanote Line, for much of the distance along Meiji-dōri, a peripheral road once served by Tōkyō's longest trolleybus line. Fukuoka, Kōbe, Kyōto and Sendai built metros designed for through service with connecting rail lines. Nagoya and Tōkyō continued metro expansion, building lines designed for through service. Kitakyūshū eventually built the first "urban" monorail in Japan. This was not the start of a Japanese monorail "revival," as stated by some non-Japanese sources, but the first application of monorail after the initial periods of development, refinement and adoption of standards.

Fukuoka (1.1 million) provides a useful example of site-specific factors that tend to discourage monorail construction. The city is the capital of Fukuoka Prefecture, and the business, commercial and transportation hub of Northern Kyūshū. The principal rail station (which is named "Hakata") is located about a mile south of the business center, and Fukuoka Airport is located about two mi) south of the station. The rail line extending westward from Fukuoka, the Chikuhi Line, had a poorly-located entrance to Fukuoka and a very poorly-located entrance to Karatsu (80,000), a regional center about 50 km (30 mi) to the west. The long-established Kyūshū University is located about 3 km (2 mi) east of the center. Two km (1 mi) mile farther east, at Kaizuka, is the terminal of an independent rail line, the Miyajidake Line of the Nishi-Nippon Railroad Co., Ltd. (Nishitetsu).

Over a period of 15 years, Fukuoka built a 1067-mm (3'6") gauge metro network to link these and other destinations (including the "main" Nishitetsu terminal, at Tenjin). The major line extends north from Hakata station, then turns west to Tenjin and Meinohama, roughly 8 km (5 mi). Here, the line connects with the JR-Kyūshū Chikuhi Line, which received 1500-volt DC electrification and a new entrance, on concrete viaduct, to Karatsu. The other branch extends to Kai-zuka. The surface-level passenger interchange here will eventually provide through running for Miyajidake Line. This will occur once traffic grows to justify the investment needed to upgrade the Nishitetsu line. Total route length, including an extension from Hakata station to the airport, is about 16 km (10 mi). Monorail alternatives could not have provided through-running access to central Fukuoka for Chikuhi Line and (eventually) Miyajidake Line trains.

TABLE 5: JAPANESE MONORAIL CONSTRUCTION AND OPERATING DETAILS

Operator	Route Length km / mi	Scheduled Running Time Between Terminals	Passenger (commercial) Speed	Maximum Permitted Speed	Maximum Grade	Minimum Curve Radius
Chiba	L 1: 3.2 / 2.0	10 min	20.2 km/h 12.5 mph	65 km/h 40 mph	6 percent	50 m 164 ft
	L 2: 12.0 / 7.4	26 min	30.0 km/h 18.6 mph			
Inuyama - Nagoya RR	1.2 / 0.7	4 min	18 km/h 11 mph	40 km/h 25 mph	9.7 percent	
Kitakyūshū	8.8 / 5.5	19 min	27 km/h 17 mph	65 km/h 40 mph	4 percent	80 m 263 ft
Naha	12.9 / 8.0	27 min	28.1 km/h 17.4 mph	65 km/h 40 mph	6 percent	
Ōsaka	ML:21.2 / 13.1	36 min	35.0 km/h 21.7 mph	75 km/h 46.5 mph	6 percent	100 m 328 ft
	BL:2.6 / 1.6	5 min	29.4 km/h 18.2 mph			

Operator	Route Length km / mi	Scheduled Running Time Between Terminals	Passenger (commercial) Speed	Maximum Permitted Speed	Maximum Grade	Minimum Curve Radius
Shōnan	6.6 / 4.1	14 min	28.9 km/h 17.9 mph	75 km/h 46.5 mph	7.4 percent	50 m 164 ft
Tōkyō Maihama	5.0 / 3.1 single beam	13 min	24.0 km/h 14.9 mph			
Tōkyō Monorail	16.9 / 10.5	22 min	40 km/h 25 mph	80 km/h 50 mph	6 percent	120 m 394 ft
Tōkyō Tama	16.0 / 9.9	36 min	26.9 km/h 16.7 mph	65 km/h 40 mph	5.8 percent	100 m 328 ft

VIII. Standards Adopted For Supported and Suspended Monorails

Monorail suppliers and operators organized the Japan Monorail Association (日本モノレール協会 *nippon <monorail> kyōkai*) and began large-scale research and development in 1967.

The goal was to establish design and application standards for monorail technology in Japan. The first major result was establishment of standards for supported monorails (跨座型モノレール *kozagata-<monorail>*) in 1968. These include rubber tires, bogies with two driving axles at either end of each vehicle, and passenger compartment mounted entirely above driving and guide wheels to maximize interior space. The first monorail built to these standards was the Expo '70 world's fair line in Ōsaka (above).

The Shōnan Monorail is considered the first of Japan's "second-generation" monorail lines. It is true that this line was built after the commencement of monorail research and development in 1967. However, it is reasonable to describe it as a full-scale prototype, for it served as the basis for JMA standards for suspended monorails (懸垂型モノレール *kensuigata-<monorail>*).

The proprietary nature of various new transit technologies is a major concern in the U.S., particularly so following the experience of Jacksonville, FL. This city purchased proprietary technology for the first stage of its "Automated Skyway Express." When the time came to build the

second stage, the original supplier's bids were so high that the operator scrapped the original system, then purchased a replacement proprietary system from a different supplier.

As a practical matter, monorail and <NTS> technology are not "proprietary" in Japan, at least not in the U.S. sense. Any supported monorail, suspended monorail or <NTS> facility built with public investment must conform to design standards for that mode. It is true that supported monorail is Hitachi's domain, and that suspended monorail is Mitsubishi's domain. However, the relationship among suppliers, operators and state transport and finance ministries is much different than in the U.S. State authorities have, and use, the "power of persuasion" to encourage suppliers to cooperate with each other, and with transport operators, "for the good of all concerned" - that is, to secure lower costs. Given the importance of consensus and cooperation in Japanese culture, it is very difficult to imagine a situation similar to the one faced by Jacksonville would occur in Japan.

Various Japanese rail operators often divide large orders for rolling stock among several car-builders. Kawasaki Heavy Industries, Ltd., has shared recent some orders for supported monorail stock with Hitachi, Ltd.

IX. Mature Technologies Gain Application

北九州 Kitakyūshū

北九州高速鉄道小倉線 *kitakyūshū kōsoku tetsudō kokura sen*

Kitakyūshū Rapid Railway Co., Ltd., Kokura Line

Supported system: Kokura (小倉) to Kikugaoka (企救丘), 8.8 km (5.5 mi). Opened 1985.

Fare	Up to	Equivalent per km (per mi)
\$1.30	0.5 km (0.3 mi)	\$2.60 (\$4.30)
\$1.40	0.8 km (0.5 mi)	\$1.75 (\$3.50)
\$1.60	3.2 km (2.0 mi)	\$0.50 (\$0.80)
\$1.90	4.8 km (3.0 mi)	\$0.40 (\$0.60)

Fare	Up to	Equivalent per km (per mi)
\$2.20	7.3 km (4.5 mi)	\$0.30 (\$0.50)
\$2.40	8.8 km (5.5 mi)	\$0.25 (\$0.40)

The "Kitakyûshû Rapid Railway, Kokura Line," was the first "urban transport" monorail in Japan. The Tôkyô Monorail was built as an "airport-access railway" and this remains its primary function.

No two cities are exactly alike, but Kitakyûshû ("key-tuh-cue-shoe," = "North Kyûshû") stands out as unique in Japan. It grew up as the country's major steelmaking center, as five separate cities that were not amalgamated until 1963. It sprawls out over more than 30 km (20 mi) east to west. Heavy industry has become less important in recent years, but Kitakyûshû retains a highly industrialized cityscape.

The city's principal transport corridor extends from east to west. Until 1985, this was served by trams operated by the Nishi-Nippon Railroad Co., Ltd., (西日本鉄道) known popularly as *Nishitetsu* (西鉄 "Nish-tets"). Prolonged, inexorable traffic declines, because of population shifts, falling industrial employment and railroad competition, brought about motorbus substitution in 1985 and 1992; the last vestige was replaced in 2000.

The "railroad competition" mentioned above became far more formidable after JNR electrified its Kagoshima Main Line in 1961. Today, JR-Kyûshû operates three local and three "rapid-service" trains per hour through Kitakyûshû, a "rapid-transit" or *S-Bahn* service in all but name. These trains provide commercial speeds exceeding 50 km/h (30 mph).

TABLE 6: JAPANESE MONORAIL SERVICE DETAILS

Operator	Route Length km / mi	Through Fare	Service Hours	Midday Service Frequency	Down (outbound) Services Weekday / Sun-Hol	Up (inbound) Services Weekday / Sun-Hol
Chiba - Line 1	3.2 / 2.0	\$2.25	5:30 am - 11:50 pm	10 min	126 / 109	127 / 110

Operator	Route Length km / mi	Through Fare	Service Hours	Midday Service Frequency	Down (outbound) Services Weekday / Sun-Hol	Up (inbound) Services Weekday / Sun-Hol
Chiba - Line 2	12.0 / 7.4	\$3.75	5:30 am - midnight	10 min	124 / 132	123 / 130
Inuyama - Nagoya RR	1.2 / 0.7	\$1.25	8:50 am - 5:20 pm	30 min	18	18
Kitakyûshû	8.8 / 5.5	\$2.40	6:00 am - 11:30 pm	6-10 min	103 / 94	103 / 93
Naha	12.9 / 8.0	\$2.40	6:00 am - 11:30 pm	10-12 min	101	101
Ôsaka - Main	21.2 / 13.1	\$4.50	5:45 am - 11:30 pm	10 min	110 / 102	108 / 101
Ôsaka - Branch	2.6 / 1.6	\$2.00	6:25 am - 11:35 pm	20 min	50 / 49	51 / 49
Shônan	6.6 / 4.1 single beam	\$2.50	5:30 am - 11:30 pm	7.5 min	133 / 113	133 / 113
Tôkyô Maihama	5.0 / 3.1 single beam loop	\$1.70	6:00 am - 11:59 pm	6 min		
Tôkyô Monorail	16.9 / 10.5	\$3.90	5:00 am - 11:30 pm	4-5 min	253 / 234	255 / 236
Tôkyô Tama	16.0 / 9.9	\$3.30	5:30 am - midnight	10 min	122 / 107	119 / 106

The monorail was built to serve a different travel corridor, extending southward from Kokura, the business-center "hub" of Kitakyûshû. The inner part of this route, in an area of log-established residential development, was once served by the city's "original" tramway line (opened 1906-1907, electrified 1923, replaced by motorbus 1980). This extended 4.5 km (2.8 mi) southward to Kitagata; a short-lived (1923-1925) horsecar line once extended 3.1 km (1.9 mi) farther south to Tokuriki. By the early 1970s, suburban development south of Kitagata created a need for improved transportation. Planners eventually rejected the idea of a streetcar extension. Nishitetsu's slow (18 km/h (11 mph) commercial speed) Kitagata Line, built in narrow streets, could not provide the needed capacity.

The city government outlined monorail development in its first long-term comprehensive plan, adopted in 1965. This included a figure-eight line, underground in business centers and elevated elsewhere. However, the legal and administrative framework for application of monorail technology to urban transport did not exist at the time. In response to rising traffic congestion,

erosion of public transport ridership and population shifts to outlying areas, planners outlined three monorail lines:

--Kokura Line (小倉線), Kokura southward to Tokuriki and Sone.

--Kurosaki Line (黒崎線), Kurosaki southwestward toward Omine.

--Tôzai Line (東西線), Kokura westward to Kurosaki (Tôzai = "East-West").

The Kokura Line corridor did not have sufficient traffic to justify a full-scale rail line. Its logical connection, the JR-Kyûshû Hita-Hikosan Line, did not carry sufficient traffic to justify the investment required for electrification or additional track capacity. The Construction Ministry planned an elevated express highway in the corridor, and a monorail could be built within the same alignment. There was no available surface alignment within the corridor. The line would be relatively short, and expansion would not be required for many years, until other lines or branches, forming a network, could be justified.

Monorail planning, started in 1976, stirred considerable controversy. On-line residents raised issues including noise, vibration, obstruction of views and light, and privacy intrusions. More than 12,000 comments were received during public consultation. The city organized a third-sector company, Kitakyûshû Rapid Railway Co., Ltd., in 1977 to finance construction and operate the line. At the time of organization, shareholders and percentages of stock held were:

Kitakyûshû City	52 percent.
Nishi-Nippon Railroad Co., Ltd.	20 percent.
Kyûshû Electric Power Co., Ltd.	6 percent.
Nippon Steel Corp.	6 percent.
Sumitomo Metal Industries, Ltd.	5 percent.
The Fuji Bank, Ltd.	3 percent.
The Fukuoka Bank, Ltd.	3 percent.
Saibu Gas Co, Ltd.	2 percent.
The Nishi Nippon Bank, Ltd.	1 percent.
The Yamaguchi Bank, Ltd.	1 percent.
The Fukuoka Sogo Bank, Ltd.	1 percent.

The Transport Ministry authorized the Kokura Line monorail project in 1977, and construction started in 1978. Test operations at the maintenance facility, located near the outer terminal, began in 1981. Opening was postponed beyond April 1983, as originally planned, because of noise-reduction and vehicle-design issues. Revenue service began in 1985. In 1998 a short (0.5-km (0.3-mi)) extension brought monorail trains to a new terminal in the rebuilt Kokura station complex.

The line was built over a newly widened street in central Kokura, supported by T-shaped pillars. The middle portion is built beneath the highway deck, where much more massive pillars support the monorail and the highway above. The southern, outer portion was built over a new road in an area of new suburban development. This portion is quite scenic, with views of the mountains to the south.

Construction cost was originally estimated at ¥51.4 thousand million (roughly \$350 million in today's dollars), with "infrastructure" (the guideway) accounting for 45 percent of this. A metro was estimated to cost three times this amount. The actual cost was about 32 percent higher, ¥68.1 thousand million (about \$460 million).

Of the infrastructure share, ¥30.5 thousand million, 44.9 percent was paid by the central government, 2/3 of this amount from road funds. The remainder was financed by the city government. Other expenses, including interest during the construction period, brought the total "infrastructure" cost to ¥33.9 thousand million (about \$230 million).

The "other" (non-infrastructure) share, which included rolling stock, power-supply and station equipment, totaled ¥34.6 thousand million (about \$120 million). This was financed by the third-sector enterprise. Investment capital provided ¥2.2 thousand million, a loan from the Kitakyûshû city government provided ¥22.4 thousand million, and a loan from the Japan Development Bank provided ¥10.0 thousand million. Each four-car train cost ¥580 million.

The monorail has 11 intermediate stations. Platforms have fixed barriers with gaps at door locations - precise spotting of trains is customary in Japan. The operating base is located a short distance beyond the outer terminal, Kikugaoka.

The line is equipped with <CTC> and <ATO> for driver-only operation, and was Japan's first "major" monorail with one-man operation of trains. Traction current is supplied at 1500V dc.

<CTC> and <ATO> stand for "Centralized Traffic Control" and "Automatic Train Operation," respectively. These are historic acronyms. Current reality is perhaps best described as 1) computer-controlled dispatching, 2) A computerized "fail-safe" or "oversight" that displays

maximum permitted speed over each section, and monitors acceleration, speed, braking and so forth to prevent unsafe operation. The electronics could in theory support driverless operation but the Transport Ministry requires double redundancy (i.e. two levels of independent "fail-safe" systems) for commercial driverless operation. A few Japanese <NTS> lines operate without drivers, but most do not.

The current ridership of 33,000 per day is less than half of the pre-construction forecast, 85,500 per day. The company became profitable from 1998, but the cumulative deficit (from the first 13 years of operation) was ¥26.3 thousand million (about \$220 million) at 1999. The company faces a downward trend over the near-term future owing to decreasing numbers of school-age children (school commuters form a significant share of public transit traffic in Japan), and declining popularity of horse racing (a racetrack is a major on-line traffic generator).

Prospects for extensions are extremely limited, for the Kitakyûshû Monorail was not built with expansion in mind. Plans such as those for the Kurozaki and Tôzai lines are typically outlined far in advance, to be implemented when the investment can be justified. These are therefore best understood as possibilities for the future, for which provisions will be made as other infrastructure projects are built. The Kurozaki Line would parallel the suburban express tramway built by the Chikuhô Electric Railroad Co., Ltd., (築豊電気鉄道) a Nishitetsu subsidiary, in 1953-1959. It is not likely that either corridor will develop traffic sufficiently heavy to justify investment in additional monorail lines for decades to come.

千葉 Chiba

千葉都市モノレール chiba toshi <monorail>

Chiba Urban Monorail Co., Ltd.

Suspended system:

Line 1: Chiba-minato (千葉みなと) to Kenchô-mae (県庁前), 3.2 km (2.0 mi). Opened 1995-1999.

Line 2: Chiba (千葉) to Chishirodai (千城台), 12.0 km (7.4 mi). Opened 1988-1991.

Fare	Up to	Equivalent per km (per mi)
\$1.60	1.9 km (1.2 mi)	\$0.80 (\$1.30)
\$1.70	3.1 km (1.9 mi)	\$0.60 (\$0.90)
\$2.20	4.0 km (2.5 mi)	" "
\$2.70	6.9 km (4.3 mi)	\$0.40 (\$0.60)
\$3.10	9.0 km (5.6 mi)	" "
\$3.40	11.0 km (6.8 mi)	\$0.30 (\$0.50)
\$3.70	13.1 km (8.1 mi)	" "
\$4.10	13.7 km (8.5 mi)	" "

The Chiba Urban Monorail, marketed under the name <Townliner> (タウンリナー), was the second large-scale suspended monorail built in Japan, and perhaps the first in the world to begin regular operation with trains traveling from one line to another.

Chiba, a prefectural capital and regional center east of Tôkyô, grew from 90,000 people in 1940 to nearly 900,000 in 2000. The population of Chiba Prefecture increased from two million in 1946 to 5.9 million in 2000. Tôkyô's suburban fringe now extends well beyond Chiba, which has become one of the capital's satellite towns.

By the 1970s, rapid urban growth and plans for new residential and commercial development northeast, southeast and west of the city center created a need for better local transportation than regional rail services and surface buses could provide. However, the anticipated volume of traffic was not sufficient to justify metro construction, and no surface alignments were available. As in Kitakyûshû, the logical choice was monorail. Planners, starting in 1975, outlined a two-line network, choosing the suspended system to avoid operating problems during freezing weather. However, the use of steel rather than concrete as the primary construction material has an upward influence on operating expenses; planners might not have anticipated annual expenditures of ¥300 million (about \$2.5 million) for structure painting.

The company was organized as a third-sector venture in 1979. At the time of organization, shareholders and percentages of stock held were:

Chiba Prefecture	26 percent.
Chiba City	26 percent.

Keisei Electric Railway	10 percent.
Kawasaki Steel Corp.	8 percent.
Nippon Steel Corp.	8 percent.
Mitsubishi Heavy Industries, Ltd.	6 percent.
Five other suppliers	4 percent total.

The Chiba Bank, Ltd., The Chiba Kogyo Bank, Ltd., and 22 other corporations 12 percent total.

At the start of planning, construction was anticipated to start in 1979, followed by opening of the first segment in 1983 and completion in 1986. Progress was slowed by financial considerations. The company secured its concession in 1981 and started construction near the end of that year. Unable to build the "urban" part of the network as the first stage, the company built the "suburban" portion of Line 2 first. Service opened in 1988, and Line 2 was completed to Chiba station in 1991. A revised Line 1 was started in 1991, opened in 1995 and completed in 1999.

The monorail operates two-car aluminum-bodied trains, with each train having a seating capacity of 42 passengers. The maximum service level operated currently, on Line 2, is 11 thd; the designed maximum is 20 thd. Most trains operate with two cars, but a few four-car trains operate on Line 2 during the a.m. peak period. The completed network has 40 cars, well below the planned fleet size of 64 cars. More would be added if traffic grows to levels sufficient to require operation of additional four-car trains. Traction power is supplied at 1500V dc.

Line 1 has three intermediate stations, including Chiba, shared by Line 2 trains. Line 2 has 11 intermediate stations. The four-beam monorail facility at Chiba station provides cross-platform transfers between the two lines - and also permits trains to travel between lines. A few Line 2 trains continue beyond Chiba station to Chiba-minato. These operate during early morning hours on weekdays, somewhat later on Sundays and holidays.

Most of the monorail network is built over two-lane roads, and some sections of guideway stand up to six stories high. In downtown Chiba, near Sakae-chô station on Line 1, the monorail structure is built over a canal flanked by the traffic lanes, along a road lined by medium-rise office buildings. The monorail stands 5-6 stories tall in this area, making for one of Japan's more interesting cityscapes.

In 1978, project cost was estimated at ¥85.0 thousand million; ¥46.8 thousand million for infrastructure (the guideway) and ¥38.2 thousand million for equipment and rolling stock. Related road construction was estimated to cost an additional ¥16.0 thousand million. The "infrastruc-

ture" share would be financed by central and local government funds, including a 44.9 percent central government grant. Other expenses, including rolling stock and equipment, would be financed by the third-sector company, from invested capital and a Japan Development Bank loan for ¥40.8 thousand million. The actual cost was ¥255 thousand million (about \$2.1 billion), ¥207 thousand million (\$1.7 billion) for infrastructure and ¥48 thousand million (\$400 million) for other expenses.

Ridership forecasts during the early planning period were 83,000 passengers per day at opening, 158,000 per day following completion of the network, 167,000 per day by 1990 and 191,000 by 2010. Peak-period volumes were forecast to require 4-car trains operating every 4 min 10 sec. The originally-planned fleet size was 64 cars. The system was projected to become profitable after nine years of operation. Cumulative profits would offset cumulative losses (from the initial years of operation) after 14 years. These projections would prove highly optimistic.

Monorail construction was beset by delays, and suburban housing development did not proceed at the anticipated pace. The ridership forecast was revised downward in 1986, to 15,000 passengers per day at opening and 67,000 per day over the completed network, with peak-period traffic requiring two-car rather than four-car trains.

The initial segment of Line 2 carried 9,000 passengers per day upon opening (1988), but traffic generated by a new university near the outer terminal soon boosted this to 14,000 per day. However, the anticipated traffic has not developed: the completed Line 2 was forecast to carry 67,000 passengers per day, but traffic on the completed network was 45,000 per day at 2000. Reasons for the ridership shortfall include a stagnant economy and decreasing numbers of school-age children.

The municipal and prefectural governments decided late in 2001 to defer construction of a planned extension of Line 1. This was outlined to extend from Kenchô-mae to Seikuki-<terminal> (星久喜ターミナル). The first 3.4-km (2.1-mi) segment, to Chûô-hakubutsukan - Shiritsu-byôin-mae (中央博物館・市立病院前), was authorized earlier in 2001. Completion was forecast for the beginning of 2008, with no date set for the remaining 1.8-km (1.1 mi) to Seikuki-<terminal>. Regional transport development plans do not show any additional monorail lines planned for Chiba.

Operating deficits continue to accumulate, and cumulative losses reached ¥13.5 thousand million (about \$110 million) by 1997. In response, the company has curtailed expenses, including gradual

conversion of stations to unattended operation. The prefectural government established a "Chiba Urban Monorail Investigation Committee" in 2002 to study possible solutions, including closure. The committee submitted its report near the end of 2002; no decision had been announced by municipal or prefectural authorities at the time of writing.

大阪 Ōsaka

大阪高速鉄道 ōsaka kōsoku tetsudō Ōsaka Rapid Railway Co., Ltd.

Supported system:

Ōsaka Monorail Line: Kadoma-shi (門真市) to Ōsaka-kūkō (大阪空港), 21.2 km (13.1 mi).

Opened 1990-1997.

Saito Line: Bampaku-kinen-kōen (万博記念公園) to Handai-byōin-mae (阪大病院前),

2.6 km (1.6 mi). Opened 1998.

Fare	Up to	Equivalent per km (per mi)
\$1.70	1.9 km (1.2 mi)	\$0.90 (\$1.40)
\$2.00	4.0 km (2.5 mi)	\$0.50 (\$0.80)
\$2.30	6.0 km (3.7 mi)	\$0.40 (\$0.60)
\$2.70	8.1 km (5.0 mi)	\$0.3 (\$0.50)
\$3.00	10.0 km (6.2 mi)	" "
\$3.20	11.9 km (7.4 mi)	\$0.25 (\$0.40)
\$3.50	14.0 km (8.7 mi)	" "
\$3.70	16.0 km (9.9 mi)	" "
\$4.00	18.1 km (11.2 mi)	" "
\$4.20	20.0 km (12.4 mi)	\$0.20 (\$0.30)
\$4.50	21.2 km (13.1 mi)	" "

This line ranks as the world's longest monorail and the first to open a branch (although there is no through running between the branch and the main line, as in Chiba). It was built as a peripheral connector and airport-access line, serving Ōsaka's northern suburbs. The line does not operate within the Ōsaka municipal boundary; the name in this case refers to Ōsaka Urban Prefecture.

Tōkyō's various rail networks include the long-established Yamanote loop and several peripheral lines. However, Ōsaka's rail networks included only radial lines until fairly recently. An established urban rail service was extended to form the Ōsaka Loop Line in 1961. A railway along the current monorail route was first proposed in 1966, to provide access to the Expo '70 world's fair. This idea did not advance, but suburban residential development eventually created a need for improved transportation in the corridors. Meanwhile, traffic growth at Ōsaka Airport, northeast of the city center, created a need for a fixed link. However, traffic was not sufficient to justify metro construction, and surface alignments were not available. As in Kintakyūshū and Chiba, monorail was the logical choice.

Monorail planning began in 1980, and the third-sector company was established at the end of the year. At the time of organization, shareholders and percentages of stock held were:

Ōsaka Urban Prefecture	52 percent.
The Daiwa Bank, Ltd.	5 percent.
Hankyū Corporation	5 percent.
Kansai Electric Power Co., Inc.	5 percent.
Keihan Electric Railway Co., Ltd.	5 percent.
Kinki Nippon Railway Co., Ltd.	5 percent.
Nankai Electric Railway Co., Ltd.	5 percent.
Ōsaka Gas Co., Ltd.	5 percent.
The Sanwa Bank, Ltd.	5 percent.
The Sumitomo Bank, Ltd.	5 percent.
Hanshin Electric Railway Co., Ltd.	2 percent.
North Ōsaka Express Electric Railway	2 percent.

Six online cities (Toyonaka, Ibaraki, Yaita, Settsu, Moriguchi and Kadoma) invested subsequently, bringing the "public-sector" share to 54 percent.

Most of the line is built alongside the *Kansai <Driveway>* (関西ドライブウェイ), an elevated toll highway. The structure stands seven to eight stories high at locations such as the bridge over the Tōkaidō Shinkansen. Stations are built long enough for six-car trains, but most trains operate with four cars. Traction current is supplied at 1500V dc.

Construction started in 1982, but financial constraints and objections by on-line residents along the western part of the route slowed progress. One hundred people, seeking cancellation of planning decisions, filed court action in 1982; this was heard eventually by Japan's Supreme Court and rejected in 1988.

The main line, named the "Ōsaka Monorail Line" (大阪モノレール線) was opened in stages between 1990 and 1997. The western terminal, Ōsaka-kūkō, serves Ōsaka Airport. The monorail connects with several other rail lines between the airport and its eastern terminal, Kadoma-shi. The line has 12 intermediate stations. The 52 aluminum-bodied, air-conditioned cars form the second-largest monorail fleet in Japan.

Prior to construction, the main line was estimated to cost ¥81.9 thousand million, ¥40.3 thousand million for infrastructure and ¥41.6 thousand million for equipment and rolling stock. Of the "infrastructure" (guideway) share, ¥44.9 percent would be paid by the central government (2/3 of this amount from road funds), and the remainder by the prefecture. Of the "other" share, the third-sector company would pay 20 percent from investment capital and borrow the remainder; 37.5 percent of borrowed funds would come from the prefecture and 62.5 percent from the Japan Development Bank. The actual cost was ¥224.1 thousand million (about \$1.9 billion), ¥157.1 thousand million (\$1.3 billion) for infrastructure and ¥67 thousand million (\$600 million) for equipment and rolling stock.

The initial traffic forecast was 100,000 passengers per day. This was revised downward to 70,000 per day owing to lack of a good connection with the busy JR Kyōto Line (also known by its traditional name, Tōkaidō Main Line). Both lines carried a total of 78,000 passengers per day at 2000.

The Hanshin-Awaji earthquake of January 17, 1995 inflicted heavy damage to various transportation facilities in and around Kōbe, but not in Ōsaka, 30 km (20 mi) east. The Ōsaka Monorail, together with other transport lines built on viaduct, was closed for inspection and reopened on the day following the earthquake, January 18. Rumors that the monorail provided the only transportation in the area served following the earthquake have no basis in fact.

The branch line, officially the *kokusai bunka kôen-toshi <monorail>* (国際文化公園都市モノレール, "International Culture Garden City Monorail"), is also known as the Saito Line (彩都線, *Saito* = "beautiful-colored city"). Opened in 1998, it extends from the Expo '70 Commemorative Park (*Bampaku-kinen-kôen*) to the Ôsaka University Hospital (*Handai-byôin*). Most of the branch, which has one intermediate station, is built over local streets. The branch diverges from the eastward main line to Kadoma-shi just east of the three-beam Bampaku-kinen-kôen station.

The branch is planned for extension from Handai-byôin-mae to Higashi-<Center> (東センター), 6.5 km (4.0 mi), by 2007. Long-term plans envision extensions of the main line at both ends to form a 25-mile semicircular line between Mukonosô, Itami, Ôsaka Airport, Kadoma-shi, Ibarata, Aramoto and Sakai.

東京 Tôkyô

多摩都市モノレール *tama toshi <monorail>*

Tôkyô Tama Intercity Monorail Co., Ltd.

Supported system: Kamikitadai (上北台) to Tama Center (多摩センター), 16.0 km (9.9 mi).

Opened 1998.

Fare	Up to	Equivalent per km (per mi)
\$0.80	between two adjacent stations	
\$1.70	3.1 km (1.9 mi)	\$0.60 (\$0.90)
\$2.00	5.0 km (3.1 mi)	\$0.40 (\$0.60)
\$2.30	6.9 km (4.3 mi)	\$0.30 (\$0.50)
\$2.70	10 km (6.2 mi)	\$0.25 (\$0.40)
\$3.00	13.1 km (8.1 mi)	" "

Fare	Up to	Equivalent per km (per mi)
\$3.30	16.0 km (9.9 mi)	\$0.20 (\$0.30)

This north-south peripheral line was built to serve new housing developments in Tôkyô's western suburbs, and was opened in 1998 and 2000. Most of the line is built over two-lane roads.

Planning began in 1977, but the project was delayed by government financial reforms following the 1979 oil crisis, intended to reduce bonded debt. The third-sector company was organized in 1986. At the time of organization, shareholders and percentages of stock held were:

Tôkyô Metropolitan District	25 percent.
Hachiôji, Tachikawa, Hino, Higashi-Yamato and Tama cities	2 percent each.
Seibu Railway Co., Ltd.	18 percent.
Keiô Electric Railway Co., Ltd.	10 percent.
Odakyû Electric Railway Co., Ltd.	6 percent.
The Fuji Bank, Ltd.	5 percent.
The Industrial Bank of Japan, Ltd.	5 percent.
Tôkyô Electric Power Co., Inc.	4 percent.
18 other corporations	16 percent total.

The project was authorized in mid-1990, and construction started late that year. The original cost estimate was ¥156.8 thousand million. At 1996, the cost was estimated at ¥179.5 thousand million, ¥62.7 thousand million for infrastructure (the guideway) and ¥114.8 thousand million for equipment and rolling stock. Of the latter amount, 80 percent was to be financed by borrowing from the private sector and a Japan Development Bank loan. Final cost: ¥242.2 thousand million (about \$2.0 billion).

The line has 18 stations, including terminals. Although these have numerous escalators and elevators, access to trains is relatively slow because of the distance between monorail platforms, connecting rail services and local destinations. Each of the four-car formations has a licensed capacity of 415 passengers (177 seated, 238 standing). Traction current is supplied at 1500V dc. The maximum permitted speed is 65 km/h (40 mph), but trains slow to 30 km/h (19 mph) at curves and when approaching stations.

A medium-term project would bring this line 6.8 km (4.2 mi) northwest from Kamikitadai to Hakonegasaki (箱根ヶ崎), on the JR Hachikô Line, to serve new housing developments. Exten-

sions from Tama Center are forecast as long-term projects to reach Machida (13 km (8 mi) southeast) and Hachiôji (17 km (11 mi) west and north).

東京 Tôkyô - Maihama

舞浜リゾートラインディズニーリゾートライン

maihama <resort line disney resort line>

Maihama Resort Line Co., Ltd., Disney Resort Line

Supported system: 5.0 km (3.1 mi) single-beam, one-way loop from <Resort Gateway Station> (リゾートゲートウェイ・ステーション). Opened 2001.

Service operates every 3-10 min; every 6 min most of the day; every 3-4 min at peak periods. Trains operate clockwise around the loop.

This line connects Maihama station and Tôkyô Disneyland (東京ディズニーランド) with a new theme park, Tôkyô DisneySea (東京ディズニーシー), and other resort and commercial development. A supported monorail line, with five six-car trains built by Hitachi, it is equipped for driverless operation although attendants open and close train doors. Traction current is supplied at 1500V dc. The line is wholly owned by the Oriental Land Co., which operates Tôkyô Disneyland. Japanese publications state that vehicle specifications have not been made public, as is the practice for all new rolling stock built for service on public railways and urban transport facilities.

那覇 Naha

沖縄都市モノレール *okinawa toshi <monorail>*

Okinawa Urban Monorail Co., Ltd.

Supported system: Naha-kûkô (那覇空港) to Shuri (首里), 12.9 km (8.0 mi). Opened 2003.

Fares	Up to	Equivalent per km (per mi)
\$1.70	4.0 km (2.5 mi)	\$0.40 (\$0.70)
\$1.90	6.9 km (4.3 mi)	\$0.25 (\$0.40)
\$2.20	10.0 km (6.2 mi)	\$0.22 (\$0.35)
\$2.40	12.9 km (8.0 mi)	\$0.20 (\$0.30)

This line serves the capital of Okinawa Prefecture, extending from Naha Airport through the business and administrative center to the Shuri historic district. Construction was started in 1996. The opening ceremony was held on 10 August 2003, and the first day of commercial operation was 11 August. Unfortunately, the latter day was marred by a door failure that caused a train to stop between stations, trapping passengers for about one hour. More fortuitously, the line carried its millionth passenger on 31 August 2003, the 20th day of operation.

The estimated cost at the start of construction was ¥108.1 thousand million (about \$900 million), ¥65.7 thousand million (\$550 million) for infrastructure and ¥42.4 thousand million (\$350 million) for equipment, including the rolling-stock base, power supply and signal systems. Following completion, total cost is stated at ¥112.8 thousand million (about \$1.07 billion). Of this amount, about ¥70 thousand million (\$660 million) paid for infrastructure and ¥42.8 thousand million (\$410 million) for rolling stock.

Okinawa island, Japan's fifth largest, once had a small railway network serving the southern portion of the island, extending north, east and south from Naha. This was built from 1914 under prefectural sponsorship. Two rural horse tramway lines were built by private companies. Naha had a short (6.9-km (4.3-mi)) electric town tramway line to Shuri, the island's ancient capital, from 1914. Storm (typhoon) damage brought an end to tramcar operation in 1933, but the rail lines continued operation until 1944, when they were caught in the middle of one of the deadli-

est campaigns of World War II. After the fighting was over, U.S. military forces were in control and quickly built wide paved roads, some on the former rail alignments.

The U.S. returned Okinawa Prefecture to Japan in 1972. By this time, peak-hour road congestion along Naha's main street, Kokusai-dôri, and other major roads was growing to levels that required improved public transport. Studies began not long thereafter. Monorail technology was eventually selected because ground-level alignment for a conventional railway was not available, and traffic levels were insufficient to justify the expenditure required for a metro.

At 2000, Okinawa Prefecture had 1.3 million people. The majority lived on the southern third of Okinawa Island, and 300,000 lived in Naha. Nineteen percent of the total land area of Okinawa Island is occupied by U.S. military bases. The overall population density of Naha city was about 8,000 per km² (20,000 per sq mi). According to the *Okinawa romendensha tomo-no-kai* (= Okinawa Tramway Society) website, the prefecture had nearly 866,000 registered motor vehicles at the end of 2001. During 2002, prefectural authorities recorded nearly 5,000 motor vehicle accidents and 53 fatalities.

Okinawa Urban Monorail Co., Ltd., is a third-sector enterprise, with investors including Okinawa Prefecture, Naha City, and the Okinawa Promotion and Development Finance Corporation. It uses two-car formations built by Hitachi for driver-only operation, each with a licensed capacity of 158 passengers. The company plans to operate service every 7.5 to 12 minutes throughout most of the day, with a minimum headway of 6.5 minutes. The maximum "licensed" peak-period capacity is 2,123 phd. Stations were built for an eventual maximum train length of four cars. Traction current is supplied at 1500V dc.

The monorail was built over streets, roads and drainage channels. It is marketed as <Yui Rail> (ゆいレール). "Yui" implies joining together, of Okinawa Prefecture citizens to build the monorail, which in turn joins together people along the line. "Yui" also implies excellence.

The monorail project has been criticized for high construction cost, unrealistic ridership forecasts and obstruction of light and views. A citizen's organization, Okinawa romendensha tomo-no-kai, advocates <LRT> and other alternatives to auto travel.

The company anticipated 35,000 passengers per day at opening. This was projected to increase to 44,000 per day after seven years of operation. Ridership averaged 32,000 per day during September and October 2003, but fell thereafter. Ridership was reported at 25,000 passengers per day at January 2004. This is concern because the line requires revenues from 35,000 passengers per day in order to avoid operating losses. At 2001, Okinawa Prefecture

external auditors anticipated operating losses if traffic fell short of the levels forecast by more than 20-30 percent.

The ridership shortfall was attributed to seasonal factors – relatively few tourists visit Okinawa during December and January – and failure of the island's bus operators to coordinate service with the monorail. The four companies stated previously that they would consider route changes to serve monorail stations. All are currently experiencing financial difficulties and have declined to change routes.

Children have fallen through the gap between platform and vehicle at stations on three occasions, most recently at February 2004. The company installed rubber "hems" along platform edges following the second such accident, but gaps of about 14 cm (approx 6") still exist at some stations. The rubber hems failed to prevent the most recent accident.

X. Prospects

Japan has built 116 km (80 mi) of monorail lines over the past 50 years. Of these, tent lines extending about 110 km (70 mi) remain in service, worked by about 320 vehicles. Daily passenger traffic is almost 500,000, with about 27 percent of this carried by the Tōkyō Monorail. It appears reasonable to say that Japanese monorails have attracted attention from overseas far out of proportion to their extent.

Monorail technology has been demonstrated to be practical and reliable. Operations of monorail networks and branches has also been demonstrated to be technically practical although the scale of operations thus far has been. Criteria for application have been established and monorail lines built in a handful of corridors where buses in mixed traffic were no longer adequate, but construction of full-scale rail lines or metros could not be justified.

However, omitting the Maihama line, which is hardly an urban transport facility, the "application" phase of Japanese monorail development has resulted in rather little. Over more than 20 years, this "third phase" has resulted in just five systems with a combined route length of 77 km (48 mi), worked by about 200 cars, carrying about 280,000 passengers per day.

This slow development reflects, among other factors, high construction costs (\$60-120 million per km (\$100-200 million per mi)), availability of other intermediate-capacity modes and limited capacity relative to rail lines. Another important factor is the expectation that operating expenses and, eventually, the capital invested to build the line, will be recovered from passenger fares. Objec-

tions from on-line residents to construction of elevated structures such as monorails have also become an important factor in recent years.

At the end of 2004, Japan had only three "active" extension projects: an 0.7-km (0.5-mi) extension of the Tōkyō Monorail to a new airport terminal, a 3.6-km (2.2-mi) extension in Chiba and a 6.5-km (4.0-mi) extension of the Ōsaka Monorail branch. Neither of the latter two had reached the construction stage at the time of a March 2001 visit. The Japanese-language literature consulted by the author contains no hint of near-term or medium-term authorization of additional extensions - nor any hint of "new" monorail systems.

In conclusion, it is clear that Japan will expand applications of monorail technology in markets where additional transport capacity is needed, where lack of available surface alignments preclude construction of lower-cost alternatives, and traffic levels do not warrant construction of full-scale rail lines, either underground or on viaduct. However, it is also clear that such expansion will occur gradually, and that rail will remain the dominant mode for major metropolitan corridors for the foreseeable future.

XI. Preserved Monorail Rolling Stock

A Japanese tabulation of preserved railway and tramway rolling stock lists the following:

- Transportation Bureau, City of Nagoya, Safege-system monorail car, at Higashiyama Botanical Garden, Higashiyama Park.
- Ueno Suspended Line (Tōkyō) cars H1 and H2 (Nippon Sharyō, 1957), at the Nippon Sharyō plant in Toyokawa, southeast of Nagoya.
- Shōnan Monorail car 301, in Kawasaki, at the Iwamoto Kōsan plant; condition unknown.
- Tōkyō Monorail 100 Series, at the company's Shōwajima operating base.

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