Monorails

Future of Urban Travel

Wind-driven monorail, invented by Henry Palmer (around 1820)
History of the Monorail

Global Monorails

The patent for the monorail can be traced back to UK patent No. 461 by Henry Palmer in the year 1821, who molded his invention into shape at London Wharf in 1824 to transport cargo. The rails were made of wood instead of iron at the time, and horse-drawn cars straddled the rail.

In 1888, a straddle-type monorail powered by a steam locomotive was installed in Ireland over a line approximately 15km long and was used to transport cargo for 36 years until 1924. In 1901, a suspended-type monorail with iron wheels was constructed in Wuppertal, Germany over a length of 13.3km, and still serves as the oldest monorail in operation as a major transportation system.

Research and development of the renovated monorail was actively pursued after World War II, and an experimental straddle-type (ALWEG type) monorail was constructed in 1957 in a suburb of Cologne, Germany. Then, in 1960, an experimental suspended-type (SAFEGE type) monorail was installed in a suburb of Orleans, France. These two systems marked the beginning of the development of the modern monorail.

The world's first ALWEG type monorail was put into practical operation in 1959 at Disneyland in Los Angeles, followed by Turin in 1961, Seattle (1962), and Disneyworld in Florida (1971).

Monorails in Japan

Since the emergence of the Wuppertal Monorail in 1901, attempts were made to install monorails at various sites in Japan, the first successful example being at Toshimaen Amusement Park in 1951.

Since the 1950s, monorails have been considered a major mode of future urban transportation. The first monorail system introduced as urban transport in Japan was the suspended-type monorail built at Ueno Park, developed by the Tokyo Metropolitan Bureau of Transportation in 1957 with the purpose to conduct a feasibility study for monorail as a means for future urban transportation. In the 1960s, thanks to imported techniques such as ALWEG and SAFEGE systems, in addition to unique technical developments pursued by Japanese enterprises, monorails were installed in various locations around Japan. Among them, Tokyo Monorail, which commenced operation in 1964, has performed a crucial role in the city's public transportation. Japan Monorail Association was established the same year to conduct research from technical and administrative perspectives, so as to ensure the adoption of the monorail as a means of urban transportation, and to promote their practical application. This research yielded results in the use of the straddle-type monorail as the transportation system for the 1970 Osaka World Exposition. Another successful example was the suspended-type Shonan Monorail, which commenced operation the same year.

The Installation of Urban Monorails in Japan was boosted up by the government’s guidance for promotion promulgated in 1972 backed by Japanese Infrastructure Subsidy System established in 1974, which enables to subsidize the construction cost of monorail infrastructure. This actually advanced the installation of Urban Monorail System in the areas of Kitakyushu, Chiba, Osaka, Tama, and Naha.

In the 21st century, Japanese-made monorail system made an advance into global market and have evolved into successful system operations in Chongqing in China, Singapore, Dubai in the United Arab Emirates, and Daegu in Republic of Korea.
The Urban Monorail

Facilities for passenger or cargo transport either straddling a track or suspended from one, are generally called monorails. Monorails are used widely, not only as urban transportation systems but also for amusement, sightseeing, and agricultural purposes.

To establish the monorail as a form of urban transportation, the Law Concerning the Promotion of the Installation of Urban Monorails in Japan was enacted in 1972. Article 2 of this law defines “urban monorails” as the following: “Passenger or cargo transporting systems for general traffic, whose carriers are suspended from, or ride on, a track constructed over a road in principle, and most of which are installed within an urban planning area.”

Straddle-type and Suspended-type Monorail Systems

Monorails are classified into straddle and suspended-type systems. Since the straddle-type travels by straddling the track, its center of gravity is situated above the track. The suspended-type, on the other hand, is configured suspending from the track, with its center of gravity under the track.

Large, Medium, and Compact Monorail Systems

Monorails developed in Japan are classified into large, medium, and compact systems, depending on the size of the cars and the overall system scale.

The large and medium-size monorail systems meet the high ridership demands of large metropolitan areas, especially effective during peak-hour situations for daily commuting. Such systems have been deployed around Japan and have a proven track record of creating a profitable operation model for public transit, as seen in the cities of Tokyo, Osaka and Kitakyushu. Such systems are most suitable for ridership demands of over 20,000pphp (passengers per hour per direction), and can carry over 125,000 passengers daily.

In order to meet the demands for a low-cost, highly versatile urban transit system especially common in regional cities around Japan, the compact monorail system was developed as a simplified version of its larger counterpart, with a significant reduction in size and weight of not only the rail cars, but also ground facilities, such as tracks, columns, and stations, to account for the need to align routes in accordance with the complicated road configurations of narrow passages (minimum width 18m) and sharp curve radii (minimum radius 35m).

<table>
<thead>
<tr>
<th>Large</th>
<th>Medium</th>
<th>Compact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train length</td>
<td>61 m</td>
<td>57 m</td>
</tr>
<tr>
<td>Shaft weight</td>
<td>11 t</td>
<td>10 t</td>
</tr>
<tr>
<td>Nominal riding capacity (0.3 m²/person)</td>
<td>415 Persons</td>
<td>348 Persons</td>
</tr>
<tr>
<td>Planned passenger volume (0.14 m²/person)</td>
<td>653 Persons</td>
<td>580 Persons</td>
</tr>
<tr>
<td>Full capacity (0.1 m²/person)</td>
<td>966 Persons</td>
<td>858 Persons</td>
</tr>
</tbody>
</table>


daylight availablility,
Features of the Monorail

Safe and Comfortable Ridership
Since monorails travel along an exclusive elevated track, comfortable, safe, and punctual operation is ensured with no concerns of traffic jams. Furthermore, since they travel over a thin single track or within a box-type track, they are resistant to severe natural conditions, such as strong winds, rainstorms, and snowfall.

Flexible Route Alignment and Train Configuration
As a result of the capacity to operate through sharp curves and large longitudinal gradients, flexible route settings (such as double, single, and loop tracks) can be applied according to the physical conditions of the urban area. In addition, various systems can be configured according to ridership demand, with the variation of car size available from compact to large, and the number of cars comprising a train from two cars to six and over.

Quiet, Clean, and Minimum Sunlight Obstruction (low pollution and environmental impact)
Rubber tires and air springs minimize noise and vibration, and eliminate concerns over exhaust gasses. The single-track structure also ensures sufficient access to sunlight even directly under the tracks, reducing its impact on the environment and ensuring adaptation with urban settings.

Comparison of CO2 emissions among passenger transport measures

<table>
<thead>
<tr>
<th>Public Transport Measure</th>
<th>CO2 Emissions (ton/passenger-km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Automobile</td>
<td>123</td>
</tr>
<tr>
<td>Airplane</td>
<td>58</td>
</tr>
<tr>
<td>Bus</td>
<td>32</td>
</tr>
<tr>
<td>Railway</td>
<td>22</td>
</tr>
</tbody>
</table>

Reference: MLIT homepage

Monorail is environmentally friendly as CO2 emission from monorail is almost equal to that of railway.

Significance of Urban Monorails

Establishing an Urban Public Transportation System while Ensuring Smooth Road Traffic
The law concerning urban monorails in Japan was enacted to establish the monorail as a real means of urban transit, capable of satisfying part of the urban traffic demand alongside automobiles, thus increasing traffic capacity, alleviating traffic jams, and ensuring operational punctuality.

Urban monorails have become an indispensable means of supporting business activities and daily communications in urban areas as well as providing mobility for impaired users in an aging society.

Effective Utilization of Urban Space
Monorails can be constructed over existing roads, parks, squares, rivers, railroad tracks, etc., exploiting the potential for flexible alignment. Less requirement of acquiring new land plays a significant role in efficient installation of monorails.

Contribution to Community Renovation
The installation of a monorail system in company with the construction of urban facilities such as shopping centers, hospitals, cultural buildings, and general playgrounds can act as an integral part of urban development/renewal projects to help resolve various urban issues such as reactivation of downtown areas and enlivenment of cities, while efficiently reorganizing urban traffic systems.

Alongside its smart structure and minimal obstruction of overhead space has low impact on the surrounding environment and scenery, new attractive urban spaces can be introduced by planting trees and adopting creative design. Urban monorails are a new means of transportation, allowing citizens to rediscover the charm of urban settings.

Roles of Urban Monorails
The urban monorail is an ideal means of transportation, adaptable to intermediate distances and capable of satisfying moderate transportation demands.

The carrying capacity of the urban monorail varies depending on size and operational interval. Its one-way carrying capacity per hour ranges from approximately 2,000 to 33,000 passengers.

If a compact monorail system consisting of four cars is operated at 10-minute intervals, its one-way carrying capacity per hour will be 2,000 passengers, and it operated at 2.5-minute intervals, the capacity increases to 7,000 passengers. This carrying capacity is approximately half that of a large monorail system, 1.6 times of LRT, and about four times of buses.

Monorails are also superior in respect of project costs, with construction being only a third of what is required for subway.
Construction and Operation of Urban Monorails

In Japan, the basic infrastructure of urban monorail, such as the track beams, columns, and stations, is regarded as part of a road, meaning the road administrator (the government or a local municipal entity) is capable of constructing monorails as part of road improvement projects.

On the other hand, the operating body of an urban monorail is commonly a local municipal entity or joint public-private venture. After undergoing licensing procedures according to the Track Law, they construct facilities related to rails, electricity, operation and management, etc., before commencing operation.

Due to this nature, the Japanese Ministry of Land, Infrastructure, Transport and Tourism grants a government subsidy from its special account for road improvement to bear part of the construction cost.

The following must be satisfied to be accepted as a recipient of the grant:

- The operator of the urban monorail must be a local municipal government or equivalent body (joint public-private venture).
- The urban monorail system shall be constructed in accordance with the "Law Concerning the Promotion of the Installation of Urban Monorails."
- Although the government abolished "Special Account for Road Improvement" in 2009, it still continues to make a government subsidy available for the construction of monorails in a similar way.

The following must be satisfied to be accepted as a recipient of the grant:

- The operator of the urban monorail system must have obtained authorization in accordance with the Track Law, or it must be certain that the operator will obtain such authorization.

Monorail Systems Currently in Operation

<table>
<thead>
<tr>
<th>Name</th>
<th>Operating body</th>
<th>Length (Unit: km)</th>
<th>Date of start of operation</th>
<th>Type</th>
<th>Passenger traffic volume (persons/day)</th>
<th>The number of cars comprising a train</th>
<th>The number of owned cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo Monorail</td>
<td>Tokyo Monorail Co., Ltd.</td>
<td>17.8</td>
<td>1984-09</td>
<td>Shackle-type</td>
<td>134,814</td>
<td>6</td>
<td>126</td>
</tr>
<tr>
<td>Tama Monorail</td>
<td>Tokyo Tama Intercity Monorail Co., Ltd.</td>
<td>15.0</td>
<td>1998-11</td>
<td>Shackle-type</td>
<td>142,498</td>
<td>4</td>
<td>64</td>
</tr>
<tr>
<td>Osaka Monorail</td>
<td>Osaka Monorail Co., Ltd.</td>
<td>28.0</td>
<td>1980-06</td>
<td>Shackle-type</td>
<td>131,505</td>
<td>4</td>
<td>88</td>
</tr>
<tr>
<td>Kita-kyushu Urban Monorail</td>
<td>Kita-kyushu Urban Monorail Co., Ltd.</td>
<td>8.8</td>
<td>1983-01</td>
<td>Shackle-type</td>
<td>33,929</td>
<td>4</td>
<td>36</td>
</tr>
<tr>
<td>Chiba Urban Monorail</td>
<td>Chiba Urban Monorail Co., Ltd.</td>
<td>15.2</td>
<td>1988-03</td>
<td>Suspended-type</td>
<td>51,377</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>Shonan Monorail</td>
<td>Shonan Monorail Co., Ltd.</td>
<td>6.6</td>
<td>1970-03</td>
<td>Suspended-type</td>
<td>28,825</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>Sky Rail</td>
<td>Sky Rail Service Co., Ltd.</td>
<td>1.3</td>
<td>1998-08</td>
<td>Suspended-type</td>
<td>1,555</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Ueno Zoo Monorail</td>
<td>Tokyo Metropolitan Government</td>
<td>0.3</td>
<td>1957-12</td>
<td>Suspended-type</td>
<td>3,530</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Disney Resort Line</td>
<td>Maihama Resort Line Co., Ltd.</td>
<td>5.0</td>
<td>2001-07</td>
<td>Shackle-type</td>
<td>50,067</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>111.9</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Monorails play an important role as a major means of public transportation in major cities throughout Japan.

Their roles include: (1) Access to airports, (2) Major public transit, (3) Circular public transit to connect radial trunk lines, (4) Public transit to support trunk railway networks, and (5) Access to housing complexes, parks, shopping centers, and so on.

In certain mid-sized cities, they also serve as a core public transportation system.
The Osaka Monorail consists of the Main Line, which runs 21.2km between Osaka Airport and Kadoma-shi Stations, and the Saito Line, which runs 6.8km between Bampaku-kinen-koen and Saito-nishi Stations, covering a total line length of 28.0km.

The Saito Line has become a major form of access to Saito (International Culture Park) under development along the Hokusetsu Hillside.

Line extension project from Kadoma-shi to Uriudo (9kms) is progressing.

The Tama Monorail is a new transportation system in the Tama District of Tokyo that opened full commercial operations along its entire line on January 10, 2000.

It travels the distance of 16.0km from Tama Center Station to Kamikitadai Station in 36 minutes.

The 4-car train, with a carrying capacity of 412 passengers, is operated by a single driver.

The Tokyo Monorail started operations on September 17, 1964.

It travels the distance of 17.8km between Hamamatsucho and Haneda Airport Terminal 2 in 18 minutes and 55 seconds (by Haneda Express).

The total passengers of Tokyo Monorail exceeded 2,000 million in 2017.

Track Record of Monorails in Japan
The Kitakyushu Urban Monorail, which started operations on January 9, 1985 as Japan’s first urban monorail system, travels 8.8km from Kokura to Kikugaoka in 19 minutes. It is operated as a safe and efficient transportation system for Kitakyushu City residents.

On April 1, 1998, the line was extended from Heiwa-dori Station to Kokura Station. It is used as a major means of public transit by approximately 11.0 million passengers annually.

The Chiba Urban Monorail began operations in March 1988 for the 8.1km distance from Sports Center Station to Chishiro-dai Station. After undergoing three extensions, it has become the world’s longest (15.2 km) suspended-type monorail system.

The Okinawa Urban Monorail is a long-awaited track transportation system in Okinawa that started operating on August 10, 2003. It travels 12.9km from Naha Kuko Station to Shuri Station in 27 minutes.

The extension section from Shuri to Tedako Uranishi with 4.1km is currently under construction.

The Shonan Monorail was first operated in March 1970 for the 4.7km distance and now extends the entire distance of 6.6km from Ofuna to Shonan-Enoshima for nearby residents commuting to offices and schools, in addition to providing an attractive access like a roller coaster to a lot of tourist spots along the line.

Global website: http://kamakura-enoshima-monorail.jp/
Chongqing Monorail, China

Chongqing is the largest industrial city in Southwest China. With the spurt of economic activity in recent years, traffic jams have been worsening in the urban areas around the city. However, due to the geographic conditions of central Chongqing, located at the hilly intersection of the Chang Jiang and Jialing Rivers, it is extremely difficult to construct new roads to alleviate traffic congestion.

Under such circumstances, the Chinese government requested Japan to investigate the feasibility of the Chongqing Rapid Railway Transit Construction Project. As a result of the investigation, the Chinese government decided to construct a monorail system with the use of a loan provided by the Japan Bank for International Cooperation.

Official Development Assistance (ODA)

Developing countries through the course of rapid urbanization are faced with problems such as the functional decline of urban activities due to traffic jams and degradation of the urban environment.

It is essential to establish a base for public transportation such as subways and monorails to thoroughly solve these problems. However, since developing countries face both technical and financial challenges in their capacities to do so, the Japanese government provides such support to establish public urban transportation systems as part of Official Development Assistance (ODA).

After Chongqing monorail started operation in 2005, Chongqing government has promoted the monorail line extension project with its own finance. Chongqing monorail at present consists of 2 lines with total length of about 98.5km.
Singapore (Sentosa) · United Arab Emirates (Dubai) · Republic of Korea (Daegu)

Sentosa Monorail, Singapore
Due to their highly adaptable characteristics as urban transport, monorail systems are being constructed in various places around the world.

In 2002, Japan won the international competition for supplying the monorail system for Sentosa Development Corporation of Sentosa Island, one of the most popular tourist attractions in Singapore.

Sentosa Monorail, the first compact-type monorail system developed under the leadership of Japan Monorail Association, began its operation in January 2007 and runs the route of 2.1 km and four stations with 2-car trains.

The Palm Jumeirah Monorail, Dubai
The Palm Jumeirah Monorail was built with Japanese monorail technology as the first such system in the Middle East.

The monorail travels 5.4 km from Palm Jumeirah, an artificial island developed off the coast of Dubai, to the mainland with four stations along the line. The Palm Jumeirah Monorail, a fully automatic and driverless system, began commercial operations in April 2009. It is currently capable of carrying up to 2,400 passengers in four sets of three-car trains, while the system can be enhanced to the full capacity of 6,000 passengers.

Daegu Monorail, Republic of Korea
Daegu Metropolitan City is the fourth largest city in the Republic of Korea with a population of 2.5 million. The monorail system was applied for the urban railroad line No.3 following two conventional subway lines.

The monorail has started operation in April 2015 with a 24 km line and 30 stations. Thanks to its unique infrastructure design and harmonization with urban environments, it has become the symbol of the city and promoter of urban tourism.

Development of Compact Monorails

Compact Straddle-type Monorail System
There are currently 10 urban monorail systems in Japan, with a total line distance of 112 km.

There are three major tasks to be accomplished in order for urban monorail systems to meet the expectations of semi-large or local hub cities as the ideal transportation system, and for this purpose, the Japanese monorail industry has developed a compact straddle-type monorail called “SMARTRAN.”

SMARTRAN

Reduction in Construction Costs

The construction costs of building a major urban transit system can be a burden for some regional municipalities with limited resources for public infrastructure. To further promote the introduction of urban monorail systems in such circumstances, it is essential to minimize these costs.

- Developing compact cars proportionate to demand enables a significant reduction in costs. We propose a compact monorail system with a construction cost as low as ¥5.0 billion/km.
- In addition to the reduction in car size, the following items were also considered:
  - Downsizing of infrastructure
  - Simplification and downsizing of stations
  - Overall simplification of E&M systems

Reduction of Required Space
In the past, several plans have unfortunately been abandoned due to lack of land required for building a large-scale urban transport system.

The compact monorail system has been developed with the purpose of installing public transport in a minimized setting by trimming down the entire system, including the cars themselves.

- Downsizing of cars reduces required space, allowing the system to be introduced to roads as narrow as 18m.
- The improved car structure allows flexible compatibility with various road alignments, minimizing interruption with residential areas, especially when turning at crossings.

Improved Profitability
To ensure business profitability, reduction of both maintenance and construction costs is essential

- A reduction in construction costs decreases the load on operators and improves profitability.
- Simplification of the total system and downsizing of station facilities reduces maintenance costs.
Size Comparison with Conventional Large Monorails

- The width of a conventional large monorail car is 2.98m. By reducing the width to 2.71m, the clearance limit of a double-track line can be reduced to 90% of its original size.
- The car length can also be reduced from 15m to 11m (front car).
- Bogies are placed under the connecting portion of cars.
- The minimum curve radius is 35m, and the maximum longitudinal gradient is 60‰.

Outline of Japan Monorail Association

Establishment and History

Around 1960, when the move to introduce modern monorails became increasingly apparent in Japan, the “Monorail Study Group” was established by those concerned to develop monorail toward the realization of practical implementation as early as possible.

After several years of research and investigation, the group was reorganized in 1964 as Japan Monorail Association to further develop and strengthen the dissemination activity of monorails.

The Japan Monorail Association was formally established on August 10, 1964, as a special public institution with a governmental permission, after the inaugural General Meeting with the initial membership of 92 companies on June 8, 1964.

Purpose and Tasks

The purpose of Japan Monorail Association is defined as follows:

- Performing investigation and research into monorails and LIM-trains (collectively referred to as “monorails”) as well as diffusing knowledge on monorails for the improvement and progress of monorails.
- The tasks vigorously pursued by the Association to achieve these goals are determined as follows:
  - Investigation and research of various issues concerning monorail
  - Trusted research and design of monorails
  - Cooperation with municipalities constructing or planning for future monorail systems
  - Data and information collection regarding monorails
  - Statement of official opinions on monorails
  - Publication of related documents, organization and execution of workshops, and others

Charter

The transportation conditions in our country have changed drastically in recent years. The commuting population in major cities has increased significantly, and their transportation demand can no longer be satisfied by existing railroads and ground transportation systems alone, which are facing plummeting efficiency due to the extraordinary increase in the number of automobiles. Appropriate measures must be taken immediately to fight this problem.

To solve the transportation problem in urban areas, the authorities concerned have been focusing on forming substantial subway networks, constructing automobile expressways, extending suburban private railways into urban areas, and forming grade separations, all of which are gradually paying off.

However, these conventional measures have come to grips with surging construction cost, the difficulty of procuring sites, and many other challenges, which is why the establishment of an innovative transportation system has been long awaited.

Under such circumstances, monorails are attracting considerable attention as the third means of transportation. Monorails are an effective and ideal means of urban transportation, capable of relieving traffic jams, and featuring a lower construction cost and shorter construction period compared with subways. Research and development on monorails have been pursued vigorously in recent years in various countries worldwide. Monorails can also serve as a passenger transport system in leisure venues and a means of transportation in areas prone to heavy snowfall. The construction of monorails can thus be expected to grow as a promising business in future.

From this perspective, we shall collaborate to establish “Japan Monorail Association” and carry out various activities and research to develop monorails that are ideal for urban transportation conditions, landscapes, and climate unique to our country, and spread the use of monorails, thus contributing to develop the transportation business in our country.

May 8, 1964